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# Strategies for maintenance management of railway track assets

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**A Dissertation Submitted in Partial Fulfilment of the Degree of**

**MAGISTER INGENIERIAE**

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**ENGINEERING MANAGEMENT**

**at the**

**FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT**

**of the**

**UNIVERSITY of JOHANNESBURG**



**by**

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**2019**

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## **DECLARATION**

I, Mpho Matsaung, hereby declare that this research report is my own original work and that all sources have been accurately reported and acknowledged, and that this document has not previously in its entirety or in part been submitted at any university in order to obtain an academic qualification.

Mpho Matsaung

Signature:.....

Date: October 2019



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## **ABSTRACT**

Population growth and environmental issues are revitalizing the railway sector in a tremendous way. An increase in frequency of passenger traffic and rising loads of freight trains has an impact on dynamic railway track properties and components thereof. The challenge from the railway fraternity is to rise to the challenge by ensuring a safe, reliable and affordable mode of transport. The purpose of this research is to investigate the capacity needed to meet demand by maintaining the track components of the railway infrastructure cost effectively. The railway track is the most critical in terms of safety, influence on maintenance costs, availability and reliability of the train service. Profillidis (2012) highlights the fact that track maintenance expenses represent a significant percentage of total railway infrastructure expenses. In literature, different maintenance strategies, approaches and concepts are discussed in light with arguments raised by different scholars and researchers. The main research methodology utilised was the case study on maintenance strategies from different countries where data was mostly available. The reason for the chosen method was to standardise the research method across different countries as this made it easy to obtain the findings and arrive at recommendations of the research.

The broader findings from different maintenance strategies were that the track maintenance approach still has to evolve from working in silos to working in a system that acknowledges that decisions taken from other departments can affect the quality of maintenance in future. The deterioration of the track system is mostly affected by the initial quality of the railway track after commissioning due to workmanship and track design, maintenance approach, type of rolling stock tonnages, speed of rolling stock, and environmental related issues. Design phase of the track acknowledges the systems thinking approach for quality and structural integrity. However, more can still be done to adopt approaches that foster inter-departmental coordination in the maintenance phase of the railway track asset lifecycle. Transnet faces a challenge of fulfilling its obligation by providing quality and cost effective maintenance to increase the reliability, affordability, availability and safety of its infrastructure with the ever-increasing freight volumes. The traditional approach of maintaining railway track assets does not bring in required outcomes that ensure high quality and cost effective maintenance as required by high intensity asset utilisation. Data collected from the

Railway to Safety project in Transnet highlighted challenges related to maintenance, and proposals were made to address those maintenance challenges. In the Roadmap to Safety project, Transnet benchmarked its maintenance approach and strategy against DB's strategy. A continuous improvement process is thus recommended in order to reach the level of DB and possible future certification of ISO 55000. Adoption of asset management principles through ISO 55000 which were adopted from PAS 55, is the future of a well-structured asset-centred organisation. Asset management policies, strategies and frameworks are the foundation of an effective maintenance strategy. These foundation blocks are strongly recommended as they promote maintenance strategies like the risk based maintenance strategy and reliability centred maintenance amongst other maintenance strategies. The other important element from the application of asset management methodologies is to inculcate the culture of conducting risk assessments as the baseline for maintenance planning and prioritization. This assists in giving high risk assets the attention they deserve, and the process of risk assessment itself promotes a systematic way of sharing knowledge and continuously improving maintenance strategies within an organisation. For the railway tracks, maintenance that is preventive should be considered, not ignoring issues of passenger well-being and security, it will also be cost-effective as a considerable amount of the railway costs is owing to maintenance of the railway track.

The limitation of this research was the fact that due to lack of data and the broad scope of the research, maintenance strategies from other countries prominent in railway operations were not covered. The other limitation is that, only a certain type of track design was looked at, which is track with ballast. The slab track, which is predominantly preferred for high speed trains, was not part of the research scope.

Further research opportunities can be explored on the costs and benefits of choosing one track design over the other.

The following factors have to be taken into consideration:

- The lifecycle costs,
- The ability of infrastructure owners to influence the manufacturers' specifications of other track components due to environmental and operational dynamics in the area.

- Material availability for that region, and
- The type of dominant traffic (e.g. medium and high-speed passenger traffic or high tonnage freight traffic).



## **TABLE OF CONTENTS**

<b>Chapter 1</b>	<b>Introduction and Problem Statement</b>	<b>14 - 21</b>
1.1	Introduction	14 - 16
1.2	Problem Statement	16 - 19
1.3	Research Questions	19
1.4	Research Purpose	19
1.5	Research Objective	20
1.6	Significance of Study	20
1.7	Research Delimitations	20
1.8	Conclusion	21
<b>Chapter 2</b>	<b>Literature Review</b>	<b>22 - 58</b>
2.1	Introduction	22
2.2	Introduction to Track Maintenance	22
2.3	High Speed Railway Tracks in Europe	22 - 26
2.4	High Tonnage Railway Tracks in South Africa	26 - 29
2.5	Vehicle – Track Interaction	29 - 32
2.6	Track Deterioration	32 - 34
2.7	Reliability Centred Maintenance	34 - 35
2.8	Risk Based Maintenance Strategy	35
2.9	Common Maintenance Strategies	35 - 38
2.10	Future Maintenance Strategy	39 - 40
2.11	Maintenance Plan	40 - 42
2.12	International Union of Railways (UIC)	43
2.13	Railways and Asset Management	44 - 45
2.14	Asset Management : PAS 55 and ISO 55000	45 - 48
2.15	Quantitative Methods Required for Implementing ISO 55000 and PAS 55	48 - 50
2.16	Railway Operational and Infrastructure Management Approach	50 - 51
2.17	Asset Management Information Systems	51 - 53
2.18	Conclusion	53 – 56



<b>Chapter 3</b>	<b>Research Design and Methodology</b>	<b>57 - 115</b>
3.1	Introduction	57
3.2	Transnet Freight Rail Case Study	57 - 80
3.3	Gautrain Maintenance Strategy	80
3.4	Passenger Rail Agency of South Africa	81
3.5	Other SADC Countries	81
3.6	Portugal: Lisbon – Porto Case Study	81 - 83
3.7	European Track Research Project	84 - 85
3.8	Italian and Serbian Comparisons Case Study	85 - 91
3.9	Swedish Case Study	91 - 99
3.10	Track Strategy Project of the Austrian Federal Railways	99 - 102
3.11	Track Maintenance Cost Allocations Strategies	102 - 103
3.12	Asset Management in Practice	103 - 111
3.13	Conclusion	111 - 115
<b>Chapter 4</b>	<b>Research Findings</b>	<b>116 - 124</b>
<b>Chapter 5</b>	<b>Conclusion and Recommendations</b>	<b>125 - 128</b>
<b>Chapter 6</b>	<b>References</b>	<b>129 - 135</b>
	<b>APPENDIX A:</b>	<b>136 - 141</b>

## **LIST OF FIGURES**

Figure 1	Global Rail Gauges (2012)	15
Figure 2	Rail Gauge and Connectivity in Africa (2012)	16
Figure 3	Freight and Passenger Statistics (2012)	17
Figure 4	Transnet Annual Results (10 Years overview)	18
Figure 5	Transnet Annual Results Media Presentation (2018)	19
Figure 6	European High Speed Lines Infrastructure (2009)	23
Figure 7	Typical Cross-Sections of HS Ballasted Tracks (2010)	26
Figure 8	Enhanced Track Design for High Speed Tracks (2013)	26
Figure 9	Breakdown of Maintenance Strategies (2013)	36
Figure 10	Changes in Maintenance Philosophy (2013)	36
Figure 11	Continuous Improvement Maintenance Process (1997)	38
Figure 12	Transition from Old Strategy to Future Strategy (2013)	39
Figure 13	Transition Procedure to a Rational Maintenance (2013)	40
Figure 14	Asset Centric Business Model (2012)	44
Figure 15	Asset Management Framework (2010)	45
Figure 16	Elements of Asset Management System (2013)	46
Figure 17	Rail Break Analysis Iron Ore Line	61
Figure 18	Process of Occupation	64
Figure 19	Organisational Structure: Infra Depot	67

## **LIST OF FIGURES**

Figure 20	Workshops Attendance	71
Figure 21	SAP Plant Maintenance Module	73
Figure 22	Four Topics for Maintenance Improvement	77
Figure 23	Improvement of Maintenance Intervention	77
Figure 24	Pareto Optimal Front	82
Figure 25	Comparison of Pareto Optimal Front for Varying Budgets	83
Figure 26	Organisational Chart of Innotrack Project	85
Figure 27	Ranking of Track Faults (2012)	85
Figure 28	Modular Architecture of RMMS (2014)	87
Figure 29	RMMS Visualization (2014)	88
Figure 30	Infrastructure Management and Performance Measurement	92
Figure 31	Overview of Line Failure Characteristics	94
Figure 32	Contribution of Infrastructure Type to Train Interruption	95
Figure 33	Pareto Chart of Higher Level System Failure	96
Figure 34	Categorization of traffic Zones Based on Risk (2011)	97
Figure 35	Categorization of traffic Zones Based on Risk (2012)	97
Figure 36	Root Cause Analysis of Infrastructure Bottleneck	98
Figure 37	Picture of Main Track Components	102
Figure 38	Asset Management Conceptual Model	107
Figure 39	Plan for Developing the Asset Management Plan	109
Figure 40	Asset Management Development Areas	110

## **LIST OF TABLES**

Table 1	South African Coal Line Profile (2011)	27
Table 2	South African Iron Ore Line Profile (2011)	27
Table 3	Mechanical Properties of High Strength Rails (2001)	29
Table 4	Summary of Condition Assessment in Railways (2010)	31
Table 5	Parameters Used for Decision Rules (2013)	42
Table 6	Track Maintenance Activities	60
Table 7	Daily Targets	62
Table 8	Maintenance Strategy Budget Expenditure: 10 Months of 2018/19 Financial Year	62
Table 9	Functions of On-track Machines	63
Table 10	Requirements for Infrastructure Management Plan	64 - 65
Table 11	Classification and Standards for Running Lines	66
Table 12	Automated Geometrical Condition Assessment of Track Parameters.	67
Table 13	Key Benchmarks: Facts & figures - SAP Module PM – Infra	74
Table 14	Advantages of Interventions	78 - 79
Table 15	Synthesised performance system	93
Table 16	Line Classes in Trafikverket and their Description	94
Table 17	Summary of Main Track Findings	100
Table 18	Summary of Points and Crossings Findings.	101

## **LIST OF ABBREVIATIONS**

AAMCoG	Australian Asset Management Collaborating Group
AMP	Asset Management Plan
ASCE	American Society of Civil Engineers
BSI	British Standards Institution
CAPEX	Capital Expenditure
CBM	Condition Based Maintenance
CM	Corrective Maintenance
COPEX	Capitalised Operational Expenditure
DB	Deutsche Bahn
DEU	Delegation of the European Union
DOT	Department of Transport
DSS	Decision Support System
EAM	Enterprise Asset Management
EAR	European Agency for Reconstruction
EBRD	European Bank for Reconstruction and Development
EC	European Community
EIB	European Investment Bank
ERA	European Railway Agency
EU	European Union
GIS	Geographic Information System
FHWA	Federal High Ways Administration
FIA	Flight Integration Assessment
FIT	Failure in time
FMEA	Failure Mode and Effect Analysis
FMECA	Failure Mode Effect and Criticality Analysis
HM	Her Majesty's
HSL	High Speed Line
IHHA	International Heavy Haul Association
IM	Infrastructure Manager
IMMS	Infrastructure Maintenance Management System
IAM	Institute of Asset Management
ISO	International Organization for Standardization
IT	Information Technology
Km	Kilometres
LCC	Life Cycle Costing
LiDAR	Light Detection and Ranging
LU	London Underground
MFOP	Maintenance Free Operating Period
MGT	Million Gross Tonnes
MM	Maintenance Management
MMIS	Maintenance Management Information System
M&R	Maintenance and Renewal
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
NSW	New South Wales
OECD	Organisation for Economic Co-operation and Development

## **LIST OF ABBREVIATIONS**

OHSAS	Occupational Health and Safety Assessment Series
OHTE	Over Head Track Equipment
ORR	Office of Rail Regulation
PAS	Publicly Available Standard
PDM	Predictive Maintenance
Plc	Public limited company
PM	Preventive Maintenance
PMO	Plant Maintenance Orders
PRASA	Passenger Rail Agency of South Africa
RAMS	Reliability, Availability, Maintainability and Safety
RBM	Risk Based Maintenance
RCF	Rolling Contact Fatigue
RCM	Reliability Centred Maintenance
RFI	Rete Ferroviaria Italiana
RMMS	Railway Maintenance Management System
RSR	Railway Safety Regulator
RTF	Run to Failure Maintenance
SABS	South African Bureau of Standards
SANS	South African National Standard
SADC	Southern African Development Community
SARA	Southern African Railways Association
SBD	Skew Bogie Detection
S & C	Switches and Crossings
SP	Subproject
SR	Serbian Railways
TFR	Transnet Freight Rail
TMS	The Management System
UIC	International Union of Railways
UBM	Under Ballast Mat
UK	United Kingdom
UMC	Ultrasonic Measuring Car
USP	Under Sleeper Pads
USA	United States of America
USDOT	United States Department of Transportation
WIM –WIM	Wheel Impact Monitoring & Weigh In Motion Systems

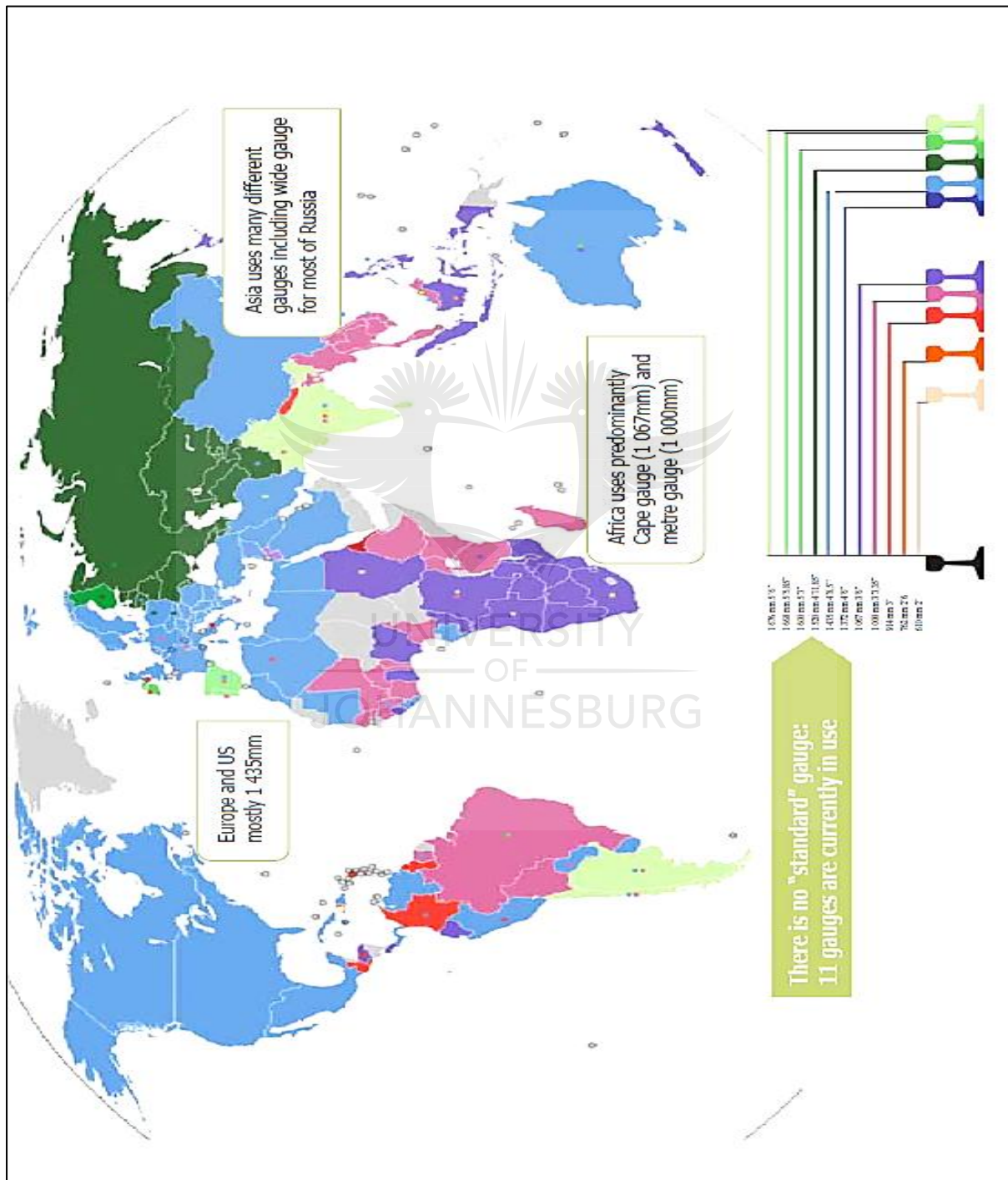
# **Chapter 1: Introduction and Problem Statement**

## **1.1 Introduction**

Transportation infrastructure is the backbone of every major or developing economy in the modern world. As an acknowledgement, Guler (2013) states that railways are utilized regularly and they are crucial for moving a significant number of commuters and a huge volume of merchandise daily. Guler (2013) further added that most railway organisations apply the traditional method of corrective maintenance as a maintenance strategy. Vickerman (2004) added by saying that the quality investments in railways and the related maintenance, were important vital aspects for railways, not just the number of investments. With the advent of climate change, lifecycle management to increase the reliability and availability of these infrastructure assets in order to preserve the raw materials for unnecessary frequent maintenance and /or premature total rehabilitation becomes ever increasingly important. Railway track components are those types of assets that require a strategic and disciplined approach to their maintenance from planning to execution. Monitoring of their condition and data to be collected for maintenance decision making is the most crucial element for the entire life cycle. Cost-effectiveness of maintaining these assets contribute positively to the profitability of organisations and economies of the countries globally. The development of globally recognised ISO 55000 creates an opportunity for railways to standardise their maintenance philosophies and adopt principles of physical asset management holistically. Generally, developing countries still prefer the manual labour method of maintenance combined with modern mechanical equipment where feasible. The developed countries utilize total mechanisation when doing track maintenance. The socio-economic pressures of creating employment for developing countries are much greater than in developed countries. In this chapter, the problem statement is intended to bring forth the challenge of the capacity and readiness of railway track asset owners in response to increased demand of railway services from freight customers as well as passengers. The chapter also covers research questions, research purpose, research objectives, significance of the study and research delimitations. Will the current maintenance strategies be capable to respond to shortened maintenance windows cost-effectively, without compromising safety and quality? The cape gauge of 1067mm

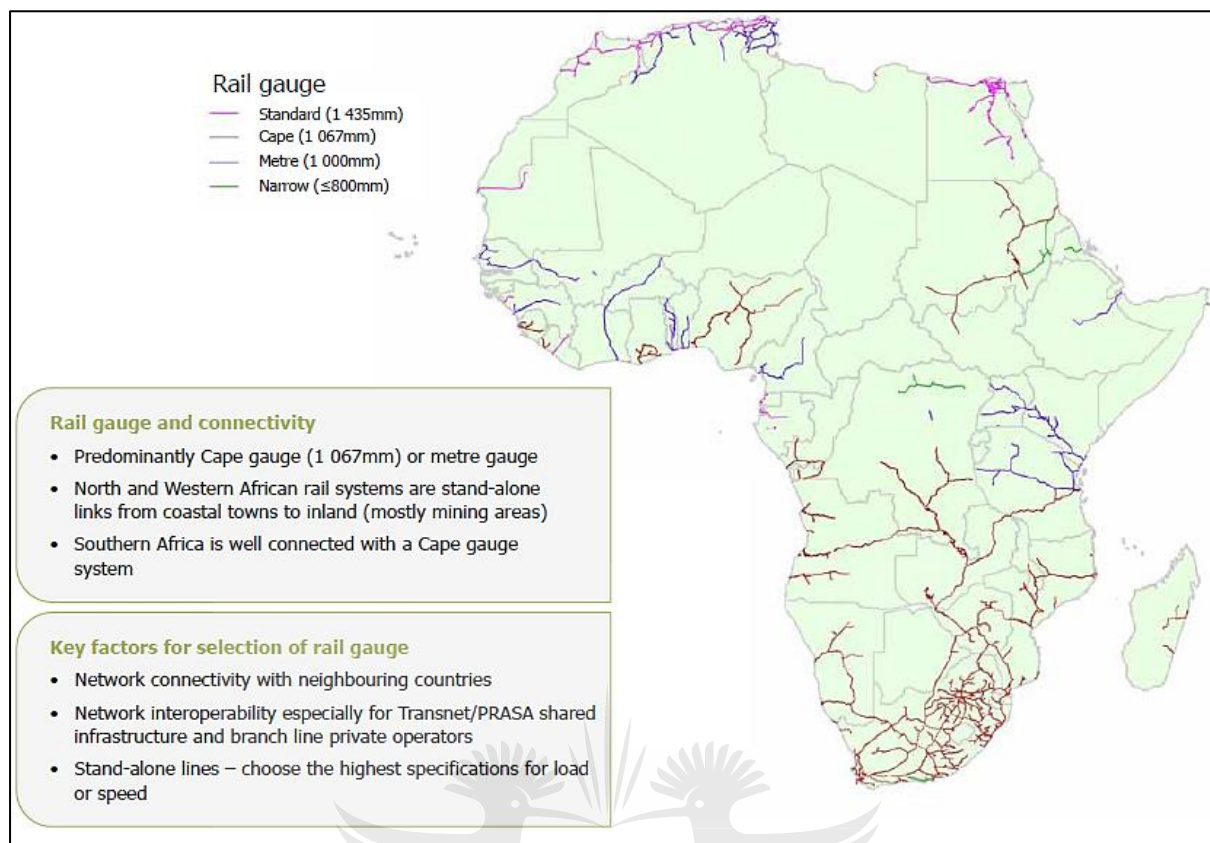


is used predominantly in developing countries of Africa and most mechanised track maintenance equipment is made for European standard gauge of 1400 mm. Gautrain is the exception in South Africa with 80 km of track from Pretoria to Johannesburg and a standard gauge of 1400 mm to accommodate its 160 km/h top speed. Figure 1 below depicts different gauges used globally:



**Figure 1: Global Rail Gauges (Source: Transnet Long Term Planning Document, 2012)**



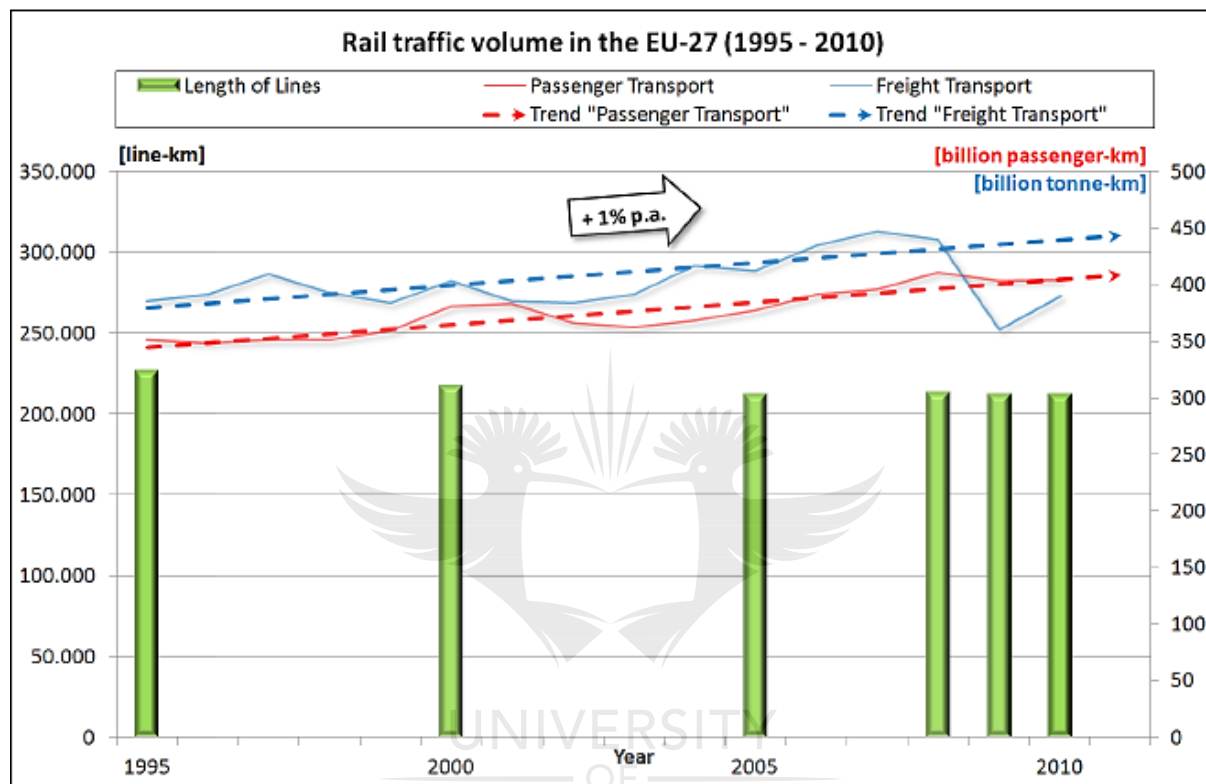


**Figure 2: Rail Gauge and Connectivity in Africa (Source: Transnet Long Term Planning Document, 2012)**

## 1.2 The Problem Statement

Different railway organisations are challenged with the rising demand of their services. This includes a rise in passenger numbers, increase in tonnages for heavy haul railways, longer trains for passenger and goods trains. Kaewunruen and Remennikov (2008) mentioned that “dynamic properties of railway track and its components are influenced by an increase in frequency of passenger traffic and rising loads of freight trains in recent years”. The population growth, the perceived environmentally clean and efficient energy used by the railways also adds to the increasing demand of railway services. All this means that the maintenance windows are shortened to give way to extra services to freight clients and passengers. Maintenance plans of the different railway organisations have to factor in these reduced windows of maintenance without compromising on quality and safety. Calçada et al (2012) mentioned that maintenance that is preventive should be considered for a railway track, in addition to the well-being and security of passengers and goods, this can be cost-effective since a large proportion of maintenance costs is because of the railway

track. The cost effectiveness of the maintenance strategies should also be considered for ensuring the viability and sustainability of railway operations. The focus of the research will be on the track maintenance strategies applied by selected international and local railway organisations. Figure 3 shows information relating to European Union Projected Rail Traffic Volumes for Freight and Passengers.



**Figure 3: Development of freight and passenger rail transport in comparison to the length of lines in the EU-27, 1995 – 2010.**

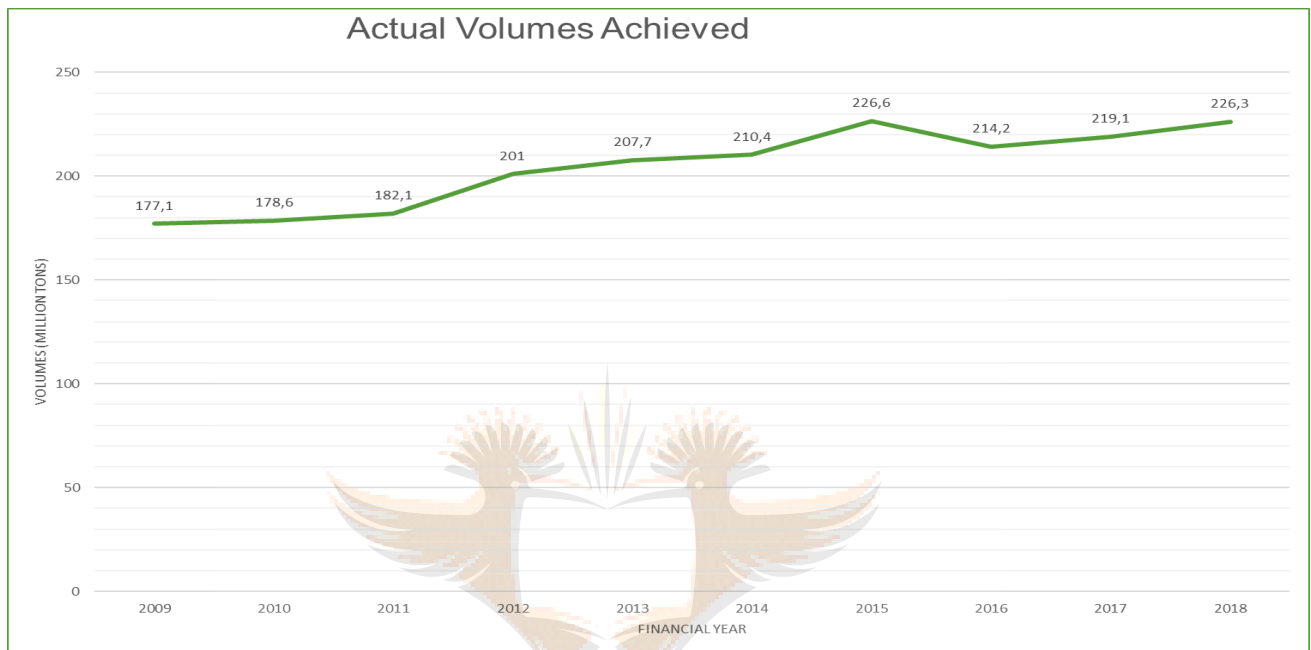
(Source: adapted from: European Union: EU transport in figures. Statistical pocketbook 2012. 1st edition. Luxembourg: Publications Office of the European Union 2012)

#### **Transnet Freight Rail's Overview (Source: [www.transnet.net](http://www.transnet.net), Business Plan Intranet)**

- Freight Rail transports **14%** of the nation's freight tonnage annually or **35% of ton kilometres**.
- Owns and maintains a network of **~20 500 route km** - (22 000 track km) connected to ports and the rail networks of neighbouring countries.
- Operates **~800 + trains per day**
- Serves **~450 key accounts**

- Conveys **98** commodity groups over more than **4 000 origin – destination combinations**
- Transports **3.5 – 4 mt** per week
- Moved **201 million tons** in 2012

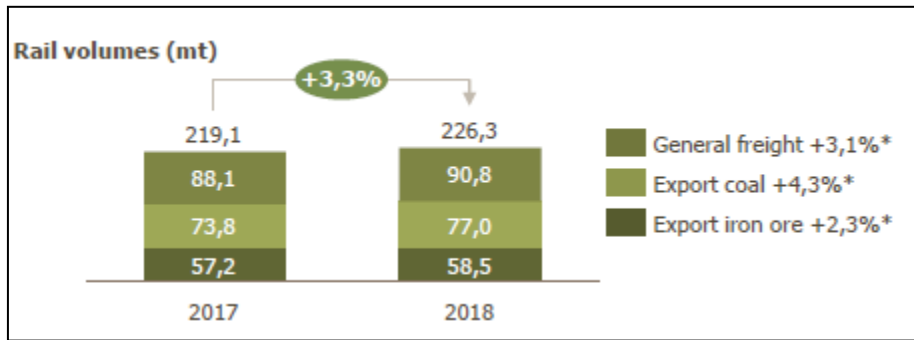
#### Transnet Freight Rail's Actual Rail Traffic Volumes



**Figure 4: Transnet Freight Rail's increasing volumes over 10 years (Source: Transnet Annual Results)**

Figure 4 above shows the Transnet annual results take from 2008/09 financial year to the 2017/18 financial year. There was a steady increase in volumes from 177,1 million tons in 2008/09 financial year to 226,3 million tons in 2017/18 financial year.

Figure 5 below shows the major contributors of volumes achieved in the last financial year. Export coal, general freight and export iron ore are key to rail volumes within Transnet. The planning and execution of the track maintenance strategy have to factor in these coming challenges. Limited track occupation time for emergency and planned track maintenance have to be optimally used and still produce quality work



**Figure 5: Transnet Annual Results Media Presentation, 2018 (Source: Transnet Audited Results for the Year Ended, 31 March 2018)**

### 1.3 Research Questions

1. What are the maintenance trends and strategies applied globally and locally for maintaining the railway track infrastructure? How is the maintenance strategy affected by high speed and low loads in contrast to low speed and high tonnages?
2. Which maintenance strategy can maximise the asset lifecycle of the railway track for international and local railway organisations?
3. What effect does different maintenance trends and strategies have on the reliability and availability of railway track, and its related maintenance costs?
4. Which is the most suitable maintenance strategy that addresses the challenges of reliability, availability and related maintenance costs of the railway track?

### 1.4 Research Purpose

The aim of the research is to contribute to the broader railway fraternity into how limited funds for maintenance of railway track can be used optimally through the adoption of contemporary maintenance technologies and philosophies. The advent of new management systems, e.g. ISO55001 presents a challenge to the railway fraternity to reconsider the approach to maintenance activities of their assets. The linking of country specific railway transport policy creation and interpretation, leading to railway company policies, strategic business and maintenance plans are crucial linkages that directly affect daily maintenance activities.

### **1.5 Research Objectives**

1. To find out the maintenance trends and strategies applied to different railway infrastructure assets globally and locally for maintaining the railway track infrastructure.
2. Establishing the maintenance strategy that can maximise the asset lifecycle of the railway track for international and local railway organisations taking into consideration the different operational, environmental and climatic conditions.
3. To establish the consequence of diverse maintenance trends and strategies on the reliability and availability of railway track and its related maintenance costs.
4. Selecting the most suitable maintenance strategy that addresses the challenges of reliability, availability and related maintenance and costs of the railway track.

### **1.6 Significance of the study**

The general railway infrastructure maintenance is important for the safe passage of trains. It is even more important on track as any major deviations from the standard can cause costly derailments and increased maintenance costs. Current methods on local and international track maintenance and the rationale behind choosing certain track maintenance strategies will be studied. External environment has an influence when considering the material type and maintenance strategy type. The study seeks to investigate whether some of the decisions taken in previous years should be reviewed considering that the climate is changing, material properties of some assets have changed, the weight of modern locomotives has increased and the freight tonnages or passengers have also increased. Maintenance strategies undertaken by different railway authorities or companies depend on the legislation of the country and the operational structure of the railway environment.

### **1.7 Research Delimitations**

Research does not include other types of track design like slab track, track with twin-block sleepers, wooden sleepers or metal sleepers and tubular track. The only focus is on the maintenance of ballasted track with mono-block concrete sleepers on both the high speed and heavy haul tracks.

## **1.8 Conclusion**

In this chapter, I have provided the context and the reason for conducting this research. Guler (2013) mentioned that railways transport a lot of passengers and goods in many countries, and for that reason, a decision support system is needed for the proper management of track maintenance and renewal. Calçada et al (2012) highlighted the importance of preventative maintenance on the track as it takes a bigger portion of maintenance management costs, besides its importance on safety and comfort. Railways have limited budgets to do maintenance and they have to ensure that the strategies being applied are among the best in the world. Optimisation of the limited resources at their disposal resulting in quality maintenance should be the primary focus of every infrastructure asset owner within the railway environment. The track structure was chosen as it is a safety critical structure and most of the budget for maintenance goes to these assets components consisting of rail, sleepers, pads, clips and ballast. Kaewunruen and Remennikov (2008) highlighted the effect that an increase in frequency of passenger traffic and rising loads of freight trains has on railway tracks and their components. Publicly available data projections depicting an increase in freight and passenger traffic in future were also shown in this chapter. The research questions presented covers the type of maintenance strategies required to address shortened maintenance windows caused by increased demand for railway services. The research purpose and objectives covered are meant to establish which maintenance strategies can be adopted to address the research questions.

The next chapter of literature review takes into consideration the current research and material covering the same topics. Published books and journals addressing these topics are considered.

## **Chapter 2: Literature Review**

### **2.1 Introduction**

The aim of this literature review is to evaluate the existing material regarding the maintenance strategies of the railway track assets. The current maintenance practices and future proposals within the literature are of importance as they give direction in terms of where the railway industry is heading. The literature review concentrates on answering the research questions with peer reviewed material, published professional journals and industry related books.

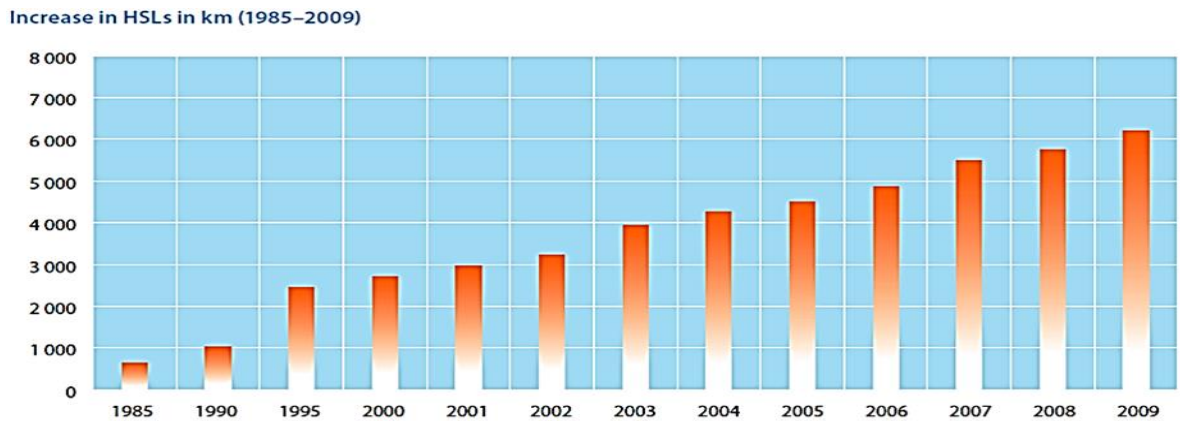
### **2.2 Introduction to Track Maintenance**

Tzanakakis (2013) describes maintenance strategy as planning of maintenance types to be executed on the track, including track components, at a particular frequency, under certain operating conditions. Railway track components consist of different items with differing material properties. Ballast, rails, sleepers, fastenings and subgrade all make up the railway track system. In South Africa, the track is also called the permanent way or perway. The width of the track differs in a lot of countries. The terminology for the track width is called the gauge. The track gauge is basically the width or spacing between two adjacent/parallel rails.

### **2.3 High Speed Railway Tracks in Europe**

According to a study, initiated by European Commission and concluded in March 2009 by MIV Consulting and Tractebel Engineering, at the end of 2009, Europe had 6 214 km of high-speed lines where trains run at speeds of 250 km/h and more. The study further established that from the time when high-speed lines were introduced, passengers selecting trains as a means of transport has continued to increase. The number of passengers on all German, Belgian, Spanish, French, Italian and British lines increased from 15.2 billion passenger-kilometres in 1990 to 92.33 billion passenger-kilometres in 2008.





**Figure 6: European High Speed Lines infrastructure (Source: International Union of Railways, High Speed Department, 2009)**

### 2.3.1 Drainage

Berggren (2009) citing Selig and Waters (1994) emphasises substructure water content that is a lot can result in various issues; therefore, drainage of water is very critical. Berggren (2009) further reiterated that drainage should be constructed correctly during the construction phase of the track, and listed the following requirements:

- Clean ballast is crucial for substructure drainage, in order to enable water to drain as quickly as it enters the inlet
- Sloping of the sub ballast and subsoil in the direction of the track edges
- Establishing a method of diverting water away from the substructure

Berggren (2009) concluded by saying that regulating ballast fouling first, then cleaning the ballast afterwards satisfies the initial condition. The second condition is to redesign the surfaces to establish accurate slopes. Nearby water drainage situation is key for dealing with the third condition. Culverts maintenance can be a simple way to improve the drainage function considerably.

### 2.3.2 Maintenance of High Speed Tracks

Teixeira and colleagues (2010) conducted a study on the life cycle costs of maintaining the ballasted track on high-speed lines. The slab track initial costs are higher than the conventional ballasted track. Ferreira and Pita (2013) mentioned that the circulation of trains at very high speeds (higher than 300 km/h) leads to important vibrations in the



track and its environment. They further suggested the appropriate track design solution for very high speed trains should be able to do the following:

- Increase the track reliability and availability
- Reduce the maintenance frequency
- Reduce the lifecycle costs of the track

Furthermore, Ferreira and Pita (2013) mentioned that track dynamically improves with solutions, such as applying soft pads under the rails, or pads under the sleepers (USP), or bituminous sub ballast (instead of the conventional granular layer), track settlement progression with time was also numerically evaluated.

Teixeira, Lopez-Pita and Ferreira (2010) after their research, recommended the use of a minimum thickness of 12–14 centimetres of a conventional bituminous mix as an alternative to the usual granular layers used in order to meet the Spanish standards for high-speed tracks. They continued to state that the bituminous sub-ballast solution might bring relevant advantages in terms of subgrade protection and life cycle: track differential settlement and track dynamic performance. The differential settlement is basically caused by different composition of subgrade materials and subsequent stiffness of the track responding in various ways to the static loads and dynamic loads caused by rolling stock. Vertical load on the track divided by deflection of the track, results in track stiffness.

Xuecheng, Hongguang and Yunmin (2010) conducted a study on the prediction and control of the permanent settlement of a track caused by traffic loading from high-speed trains. The effect of this on design and maintenance was also incorporated in the study. The findings of the study were that the accumulative settlement mainly affects the subsoil instead of the roadbed. It was therefore concluded that traffic loading plays an important role in the development of settlement of the railway track, and soil improvement is necessary for high speed railways constructed in soft soil areas to control permanent settlement after the line is put into operation.

Furthermore, Xuecheng, Hongguang and Yunmin (2010) cited Yang *et al.* (1998), noting that the Hokkaido Shinkansen in Japan was designed for train speeds of 210 km/h, but was later limited to 110–180 km/h because of the excessive post-settlement induced by the traffic loadings of the train.

In another paper on this topic, Baniward and Woodward (2007) highlighted that as the train speed exceeds a threshold value, track deflections increase considerably leading to the need for frequent maintenance and the possibility of train derailment in worst cases. As early as 1954, Kenny [cited by Baniward and Woodward (2007)] presented an analytical solution for beams on Kelvin foundations under moving loads. He presented relationship for critical velocity of the beam-foundation system defined as 'a speed at which dramatic increases in the beam displacement is observed:

$$V_{cr}=4\sqrt{(4kEI/\rho^2)}$$

Where k, is the foundation of modulus stiffness (spring constant), E and I are the elastic modulus and moment of inertia of the beam respectively, and  $\rho$  is mass per unit length of the beam.

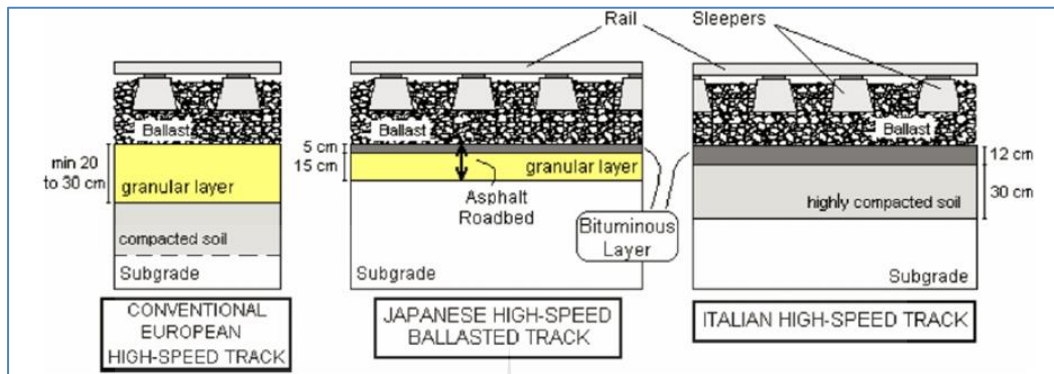
Banimard and Woodward (2007) continued by mentioning that in practice, the lowest critical velocity is only of interest in defining the speed limit to which the train can travel. That velocity is termed "critical track velocity". In 2006, Malik et. al. [cited by Baniward and Woodward (2007)] and others discussed that when the train speed is under the critical track velocity, no ground wave is propagated, provided that there is no major structural or geometrical irregularities present within the track (e.g. track faults) to excite the train.

Furthermore, Banimard and Woodward (2007) mentioned that as the train speed approaches the subgrade Rayleigh wave velocity, the track displacement increases dramatically. They then added by saying that having a deeper ballast layer can decrease the track displacement, which seems to be more effective at higher speeds. Banimard and Woodward (2007) concluded with the following facts:

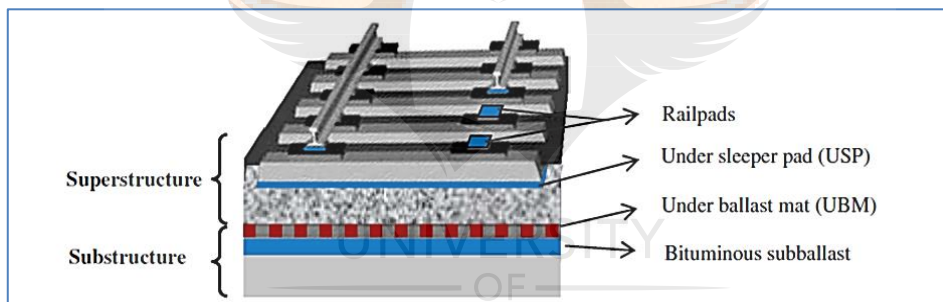
- Subgrade stiffness is a critical factor in defining the critical track velocity, closely related to the Rayleigh wave velocity of the subgrade soil.
- Track with trains running below 50% of the critical track velocity were associated with low maintenance levels.
- Ballasted tracks with running speeds from 50% to 70% of the critical track velocity were classified as high maintenance.
- Train speed of 70% and higher of the critical track velocity were associated with the rapid deterioration of the railway track and a potential risk of derailment.

- Subgrade nonlinearity does not affect the track response and maintenance levels at low train speed but has a substantial effect as the train speed starts to increase.

Figure 7 shows the different approaches in design for high-speed tracks for ballasted track, while Figure 8 shows an enhanced track design of high-speed train. The rationale behind some of these designs are explained in the preceding paragraph.



**Figure 7: Typical cross-sections of HS ballasted tracks**  
[Source: (Teixeira et al. 2006)]



**Figure 8: Schematic representation of different alternative track design solutions for enhanced dynamic performance of high-speed tracks.**  
[(Source: Ferreira P.A. and Pita A. (2013)]

## 2.4 High Tonnage Railway Tracks in South Africa

The heavy haul lines in South Africa are the coal line and iron ore line. The following data summary in Table 1 is taken from the International Heavy Haul Association Conference in Calgary, Canada 2011:

Distance	<ul style="list-style-type: none"> <li>• +/- 580 km from Blackhill to Richards Bay</li> </ul>
Topography	<ul style="list-style-type: none"> <li>• Descends from 1700 meters altitude to sea level.</li> <li>• Undulating topography and high rainfall.</li> </ul>
Axle load	<ul style="list-style-type: none"> <li>• 26 tons per axle on heavy haul and some feeder lines.</li> </ul>
Ruling Gradient	<ul style="list-style-type: none"> <li>• 1:100 North of Ermelo</li> <li>• 1:160 for loaded trains South of Ermelo on one of the two tracks, and 1:66 for empties.</li> </ul>
Gauge	<ul style="list-style-type: none"> <li>• 1067 mm</li> </ul>
Tonnage (gross tons per train)	<ul style="list-style-type: none"> <li>• 22 000 tons at 2,2km in length</li> </ul>
Capacity	<ul style="list-style-type: none"> <li>• 74 million tons export coal; 14 million tons general freight</li> </ul>

**Table 1: Coal Line Profile (Source: International Heavy Haul Association Conference in Calgary, Canada, 2011)**

Distance	<ul style="list-style-type: none"> <li>• 861 km from Sishen to Saldanha</li> </ul>
Topography	<ul style="list-style-type: none"> <li>• Semi-desert, descending to the coast from 1 295 m above sea level at the Sishen mines.</li> </ul>
Axle load	<ul style="list-style-type: none"> <li>• 30 tons per axle</li> </ul>
Ruling Gradient	<ul style="list-style-type: none"> <li>• 1:250 loaded trains</li> <li>• 1:100 empty trains</li> </ul>
Gauge	<ul style="list-style-type: none"> <li>• 1067 mm</li> </ul>
Tonnage (gross tons per train)	<ul style="list-style-type: none"> <li>• 41000 tons @ 4 km train length</li> </ul>
Capacity	<ul style="list-style-type: none"> <li>• 60 million tons infrastructure capacity excluding power upgrades</li> </ul>
Volumes	<ul style="list-style-type: none"> <li>• 55,91million tons for 2013/14 financial year.</li> </ul>

**Table 2: Iron Ore Line (Source: International Heavy Haul Association Conference in Calgary, Canada, 2011)**

#### **2.4.1 Maintenance of High Tonnage Tracks**

According to the International Heavy Haul Association (IHHA) handbook, heavy haul traffic is defined as 25 tonne or greater axle loads, 20 million gross tonnes (MGT) annual traffic on the line or the operation of trains in excess of 5,000 gross tonnes.

### 2.4.2 Rail Profile Design

In heavy haul environment, a two-point conformal contact is usually sought, while in transit the objective was a one-point conformal contact. Rail fatigue and rail wear have to be managed in order to prolong the lifecycle of the rolling stock wheels and the rails of the track. The rail needs to be supported by a deep ballast and sub ballast, and shorter sleeper spacing. The properties of the rails (e.g. yield strength, tensile strength and brinell hardness) themselves need to be sufficient for heavy loads.

Table 3 as presented by Zakharov (2001) lists the mechanical properties of high-strength rail for some of IHHA countries. These high strength rails have a yield strength of about 760-790 MPa and a tensile strength of about 1170 MPa. Standard (as rolled) rails has lower strength characteristics and hardness with a yield strength of about 480 MPa and a tensile strength of about 960 MPa. Hardness is a vital mechanical distinguishing factor that determines rail performance to a great extent. Hardness and its presence across the railhead depth influence wear resistance, rolling contact fatigue resistance, and plastic flow of the railhead. The variety of rails on the marketplace is characterised by a comprehensive selection of surface hardnesses. Table 3 below depicts the mechanical properties of high strength rails. China has the highest yield strength rails for their heavy haul rails, followed by Russia. The USA also has a higher yield strength. All these countries have a larger land mass and due to challenging maintenance logistics try to limit regular maintenance of rail wear and rolling contact fatigue by choosing high yield strength rails. According to Tomicic-Torlakovic (2014) and Vitez and Krumez (2004), the selection of rail grades is dependent on many factors, but ultimately the main advantages for utilizing high yield strength rails for heavy haul operations is the reduced rail wear and rolling contact fatigue on the rails.

Property	USA, Canada, Brazil	South Africa	China	Russia	Sweden
Yield Strength, MPa (min)	758	640	805	794	640
Tensile Strength, MPa (min)	1172	1080	1175	1176	1080
Elongation (%)	10	9	10	6	9
Brinell Hardness at the surface	340 - 390	340	340 - 390	331 - 388	320 - 360

**Table 3: Mechanical Properties of High Strength Rails (Source: Guidelines to Best Practices for Heavy Haul Railway Operations: Wheel and Rail Interface Issues, 1<sup>st</sup> Edition, International Heavy Haul Association)**

## **2.5 Vehicle – Track Interaction**

### **2.5.1 A Systems Approach**

The basic approach for a track maintenance strategy is for maintenance personnel to consider the vehicle and environmental properties that the track is exposed to. Ebersöhn and Rooney (2001) mentioned that rail is the most expensive element of the track structure. Hence the management of wheel-rail interaction is of paramount importance. Ebersöhn and Rooney (2001) listed the following activities for the proper management of wheel-rail interaction:

1. Develop target rail profiles that are seen to achieve low fatigue and wear. Because of the heavy influence of contact fatigue on rail, these target profiles would typically incorporate some conformity with wheel profiles. A mechanical representative should be on the team to advise on implications for wheels, and to explore the potential for joint optimization of wheel and rail profiles.
2. Measure rail and wheel conditions to determine maintenance needs.
3. Develop rail and wheel wear projection methodology.
4. Develop rail and wheel fatigue life projection methodology.
5. Perform economic evaluation of different premium rail options based upon condition monitoring and execute plans to progressively balance rail strength with service environment. Determine the use of premium and intermediate rail steels in different tonnage and curvature classes based on minimum lifecycle costs. Perform analyses to determine transposition and re-use policies.

6. Perform extensive rail re-profiling to the target profile and to correct existing rail spalling, corrugations, and head checks.
7. Re-profile wheels to target profile.
8. Install lubricators in locations with history of higher rates of wear on the gauge face.
9. Develop new rail wear limits and supply new design of joint bar to support extended wear limits in secondary lines.
10. Develop new wheel wear limits.
11. Implement regular and frequent ultrasonic rail inspection as well as regular rail wear and profile condition measurement. Quality assessment is an important part of this strategy. Correlate rail deterioration with track geometry condition and gauge widening to develop joint strategies.
12. Implement regular and frequent wheel flaw inspection as well as regular wheel profile condition measurement.
13. Implement frequent maintenance rail re-profiling (grinding) on regular cycles. The objective should be to move to single pass rail grinding, with speeds adjusted to grind as fast as possible to control rail flow and fatigue occurring between grinding cycles.
14. Adjust profiling standards and rail-testing intervals to match needs of rails approaching extended wear limits.
15. Implement a condition based maintenance plan for wheel re-profiling.

Tournay (2010) added by saying that given track topology (grades, curvature) and axle loads, what can be done to control and manage wheel/rail contact from the point of view of vehicle / track dynamics are the following:

Reduce lateral & longitudinal creep forces across the contact patch by:

1. Utilizing steering trucks
2. Ensuring accurate tracking accuracy (axle alignment, bogie / body interface, wheel set geometry and wheel profiles)
3. Reduce dynamic action (stable vehicles, track discontinuities including rail joints)
4. Top of rail friction control (rolling contact fatigue and flange wear)
5. Gauge face and flange lubrication



According to the document UIC Code 715-2: Recommendations for Management of Rails (2003), rails account for 30% to 50% of the cost of new infrastructure. Management of rails plays a key role in optimising track maintenance costs.

UIC Code 715-2: Recommendations for Management of Rails (2003), continues to say that the service life of rails depends on loads sustained and the speeds operated on different lines.

### 2.5.2 Condition Monitoring

Tournay (2010) emphasised that the benefits of managing wheel-rail interaction through condition monitoring are as follows:

1. Fix that which needs fixing (focus)
2. Fix that which is causing high stresses on vehicle and infrastructure
3. Spend less time on inspection
4. Improved planned maintenance
5. Improved understanding of degradation modes
6. Improved understanding of root causes of degradation

The railway industry has developed a lot of condition assessment technologies in the last 20 years that can either be train borne or be placed on the track side. Steyn (2010) presented some of the examples of condition monitoring influencing wheel/rail interaction on the following table:

Wayside	On-board systems
Wheel Profile Monitoring	IMMS (IM2000)
Hot Bearing Detectors	Locomotive Condition Monitoring
Wheel Impact Monitoring & Weigh In Motion Systems (WIM-WIM)	Ultrasonic Measuring Car (UMC)
Long Stress Monitoring System	Skid Mark Detector
Ultrasonic Broken Rail Detector	
Skew Bogie Detection (SBD)	

**Table 4: Summary of Condition Assessment in Railway Operations, Maintenance and Business.**

**[Source: Steyn B. (2012)]**

Steyn (2010) added by saying that condition monitoring has become an integral part of the modern railways, and will become increasingly so. The thesis by Berggren



(2009) concentrated on a new method of condition monitoring for the substructure titled: “Dynamic vertical track stiffness measurements along the track”. Berggren (2009) highlighted the following:

1. The relationship between applied force on the rail and the displacement of the rail results in track stiffness.
2. The track stiffness differs by frequency, dynamic amplitude, applied preload and position along the track.
3. Track stiffness is a vital interface factor between wheel and rail contact relationship.
4. Differences in track stiffness and values that are outliers (both low and high) will have an impact on the track deterioration.

## **2.6 Track Deterioration**

Esveld (1989) mentioned that requirements for bearing strength and quality of the track depend on the following load parameters:

- Axle load: static vertical load per axle;
- Tonnage borne: sum of the axle loads;
- Running speed

Esveld (1989) further argues that accumulated tonnage is a measure of the deterioration of the track quality and as such provides an indication of when maintenance and renewal should take place. Öberg (2006) discussed the decline of track quality by looking at the following models:

- Models for deterioration due to vertical settlement;
- Models for deterioration due to wear and contact fatigue;
- General deterioration models;
- Models due to changed traffic conditions; and
- Computer-aided planning and prediction tools.

Bocciolone et al. (2007) states that it is very important to determine these degradations in early stages because track condition determines the safety and comfort of rail transport. Guler (2013) added that there are many parameters affecting track deterioration. He noted that these parameters cause settlement and lateral

displacement of the track; thus railway track components are exposed to fatigue, corrugation, wear, abrasion, defects, and damage. According to Guler (2013), the deterioration rate is higher in sharp curves and the replacement of track components occurs too frequently due to wheel/rail interaction lateral forces from the passing trains. Davis and Garnham (2009) added by saying that rails may last for 100-2500 MGT (million gross tonnes on two rails), much dependent on curve radii as the dominating causes of the deterioration differ from one application to another and between wheel and rail. Giannakos (2010) mentioned that the weak links in the track structure are the ballast and substructure as they develop residual deformations: deflections and lateral displacements proportionally related to the deterioration of the geometry of the track, which is also referred to as quality of the track.

Andersson and Öberg (2008) divided track deterioration into four mechanisms consisting of the following:

- Track settlements (due to non-uniform movements in the ballast)
- Fatigue of components including switches and crossings (internal fatigue of rails, fastenings, sleepers, ballast, damage to rail pads and so on)
- Abrasive wear
- Rolling contact fatigue (RCF) of rails (referred to as surface fatigue of rails, whereas 'component fatigue' is not only of internal fatigue of rails, but also other track components).

Profillidis (2012) mentioned that track degradation mainly includes geometrical parameters, e.g. longitudinal defect, cant deviation, horizontal defect, twist and gauge. Profillidis (2012) further highlighted that whereas the degradation of track is reversible, it is not the case with the individual track components, which mostly fail mechanically, e.g rails, fasteners, sleepers, ballast and rail pads. According to Profillidis (2012), geometrical parameters evolve much faster than mechanical properties by 5 to 15 times. Profillidis (2012) further referred to International Union of Railways (UIC) group 4, which mentioned that for railway line with average traffic of 20 000 to 40 000 tons per day, maintenance of track geometry by tamping operations will be done after 40 to 50 million tons, while rail (i.e. mechanical degradation) replacement can be done after approximately 500 to 600 million tons. Berggren (2009) added by saying

that there are diverse processes that cause a decline of various components of the railway structure. Rail wear and fatigue often characterise the rail deterioration, while deterioration in track geometry is mainly caused by ballast and soil settlements.

## **2.7 Reliability Centred Maintenance**

Tzanakakis (2013) mentioned that since the 1960's, the aviation industry in the USA through FIA introduced Reliability Centred Maintenance. The characteristics of this total approach to maintenance included the following:

1. Which is the best appropriate blend of maintenance types?
2. On a particular equipment,
3. In a certain operational setting.

Tzanakakis (2013) further observes that maintenance strategy can be defined as the best suitable combination of maintenance varieties, which applies a balanced combination of preventive, corrective, detective and adaptive duties. This mixture allows a perfect balance between maintenance costs and availability/reliability of the infrastructure. In the track context, Tzanakakis (2013) added that "maintenance strategy" can be defined "as arrangement of the types of maintenance, which is to be done to the track and its components, at a specific rate or frequency, under specific operating conditions."

Backlund and Akersten (2003) as cited by Marten (2010) identified obstacles during the planning, preparation and analysis phase of the RCM. Those obstacles included (a) lack of a computerized maintenance management system; (b) lack of a computer system; (c) lack of a plant register; (d) unavailability of documentation and information; (e) problematic routines, roles, and responsibilities; (f) communication problems; (g) lack of overarching maintenance management strategy; and (h) incomplete goal setting, and benefits identification and measurement. According to Campbell and Reyes-Picknell (2006), as cited by Marten (2010), unplanned running repair work costs 50 percent more than planned and scheduled work and emergency work will cost three times as much. Fleming (2006) as cited by Marten (2010) reported that RCM techniques are more effective than other maintenance processes and techniques. Primarily, RCM techniques are effective because they involve (a) continued periodic

maintenance that includes inspections, repairs, and performance checks; (b) conditioned-based maintenance that can assist in preventing equipment failure; and (c) run-to-fault maintenance.

## **2.8 Risk Based Maintenance Strategy**

Sakai (2010) mentioned that by introducing risk based maintenance (RBM), prioritization becomes possible in planning of maintenance inspection programs, allowing concentrated inspection of parts that truly need maintenance. Sakai (2010) further mentioned that risk can be given as the product of the probability of failure occurring to the inspected area and the consequence of failure to the surroundings. The concept is based on the Pareto principle of 80/20 rule, where 80% of the total risk of the system is concentrated in just 20% of the devices. Risk based inspections will also have to be dictated by the risk rankings of the equipment being inspected. Uniform based inspection methods that are supported by routine maintenance do not cater for the deterioration patterns of structures after long term use, where inspections in the latter stages of the lifecycle have to be more frequent. Sakai (2010) also emphasized the benefit of skills transfer in applying the risk based maintenance strategy. He mentioned that veteran employees with experience tend to make decisions in their heads on items such as what is optimum, what inspections are smoother and what needs to be prioritized to secure safety. The process of drawing out the knowledge that they practice subconsciously and transforming it into explicit knowledge for skills transfer is the most challenging part.

## **2.9 Common Maintenance Strategies**

Tzanakakis (2013) listed the maintenance strategies as follows:

1. Run to Failure Maintenance (RTF): When a facility or asset breaks down, fix it.
2. Preventive Maintenance (PM): Glossary of terms of British Standard 3811:1993 defines preventive maintenance as “the maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning and the effects limited.”
3. Predictive Maintenance (PDM): Determines the condition of in-service equipment in order to predict when maintenance should be performed.

4. Corrective Maintenance (CM): Glossary of terms of British Standard 3811:1993 defines corrective maintenance as “maintenance carried out after recognition of failure and intends to put an item into a state in which it can perform a required function.”

Figures 9 and 10 below shows the different maintenance strategies:

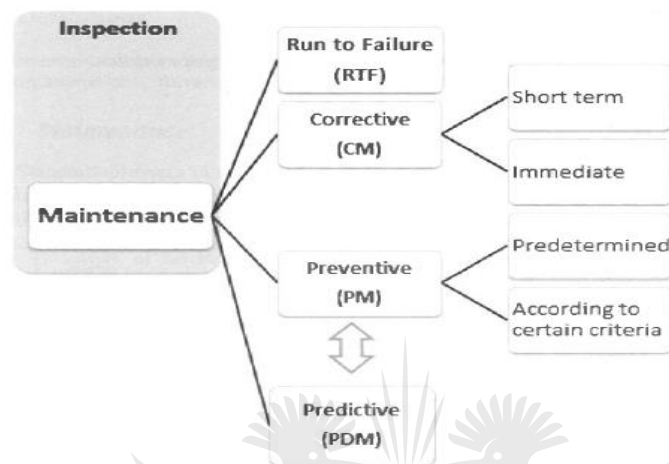


Figure 9: Breakdown of different maintenance strategy types  
[Source: Tzanakakis K. (2013).]

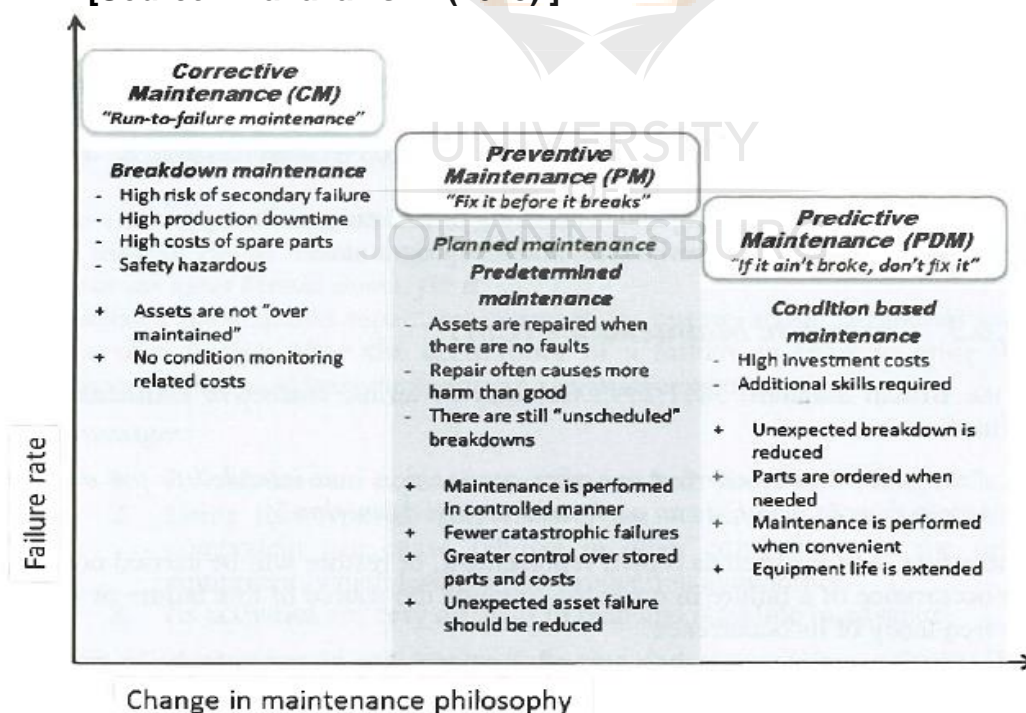


Figure 10: Changes in Maintenance Philosophy  
[Source: Tzanakakis K. (2013).]

Gräbe and Van der Westhuizen (2013) argue that the benefits of moving-ahead from maintenance that is reactive or corrective to maintenance that is condition based, brings about better effectiveness and a decrease in maintenance costs. Furthermore, Gräbe and Van der Westhuizen (2013) explained the descriptions of common maintenance strategies in the following manner:

### **2.9.1 Corrective Maintenance**

Mitchell (2007) as cited by Gräbe and Van der Westhuizen (2013) defined corrective maintenance as covering glitches typically acknowledged by production and/or operations departments. Corrective maintenance examples cover:

- Derailments
- Rail breaking
- Slipping of earthwork material
- Substructure components washing away
- Signalling or electrification failures.

Gräbe and Van der Westhuizen (2013) continued to mention that corrective maintenance approach is the costliest and must be reduced for growth in efficiency and operational costs reduction. It also increases uncertainty which affects operational consistency or reliability, provision of service and operational profits in a negative way.

### **2.9.2 Preventive Maintenance**

Routine-based and condition-based maintenance are covered by preventive maintenance. Reduction of long downtimes is one of its benefits for making certain that capacity is available. Lastly, preventive maintenance lessens uncertainty, increase reliability and improves provision of service.

#### **Routine Based Maintenance**

Routine based maintenance can be executed at time-based intervals, which can be based on operating time or calendar. Maintenance activities that are needless may be covered in routine based maintenance strategy, as those activities will not assist in asset reliability improvement. Therefore, over-maintained assets, swelling operational costs and reduced operational profit will be the result. Mitchell (2007) as cited by Gräbe



effectiveness are reached. A decrease in maintenance costs is achieved when reliability and production increases. Figure 11 below shows continuous improvement in maintenance management:

## 2.10 Future Maintenance Strategy

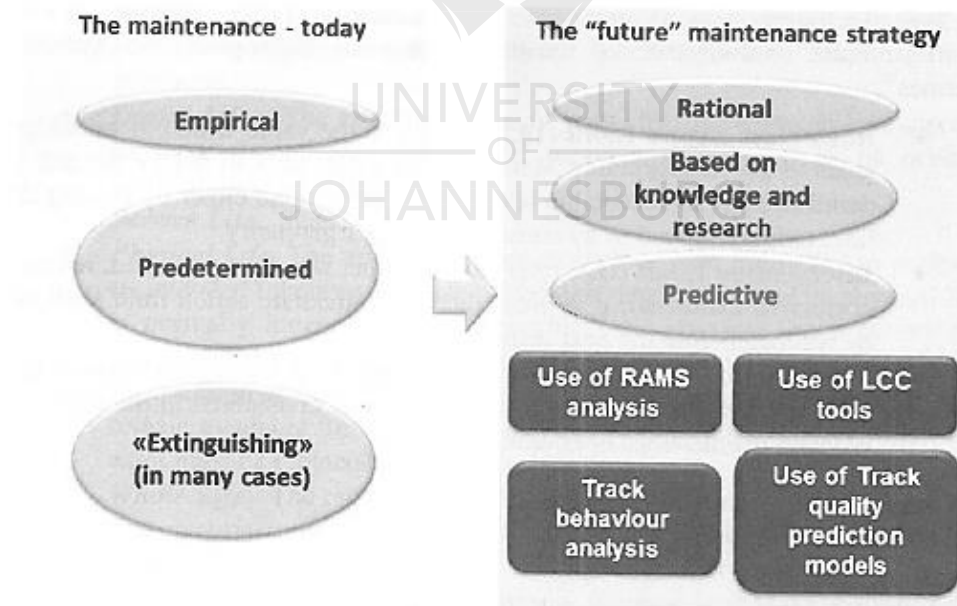
Tzanakakis (2013) proposed the following topics to be covered for future maintenance strategy:

1. Rational (reliable, cost effective, assuring long durability, with best use of the available resources such as people, equipment and money)
2. Based on good track (functional) knowledge and research on specific problems.
3. Predictive

Tzanakakis (2013) continued to propose the following tools to fulfil the above-mentioned topics:

1. Reliability, Availability, Maintainability and Safety (RAMS) Analysis
2. Life Cycle Costing (LCC) Tools
3. Track behaviour analysis
4. Track quality prediction model

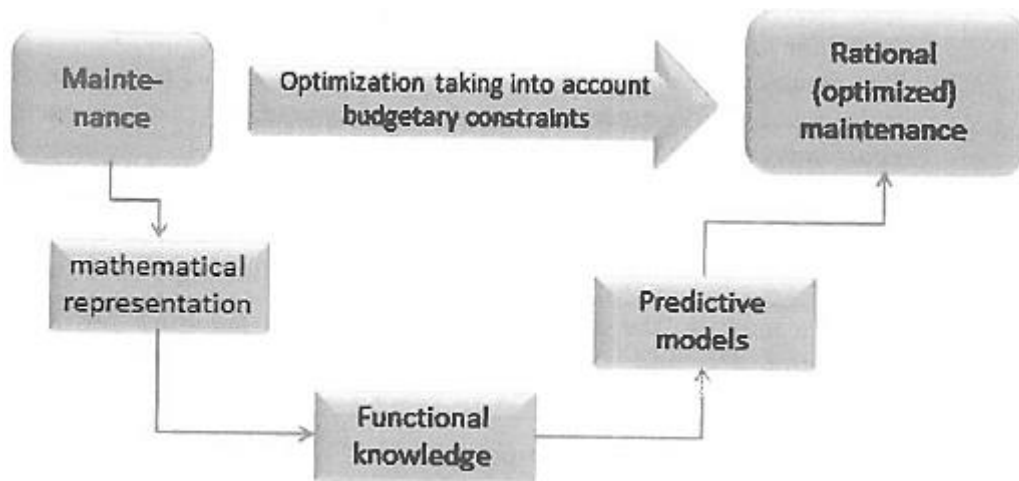
Figures 12 and 13 below depict the transitions of track maintenance:



**Figure 12: The Transition from Old Strategy to Future Maintenance Strategy.**

[Source: Tzanakakis K. (2013).]





**Figure 13: Transition Procedure to a Rational Maintenance**  
 [Source: Tzanakakis K. (2013).]

## 2.11 Maintenance Plan

A maintenance plan is derived from maintenance strategy. Tzanakakis (2013) mentioned that a maintenance plan presents “a description of the preventive and predictive maintenance and inspection tasks to be performed at maintenance objects. The maintenance plans describe the dates and scope of the tasks.” Tzanakakis (2013) goes on to say that preparation for maintenance is linked to revitalisation activities and preventive / predictive maintenance, it is impossible to plan corrective maintenance ahead of time. Profillidis (2012) highlights the fact that track maintenance expenses represent a significant percentage of total railway infrastructure expenses. Veit (2012) from Graz University of Technology highlighted the common problems of track maintenance as availability and maintainability where the sustainable solution covers both technical solution in terms of track quality and economical solution, which considers life cycle costing of the track. Veit (2012) added by saying that Life Cycle Management allows to check projects, whether they are economic or not and mentioned the following points:

1. Analysing the trends of all track data allows forecasting the future maintenance demand.
2. Whenever the future maintenance demand is known, total life cycle cost can be calculated depending on the service life of track.

3. For a certain service life average annual costs are a minimum thus leading to optimum point of time for re-investment.

Furthermore, according to Veit (2013), the cost drivers of railway track maintenance are:

1. Initial track quality precondition: subsoil quality and functionality of drainage
2. Switch density
3. Ballast Quality
4. Radii
5. Cost of operational hindrances (up to 30%)
6. Length of track work section (up to 20%)
7. Traffic density
8. Quality of rolling stock (+/-10%)
9. and of course high speed, mixed traffic, and axle load

Finally, in order to maximise the maintenance strategy, Veit (2007) proposed the following:

1. The original track quality is important because it is impossible to replicate or exceed original track quality; the worsening track condition depends on present track quality.
2. Quality of track geometry must always be defined by its rate of change.
3. In order to achieve optimisation, a single complete maintenance strategy that covers both renewal strategy and capital works is required. It is incorrect to divide capital works and renewal strategy from the maintenance strategy.

Furthermore, Guler (2013) advocated that the inputs for the decision making process in track maintenance planning has to cover the following parameters in Table 5:

<b>Maintenance and Renewal Operation</b>	<b>Parameters</b>
Ballast renewal	Type of ballast; Age of ballast and age limits; Tamping history; Tamping frequency; Condition of substructure; Amount of dirty ballast; Track geometry measurements; Deterioration of vertical geometry; Track condition indexes; Minimum ballast depth; and Reference values for ballast.
Sleepers and rail fastenings renewal	Type of sleepers; Age of sleepers and age limits; Loads and cumulative loads; Service index; Gauge value; Gauge narrowing; Gauge widening; Standard deviation of gauge; Condition of sleepers and fastenings; and Number of damaged sleepers
Rail grinding and lubrication	Track class; Transversal acceleration of bogie; Transversal acceleration of train floor; Vertical acceleration of train floor; Short wave corrugation limit value; Noise limit value; Number of damaged sleepers; Number of trains; Number of rail failures; Track curvature; Cumulative loads; and Weibull distribution parameters.
Rail renewal	Properties of rails; Age of rails and age limits; Loads and cumulative loads; Speeds; Radius of curves; Number of rail defects; Track class; Number of rail faults; and Weibull distribution parameters
Tamping	Tamping history; Track measurements; Analyzing track geometry; Track geometry limit values; Track condition indexes; Deterioration rate of track geometry; and Number of track geometry faults.
Integral renewal	Sleepers and rail fastenings renewal rules; Ballast renewal rules; Rail renewal rules; Condition of substructure; and Cost analysis.
Rails, sleepers, and fastenings renewal	Sleepers and rail fastenings renewal rules; Rail renewal rules; and Cost analysis
Sleepers, fastenings, and ballast renewal	Sleepers and rail fastenings renewal rules; Ballast renewal rules; and Cost analysis.
General measurements and spot maintenance	Periodic measurements; Condition of track components; and Cost analysis.

**Table 5: Parameters Used for Decision Rules**  
**[Source: Guler H. (2013)]**

## 2.12 International Union of Railways (UIC)

The railway fraternity in Europe created a document titled: “*Guideline for the Application of Asset Management in Railway Infrastructure Organizations*” in September 2010. UIC members of asset management committee members were the main contributors of the document. The document states that it puts more weight on evidence-based resolutions, utilizing insight on how assets deteriorate and failure to implement optimal maintenance and renewal initiatives. According to the document “*Guideline for the Application of Asset Management in Railway Infrastructure Organizations*”, the advantage of adopting an asset management method consist of the establishment of a ‘line of sight’ between strategy conceptualisation and putting strategy into practice, the ability to provide similar levels of sustainable performance with reduced workload, and showing outside interested parties that actions to be undertaken are done at the lowest total life cycle cost. The document guidelines are consistent with recognised approaches from the following documents:

- Asset Management Part 1: Specification for the Optimised Management of Physical Assets, 2008 (PAS 55-1:2008)
- International Infrastructure Management Manual, 2006
- Asset Management Overview, Federal Highways Administration. United States Department of Transportation, FHWA-IF-08-008

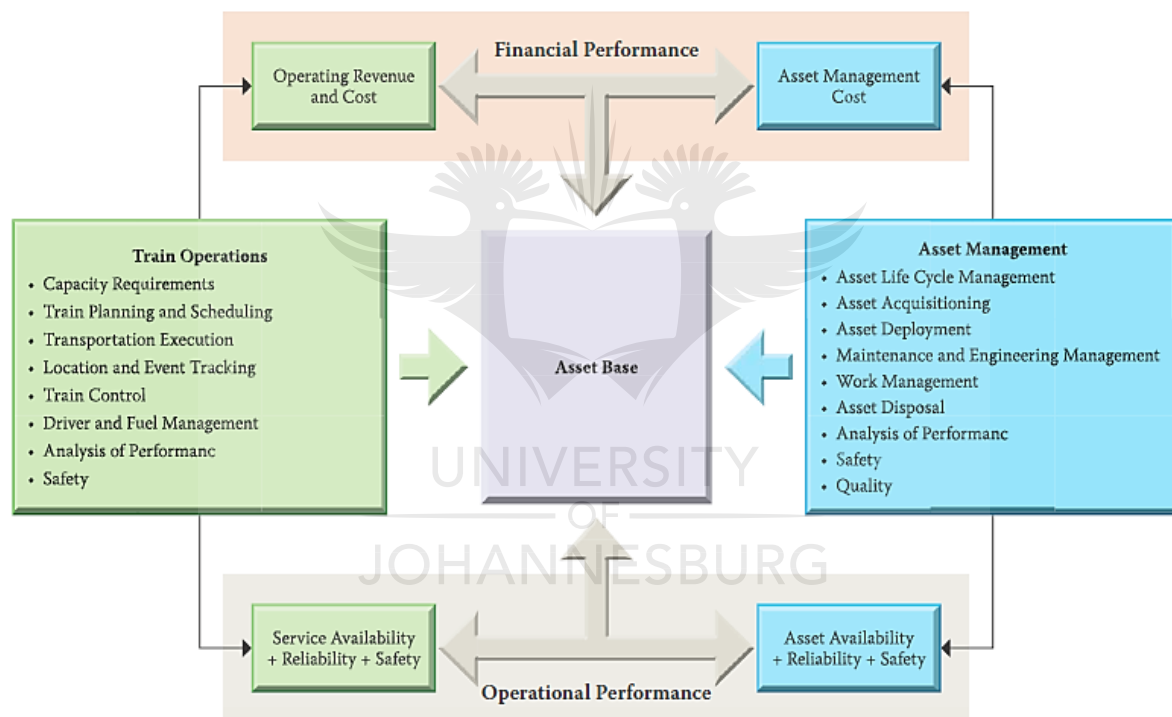
The eight key linkages with the abovementioned documents, which are the core of this guideline, are:

1. Step 1: Definition of asset management
2. Step 2: Scope of asset management
3. Step 3: Asset Management Policy
4. Step 4: Asset Management Strategy
5. Step 5: Asset Management Framework
6. Step 6: Specification: Core decisions and activities
7. Step 7: Specification: Enabling mechanisms
8. Step 8: Specification: Reviewing mechanisms

The guideline underlines the significance of presenting how the building blocks fits to produce a complete asset management system.

## 2.13 Railways and Asset Management

Gräbe and Van der Westhuizen (2013) mentioned that railways are businesses that are asset-intensive relying on diverse assets that have to be availed at the same time to support operations. Furthermore, Gräbe and Van der Westhuizen (2013) highlighted that railways should follow a combined (between business units) and collective (strategic, tactical and operational) method to manage performance utilising a cause-and-effect approach. Gräbe and Van der Westhuizen (2013) also emphasised that an asset-centric approach be adopted, whereby operations and maintenance are integrated elements of a system and need to be managed as such, as illustrated in the following Figure 14:



**Figure 14: Asset- Centric Business Model**  
[Source: Grabe P.J. and Van der Westhuizen N.J. (2013)]

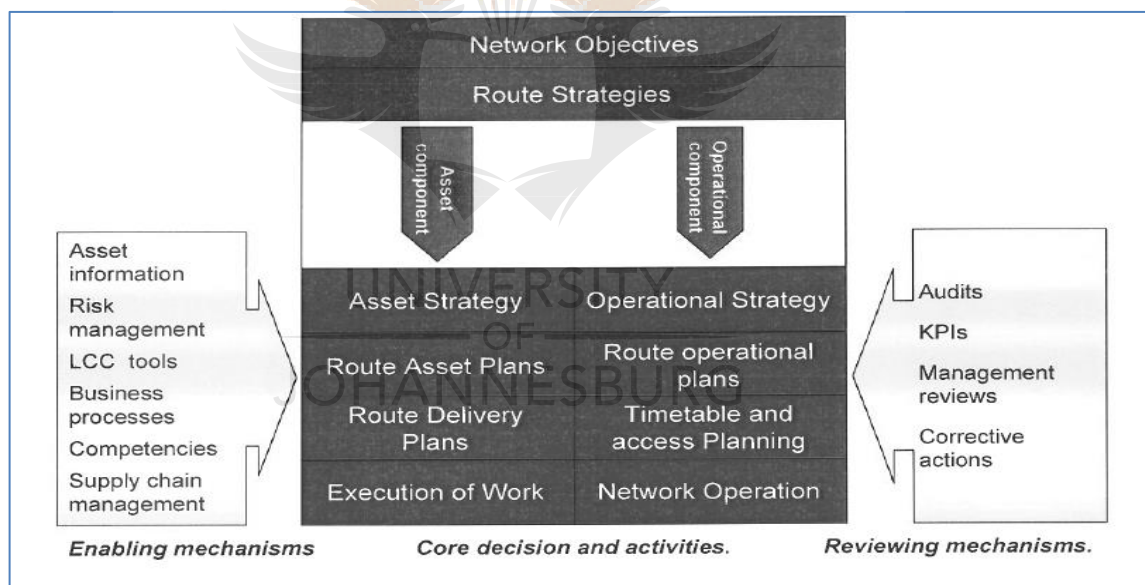
### 2.13.1 Asset Management Framework

The framework comprises of main components of the asset management system falling under three types, namely:

1. Core decisions and activities:

- Outlines the resolutions and actions connecting strategy to work execution, comprising of infrastructure work and network operation. This is the most important component of the asset management framework.
2. Enabling mechanisms:
    - The effectiveness of the core decisions and activities depends on support tools like life-cycle costing tools, asset information, business processes and competencies.
  3. Reviewing mechanisms:
    - The mechanisms are for checking and refining the efficiency of asset management system in providing sustainable outputs for type of funds committed. The feedback loop for the uninterrupted enhancement of the asset management system is provided on this platform.

Figure 15 below shows Asset Management Framework categories:



**Figure 15: Asset Management Framework**

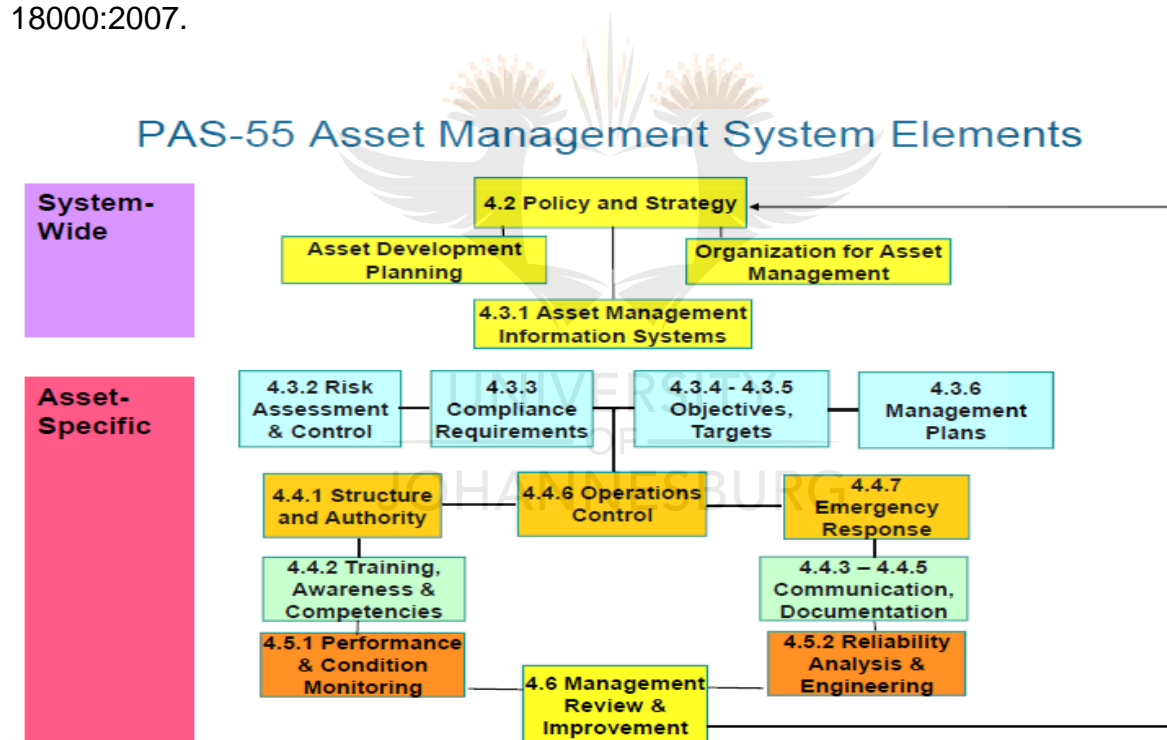
**[Source: Guideline for the Application of Asset Management in Railway Infrastructure Organizations, UIC, 2010]**

## 2.14 Asset Management: PAS 55 and ISO 55000

### 2.14.1 PAS 55

PAS 55 is a Publically Available Specification, which enhances the manner in which physical assets are being managed. PAS 55 was written by the British Standards

Institute in 2004, and then revised in 2008. According to Woodhouse (2014), organisations involved in the development of the PAS 55 specification were The Institute of Asset Managers and other 49 organisations from 15 industries in 10 countries. The creation of this specification was as a result of responding to industry and regulator request for an Asset Management Standard. The standard mainly focuses on heavy Industries (e.g. energy, utilities, and oil & gas etc.). Woodhouse (2012) continued to mention that many of the core principles of integrated, lifecycle and optimised physical asset management evolved in the North Sea oil and gas industry during the 1980s and 1990s. PAS 55 is available in 2 parts: It is PAS 55-1, which consists of 28-point requirements specification and PAS 55-2, which gives direction of how to apply PAS 55-1. The specification is in alignment with corresponding requirements of ISO 9001:2000, ISO 14001:2007 and OHSAS 18000:2007.



**Figure 16: Elements of Asset Management System according to PAS 55.**  
 (Source: Nick Hastings, Centre for Integrated Engineering Asset Management at the PAS55 AAMCoG [Australian Asset Management Collaborating Group])

Figure 16 above depicts the elements of asset management system according to PAS 55. The first overarching system wide element in clause 4.2 of PAS 55 is policy and strategy. The asset owner's top management will draft policy related to asset management where one of the policy objectives is offer a structure that will allow an asset management strategy to be aligned to tactical and operational plans for



implementation. This must be supported by an asset management information system that can give inputs to the plans and produce repository outputs for asset historical data and configuration management.

Asset specific elements consider the applicable core elements and enablers that supports the management of an asset throughout its life cycle.

### **2.14.2 ISO 55000**

Due to wide adoption of PAS 55 by industry stakeholders, and after consultation with industry and professional bodies globally, the PAS 55 specification was presented before the International Standards Organisation in 2009 as the foundation for a new ISO standard for asset management. The approval was granted and that led to the development of ISO 55000 family of standards within 3 years with 31 participating countries. The ISO 55000 family of standards consists of three documents:

- ISO 55000 Asset management — Overview, principles and terminology
- ISO 55001 Asset management — Management systems — Requirements
- ISO 55002 Asset management — Management systems — Guidelines for the application of ISO 55001

The creation of these three documents resulted in elements that were combined in PAS 55-1 to be split into ISO 55000 and ISO 55001. As depicted above, the ISO 55001 standard contains the requirements specification only, whereas in ISO 55000 the content covered is subject matter introduction, with definitions and terms. The contents in ISO 55002 are the same as in PAS 55-2 as they all give direction on the interpretation and application of the ISO 55001 requirements.

### **2.14.3 Asset Management Themes**

#### **Sustainability**

Lloyd (2012) mentioned that the rationale for the widespread adoption of asset management is based on the related factors of reduced operational and capital expenditures and the standardisation of processes and competencies. Lloyd (2012) further added that the arguments for this rationale are made from financial, social and environmental standpoints.

## **Change Management**

In terms of change management, Lloyd (2012) mentioned that one of the key battlegrounds in organisations on the lower rungs of the asset management maturity scale is information and data sharing. Lloyd (2012) continued to say that asset management decisions feed on detailed data on condition, resources, demand and performance. Lloyd (2012) reiterated the following in clause 6.4, page 21 of the *introduction chapter*: *“Without detailed data, there can be no real appreciation of constraints, returns or long-term value, and the ability to weigh the impact of different options. The ability to carry out ‘what if’ analysis and articulate choices to stakeholders is seriously diminished. Moreover, without a steady flow of reliable and steady data, decision making becomes less consistent and less transparent, and decisions become harder to defend. However, to deliver qualitative and quantitative system or network-wide data, people have to trust each other, be willing to share information and be committed to the overall goal. For these reasons, information sharing is a litmus test of progress towards an asset management system.”*

### **2.15 Quantitative Methods Required for Implementing ISO 55000 and PAS 55**

Minnaar and colleagues (2013) identified six areas in sections of PAS 55 and ISO 55 000 that requires the use quantitative methods to introduce asset management techniques. They further noted the six areas that were identified as defined in the standards, namely: data analysis, life cycle management, asset criticality, risk management, statistical failure analysis, and sustainable development. Application of statistical approaches is defined by covering six areas.

#### **2.15.1 Data analysis**

Minnaar (2013) et. al. define data analysis as processing of data, with an intend to collect valuable facts to back-up decisions that are proposed. Minnaar (2013) et. al. added by saying that PAS 55 proposes the necessity for data and data analysis, whereas ISO 55000 openly demands decision-making processes that are supported by data. Some of the important main beliefs of asset management is that “asset management turns the organizational strategic intent into decisions and actions on assets to realize their value”. Therefore, managing of assets requires thorough data analysis.

### **2.15.2 Critical Assets**

According to Minnaar (2013) et. al., ISO 55000 series calls for a strategic approach in order to determine the criticality of assets and asset systems and weigh them appropriately when making decisions.

### **2.15.3 Life Cycle Management**

Minnaar (2013) et. al. added that in “Guidelines for the application of ISO 55001 (ISO 55002)”, a few life cycle management references were mentioned “(Sections 6.1.2, 6.2.2.4, 7.5.1, and 7.5.2)”, mostly covering the financial cost of owning an asset over its life cycle. Proper management of assets over their entire life cycles should back economical decision-making.

### **2.15.4 Risk Management**

Minnaar (2013) et. al. highlighted the fact that in order for organisations to implement either PAS 55 or ISO 55001, firstly asset risks should be defined, followed by showing how a particular risk profile evolve over a particular period. Furthermore, Minnaar (2013) et. al. added that PAS 55 highlighted the importance of a synergy between an organisation’s policy for asset management and its risk management, where asset risks are considered when plan(s) for asset management are prepared. This is how diverse risks are optimised and prioritised.

### **2.15.5 Statistical Failure Analysis**

Minnaar et. al. (2013) defined statistical failure analysis as a process of determining when machinery will fail, which will assist in determining the life cycle of the assets and in managing the asset efficiently. PAS 55 advocates that organisations should establish, implement, and maintain process(es) and/or procedure(s) for analysis of past performance, display current performance, and forecast an asset’s future performance. Added to that, Minnaar et. al. (2013) acknowledged a key role that statistical failure analysis can play in improved stakeholder confidence, which can be attributed to the ability to predict, within a certain confidence interval, when an asset will fail. This is critical for accomplishing asset reliability and expected operational state.

Furthermore, Minnaar et. al. (2013) mentioned that continual improvement and preventative action is the main highlight of the ISO 55000 series. According to Minnaar et. al. (2013), key techniques that are used for implementing failure analysis are log-linear, power law point processes and Weibull distribution. The techniques mentioned

are for determining metrics such as MTBF (mean time between failures), MTTF (mean time to failure), MFOP (maintenance free operating period), and FIT (failure in time). Simulation can also be used to model asset failure through simulating organisational processes.

#### **2.15.6 Sustainable development**

Minnaar et. al. (2013) cited from PAS 55 to differentiate between *being sustainable* and *sustainable development* as stated below:

Sustainable: “achieving or retaining an optimum compromise between performance, costs and risks over the asset’s life cycle, whilst avoiding adverse long-term impacts to the organisation from short-term decisions”.

Sustainable development: “enduring, balanced approach to economic activity, environmental responsibility and social progress.”

Sustainable development is a long-term commitment by an organisation, and is an important part of asset management, as mentioned in PAS 55 Section 4.2 (g): “The policy shall clearly state the principles to be applied, such as the organisation’s approach to health and safety or sustainable development.” Regulations were also highlighted by Minnaar (2013) et. al. as an instrument that drives sustainable development. These regulations should be considered when introducing plans and procedures related to asset management as asset management is a growing field. Minnaar (2013) et. al. added by mentioning that ISO 55000 series also indicates that the asset management system should follow a long-term sustainable approach, where important methods that can be utilised to expedite sustainable development includes life cycle management and its related methods like network models and geographic integrated systems (GIS).

#### **2.16 Railway Operational and Infrastructure Management Approach**

Asmild et. al. (2009) conducted a research that considered 23 European countries between 1995 and 2001. The study analysed whether a number of restructuring initiatives that were initiated by the European Commission resulted in improved efficiency of the railway system or not. Efficiency was measured by means of Multi-Directional Efficiency Analysis that supported the study of how railway reforms affect the inefficiencies of particular cost drivers in the railway system. Asmild et. al. (2009) concluded that there is a clear positive effect on the technical efficiencies of the cost

transparency following from accounting separation. The paper also presented empirical evidence that accounting separation is important for improving technical efficiency through material and staff costs. The question that still requires additional research was this: Does complete separation brings any additional benefits, or whether the potential coordination problems outweigh the benefits?

## **2.17 Asset Management Information Systems**

Haider (2007) highlighted the following important pointers with regard to information systems for asset management:

- The aim of utilising information systems for asset management is to produce info for unified depiction of asset management.
- This can assist asset managers to have a broad view about assets under their control, i.e. beginning from planning to retirement.
- The entire lifecycle will include the asset's operational and value profile, maintenance demands and treatment history, health assessments, degradation pattern, and financial requirements to keep them operating at near original specifications.
- Three main functions of information systems in asset management are collection, storage, and analysis of information covering asset lifecycle processes; secondly, to deliver decision support abilities through the conclusions reached from analysing data; and thirdly, provision of functional integration for asset management.
- Improving the results of asset management processes via a bottom up approach, which collects and processes operational data for individual assets as a basis, and continue to show a consolidated view of the entire asset base at a strategic level.

Haider (2007) continued to say that information systems translate strategic asset management decisions through the planning and management considerations into operational actions by aligning information systems with asset management strategy. Stenström et. al (2014) made a study of how performance of linear assets can be analysed and displayed while taking into account both the technical asset and the characteristics of the potential user. The study was done to simplify cognitive tasks of

planning and decision making. Stenström et. al (2014) highlighted that performance of linear assets when considering their availability and dependability can be measured by using the following factors: measures of uptime for availability, failure frequency for reliability, active repair time for maintainability and logistic time for maintenance support. Stenström et. al (2014) emphasised that such indicators were central to performance measurement. In conclusion, Stenström et. al (2014) studied asset performance in terms of failures and cost, where the results of the study indicated that visualising performance at different technical and organisational levels in a manner that is easy to interpret, can make planning and decision making more effective by pointing out improvement areas in assets, in a way that is appealing to both technicians and managers. This is achieved as infrastructure managers improved their analysis and visualisation of performance.

Andrews et. al. (2014) investigated a stochastic model in maintaining the railway track. Andrews et. al. (2014) highlighted the following key performance indicators in the track segment prototype covering maintenance and renewal:

1. Interventions numbers
2. Speed limits numbers
3. Period of Speed limits
4. Line closure quantities
5. Period line will be closed
6. Time period track is in good, poor or satisfactory state
7. Related expenses for preventive maintenance
8. Related expenses for corrective maintenance

Andrews et. al. (2014) utilised a petrinet model of a 1/8<sup>th</sup> mile track section to study the value of strategy covering asset management in order to maintain the geometry of the section to an acceptable level. The petrinet model combined the deterioration process of the track and its reliance on the maintenance history, with all intervention possibilities for inspection, repair and renewal. Fluctuating parameters of the prototype has been applied to study performance outcomes of the track. The research covered the following factors:

- the regular inspection to endorse track geometry condition;



- track life cycle;
- routine maintenance mean time to repair;
- performance parameters were the necessity for maintenance is acknowledged.

Andrews et. al. (2014) continued to define the expenses of diverse intervention activities (measurement, tamping and renewal), together with the penalty charges of facing line closures and speed limits constraints. The lifecycle expenses for each of the potential asset management strategies were weighed and the most effective one selected.

## **2.18 Conclusion**

### **Maintenance of High Speed Lines and High Tonnage Lines**

The literature review in this chapter covered the maintenance trends and strategies applied globally and locally for maintaining the railway track infrastructure. Different strategies of track maintenance were reviewed. Train speeds of 70% and higher above the critical track velocity or track design speed leads to a rapid deterioration of the railway track due to increased vertical dynamic forces that causes rail displacement, leading to a weaker track subgrade. An important factor to consider when designing track subgrade and sub ballast layers is to enhance track stiffness that can withstand the track design speed. Therefore, for high-speed trains on a ballasted track, the subgrade and sub ballast layers should be given more attention in terms of initial track design and in service maintenance. Other factors that causes the subgrade to deteriorate significantly in service other than over speeding (speeds higher than the critical track velocity) are improper drainage design, weaker sub ballast design, substandard construction and maintenance, as well as substandard subgrade and sub ballast material. In recent times, more technologies for condition monitoring of track components are utilized for track deterioration rate. The overall sentiment is that geometrical parameters in terms of track settlement and lateral displacement should be monitored closely for ensuring track quality. This type of track deterioration can also be reversed by tamping, whereas rail defects like rolling contact fatigue and rail wear on the other hand, are not reversible.



For railway tracks where the rolling stock is predominantly low speed and high tonnage, that is those tonnages with an axle load of 25 tons or more, an important factor to consider is the contact patch in wheel - rail interaction. This wheel-rail interaction contact patch needs to be managed as it affects the rail wear rate and rolling contact fatigue on the rail. The predominant degradation mechanism of a rail (that is wear or rolling contact fatigue) in a curve will depend on the curve radius, rolling stock type and wheel and rail metallurgical profiles. That is the reason why a systems approach is encouraged when considering vehicle – track interaction and the maintenance of the wheel and rail contact patch. The benefits of managing wheel-rail interaction through condition monitoring systems like the ultrasonic measuring car (UMC) for the rails and the wheel profile monitoring system (WPMS) for the wheels are that any anomalies are detected earlier. The Guideline to Best Practices for Heavy Haul Rail Operations addresses the issues of wheel and rail interface in their entirety. For trains travelling at or beyond the critical velocity or design speed, rolling contact fatigue on the rail is not as prevalent as it is for low speed, high tonnage trains. For high tonnage trains, that is those with an axle load of 25 tons or more, the rail material has to have a high yield strength and the rail hardness of the rail head/crown should be able to withstand rail wear, rolling contact fatigue defects and rail plastic flow. In terms of maintenance of the rail and wheels, grinding of the rail head and wheel reprofiling should target to have a two point contact between the wheel and rail in order to increase the life cycle of both rails and wheels. In addition to that, for high tonnage trains, rails have to be supported by deep ballast and sub ballast and shorter sleeper spacing.

### **Maintenance Strategies**

Stand-alone maintenance strategies discussed consisted of corrective maintenance (run to failure maintenance), preventive maintenance (routine based maintenance) where assets are fixed before they break and predictive maintenance (condition based maintenance) where an asset condition is monitored and maintenance intervention only happens after data analysis flags a maintenance need. A balanced combination of all three maintenance strategies is covered under the reliability centred maintenance strategy. In a track maintenance context, reliability centred maintenance strategy can be able to accommodate different track components in terms of type and frequency of maintenance under applicable operating conditions. Reliability centred maintenance

(RCM) is an important strategy as it can synthesize all three strategies. In terms of prioritization during maintenance planning and execution, risk based maintenance (RBM) strategy allows maintenance to be concentrated firstly on assets that have a high probability of failure. Track maintenance planning is influenced mostly by the adopted maintenance strategy. Perhaps the two approaches of RBM and RCM can be integrated, by applying firstly RBM, then continuing with the RCM approach on items with the highest risks. In terms of costs related to maintenance strategies, for any railway track asset owner, corrective maintenance approach is expensive and must be reduced to improve efficiency and reduce operational cost. Corrective maintenance also increases uncertainty, which impacts adversely on trustworthiness of operations, service provision and income from operations. It is not possible to plan for corrective maintenance; it is the attitude of extinguishing the fire as you wait for assets to fail before maintenance can be done. In terms of track maintenance, the routine based maintenance and condition based maintenance are much more applicable than corrective maintenance. On certain track components like rails, subballast and subgrade, transition from preventive maintenance (routine based maintenance) to predictive maintenance (condition based maintenance) can be beneficial, as technologies exist for data collection and analysis on track behaviour, track quality prediction models and rail condition analysis.

In terms of applicable management systems, an asset management system (ISO 55000) can be adopted to facilitate the adoption and implementation of maintenance strategy that covers the whole lifecycle of an asset comprehensively. The literature of asset management is a more holistic one as it can maximise the asset lifecycle of the railway track for international and local railway organisations. The improvement of the reliability and availability of track can also be realised with the application of the holistic asset management strategy. The beginning of professional and structured railway asset management was started by the railway fraternity in Europe, through the Union of International Railways (UIC). The outcome of this initiative was the creation of a document titled: *"Guideline for the Application of Asset Management in Railway Infrastructure Organizations"* in September 2010. The document states that it puts greater importance on resolutions based on evidence, utilising insight of how assets deteriorate and failure to implement optimal maintenance and renewal initiatives. Woodhouse (2013) as cited by Lloyd (2014) presented background information that

led to the creation of PAS 55. PAS 55 then led to the creation of ISO 55000, where the asset management system elements were introduced in an internationally recognised standard. In terms of holistic asset management, the ISO 55000 asset management system elements provide a framework and platform for asset management policy creation, formulation of asset management objectives and strategies and asset life cycle management plans. Management plans should be aligned to the daily operation and control of life cycle activities (i.e. acquire/create, utilise, maintain/improve and renew/dispose). All these activities are for the continuous improvement of portfolio of physical assets utilising existing asset management resources, processes, competencies, and technologies. It can be easy for the RCM strategy to adopt the ISO 55000 as most elements are already in the maintenance strategies that are found under the RCM strategy. The following chapter will look at some of the case studies of maintenance strategies from privately owned railway companies and public organisations that apply various track maintenance strategies locally and internationally.



## **Chapter 3: Research Design and Methodology**

### **3.1 Introduction**

The research study adopts a case study methodology. The case study method was selected because it gave an insight into how different railway organisations approach the maintenance of the railway track within their organisations. The case study method used in this case is also the best method to give answers to research questions. The case studies reviewed covered the developed countries mainly in Europe. Detailed statistics from Transnet were utilised to analyse the rate of deterioration of the track infrastructure whilst taking into consideration increasing tonnages on the railway network. Transnet's data was taken from the current on-going project of Roadmap to Safety, where the benchmarking of best practices in rail network infrastructure maintenance from Deutsche Bahn in Germany is the ultimate goal of the project. Data collection for the Roadmap to Safety project was done through workshops, where the participants were maintenance personnel from various relevant departments. Utilization of maintenance machines (mechanisation) during track maintenance is popular in developed countries. A mixture of mechanisation and manual labour is still preferred in developing countries. A challenge in developing countries is to strike a balance between job creation and cost savings in terms of manual labour and the quality provided by the mechanised maintenance equipment and their costs. Data utilised for South African perspective was taken from Transnet only. International data for European railway companies was taken from the UIC and the European Railway Agency.

### **3.2 Transnet Freight Rail's Case Study**

According to the Transnet's Long Term Planning Framework, which defines Transnet's long-term port, rail and pipeline infrastructural investment based on a macro-economic freight demand forecast, the rail network consists of more than 30 000 km of track. The actual route distance is about 20 953km. The network provides excellent coverage of most of South Africa from a freight demand point of view and links all of the major mining and primary production areas with the port system. The network also covers all of the major commercial and consumer areas. Roughly 60% of the network can be classified as the "Core Network" with about 9 000 km of lines classified as "Branch lines" with the potential to service communities and activities not directly on the main corridors.

### 3.2.1 Baseline routine maintenance

Baseline routine maintenance is the maintenance strategy utilized in Transnet Freight Rail. This means that there are set dates for inspections and maintenance intervals, that cover both mechanical and manual methods. For track maintenance, the geometrical deterioration is measured by on-track measuring machine called the IM2000. The track geometry condition assessment vehicle (also known as the IM2000) records these parameters at intervals of between 250 mm and 2 000 mm, depending on the parameter measured. In turnouts, the switch point tamper is required to restore the track alignment. Tamping is basically used to restore track geometry to its construction level standard.

According to Gräbe and Van der Westhuizen (2013), requests for tamping in Transnet Freight Rail in the railway network are done by following the routine based maintenance strategy, utilising an equation by Hall (1985). To decide the time interval required for tamping, the equation utilises the traffic flow patterns of a segment shown in Equation (1) below:

$$\text{Tamping interval} \approx \frac{48}{\sqrt{\text{MGT}_{\text{section}}/\text{year}}}$$

Where; MGT = Million Gross Tons

Gräbe and Van der Westhuizen (2013) argue that to supplement the routine based maintenance strategy, Transnet Freight Rail added a compulsory condition of double tamping in all the curves, including utilising a switch-point tamper for tamping of switches (turnout). Tamping of a single switch point is estimated to be the same as tamping 400 metres of main line. These scholars further noted that sometimes excessive maintenance, because of routine-based maintenance, would not increase the reliability of an asset. This can lead to swelling costs operationally and can adversely affect operational income because of assets being maintained unnecessarily. According to Gräbe and Van der Westhuizen (2013), condition based maintenance was adopted out of the need to reduce fruitless over-maintenance and can be defined as having the objective to maintain the correct asset/equipment at the right time, thereby ensuring optimal levels of efficiency. As maintenance effectiveness increases, reliability and production increase, resulting in a decrease in the overall maintenance costs.

### 3.2.2 Condition Assessment on Railway Track

Currently the on track machines utilised for condition assessment within Transnet are the IM2000 which measures the railway track geometry and the ultrasonic measuring car that detects flaws in the rail and related welds. Radiography can also be used to determine the quality of the welding on the rails. Some of the wayside systems and on-board systems presented by Steyn (2010) in Table 4 of Chapter 2 are also utilised by Transnet as part of condition assessment of the railway track. According to Rothmann (2004), elements that should be considered by Transnet Freight Rail for condition assessment are as follows:

- A condition assessment system takes cognizance of the degradation characteristics of the various asset components. The type and rate of deterioration need to be considered when deciding on assessment methods and the frequency of inspections and measurements.
- Monitoring actual asset performance and the occurrence of breakdowns or incidents of failure are also necessary so that assessment frequencies can be adjusted to manage potential risks.
- As already indicated, Transnet freight rail's track maintenance planning is mostly driven by following a condition-based maintenance approach.
- The assessment system is therefore extremely important and it is designed to measure both functional and structural conditions, where functional condition measurements reflect the service-ability of assets or components, and structural condition measurements quantifies the strength of structures or components.

Transnet freight rail's track condition assessment system, as described in the Manual for Infrastructure Condition Assessment, comprises a combination of automated measurements and visual observations performed by maintenance staff. Data gathered from Rail Network department shows that there is a combination of approaches adopted as part of the broader maintenance strategy. The following table 6 highlights typical activities undertaken by TFR's rail network for track maintenance.

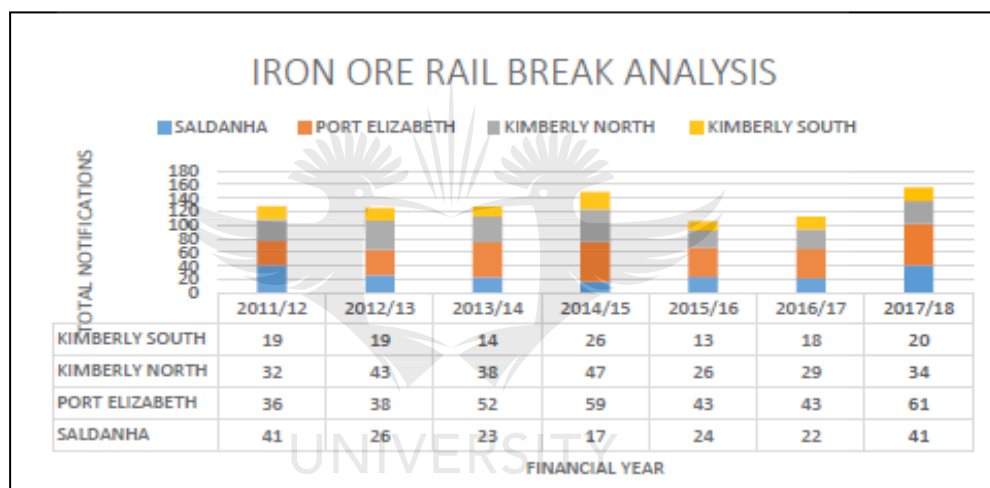
<b>Inspection Method</b>	<b>Track component / Infrastructure Item</b>	<b>Type of defect to be measured</b>	<b>Remedial action</b>	<b>Unit of measurement</b>
IM2000 / Visual inspection	Whole Track System	Track geometry measurements and rail wear	Tamping for track and grinding or planing for rail or Greasing	mm
Ultrasonic Measuring Car (UMC) / Visual inspection	Rail	Rail defects (rolling contact fatigue), surface corrugation	Grinding or Rail replacement in severe cases	mm
Visual inspection	Sleepers	Cracked or out of round sleepers	Replacement	Number off
Visual inspection	Fasteners / Pads	Loose or missing fasteners / worn out or missing pads	Replacement	Number off
IM2000 / Visual inspection	Ballast	Ballast profile measurements, Ballast Fouling Index or round ballast, Disintegrated, white ballast or blind slack, Mud hole	Screening machine to clean or replace ballast	m <sup>3</sup>
Visual inspection	Drainage	Blocked waterway and culverts; no slope for draining water away; high water table.	Unblocking of waterway and culverts; creating a slope and installing subsurface drainage to lower the water table.	m <sup>3</sup>
Visual inspection	Vegetation	Overgrown vegetation on the railway line, in yards and at level crossings	Herbicides application and cutting of vegetation	m <sup>3</sup>

**Table 6: Track Maintenance Activities (Source: Transnet's Manual for Track Maintenance, 2012)**



### 3.2.3 Rail Break Data

The rail break data, which was utilised, was collected over the years from 2011/12 until 2017/18 financial years. This data assisted in showing where there may be a rail that is vulnerable to breaking due to various reasons. The rail breaks are predominantly caused by defective welds due to poor welding practices and cracks in the rail due to lack of rail grinding. The quality of rail determines reliability and availability of the railway track network in general. Transnet Freight Rail's Rail Network department, who are the infrastructure owners, determines where and what type of maintenance is required on the railway line, factoring in available budget. The risk of having these rail breaks is that it hinders production; and safety is compromised. Figure 17 below shows a trend of rail breaks on the Iron Ore and Manganese Line:



**Figure 17: Rail Break Analysis Iron Ore and Manganese Line**

Even though the trend of rail breaks was decreasing, it is now showing an increase in 2017/18 financial year. Two heavy haul lines: Coal line and Iron Ore line contribute 66 % of TFR's total tonnages. Table 7 depicts the distribution of daily business unit targets for 2018/19 financial year.

Daily Targets for 2018/19	
Business Unit	Daily Targets Tonnages
Agriculture & Bulk Liquid	35 851
Coal	319 051
Containers & Automotive	39 191
Iron Ore and Manganese	185 423
Mineral Mining and Chrome	125 700
Steel and Cement	59 063
<b>TOTAL</b>	<b>764 279</b>
Coal + iron ore	504 474
Others	259 800
% heavy haul	66.00
% others	34.00

**Table 7: Daily Targets for 2018/19 Financial Year**

### 3.2.4 Maintenance Strategy: Budget Expenditure

During the first ten months of the 2018/19 financial years, there were budget constraints for maintenance in Rail Network. Depots had to prioritise their maintenance. Corrective maintenance strategy accounted for most of the budget expenditure than preventative maintenance strategy. Unit costs also shows that corrective maintenance is more expensive than preventative maintenance. This can be seen on Table 8 below:

Type of Machine	Percentage Budget Allocation	Unit costs per Machine	Unit of Measure	Type of Maintenance Strategy
GRINDERS	3%	R536 736,00	per day	Preventive and Corrective
SCREENERS	10%	R203 670.71	per day	Corrective
TAMPERS	86%	R35 676,57	per day	Corrective
ULTRASONIC RAIL FLOW DETECTION	0.5%	R3 850	per day	Preventive
MEASURING CAR (IM2000)	0.5%	R4 290	per day	Preventive

**Table 8: Maintenance Strategy Budget Expenditure: 10 Months of 2018/19 Financial Year**

### 3.2.5 Function of On-Track Maintenance Machines

Type of Machine	Function	Type of Maintenance Strategy
GRINDERS	Corrective grinding removes cracks from the rail	Corrective
GRINDERS	Preventative grinding in new rails prevents defect development on the rails by continuously maintaining optimal wheel-to-rail contact conditions	Preventative
SCREENERS	Replace contaminated or round ballast with new ballast	Corrective
TAMPERS	Restores the track geometry to its original parameters.	Corrective
ULTRASONIC RAIL FLAW DETECTION CAR	Early detection of rail surface defects as visual inspection leads to late detection.	Preventative
MEASURING CAR (IM2000)	Early detection of track geometrical irregularities as visual inspection leads to late detection.	Preventative

**Table 9: Functions of On-track Machines**

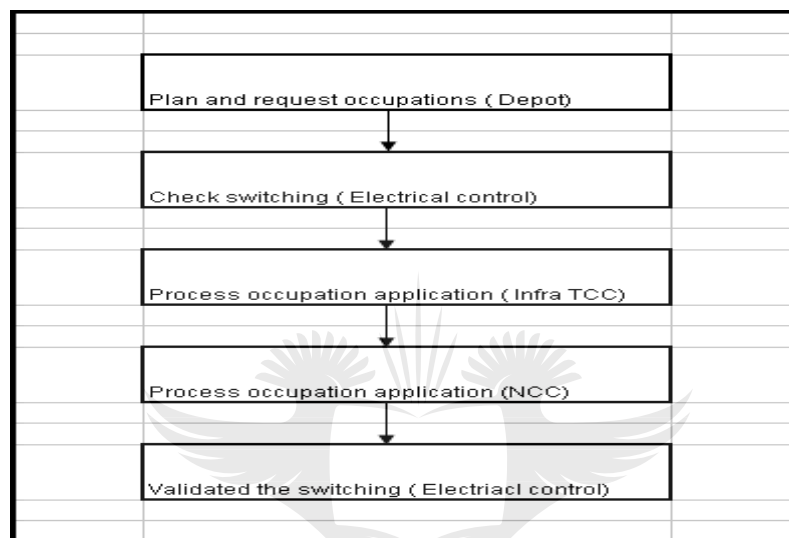
### 3.2.6 Occupations Process Data

The non-availability of the track because of occupations for maintenance hinders the productivity of the organisation; this also serves as an indication of the general quality status of the railway track infrastructure.

#### Infrastructure Occupations Management System Process

An occupation is a maintenance slot in the railway environment. It can either be Total Occupation, where no train traffic is allowed to pass or Occupation between Trains, where the maintenance will be done as train traffic is moving. Occupations have to be applied for in order to do maintenance on the rail network. The Infrastructure Technical Command Centre that is centrally based coordinates all the occupation applications countrywide from different infrastructure depots. The engineering technician will inspect the railway track and decide if maintenance is needed or not. When there is need for maintenance, the engineering technician, through the chief admin official will apply for an occupation using the IOMS system. The Infrastructure Technical Command Centre forward the application to the National Command Centre for approval. The plan is booked on the Integrated Train Plan (ITP) to adjust the movement schedule of trains.

As part of the annual budgeting process, occupation requirements for corrective preventative maintenance and projects (e.g. on-track machine and material replacement projects like rail, sleeper and complete turnout replacement), need to be communicated to the Operations Department to reach an agreement in principle on schedules and timing. This is done in order to prepare for the compilation of the train master plan. Generic occupation rules must also be agreed on per specific route that will satisfy the need of all role players and guide the process of granting occupations.



**Figure 18: Process of Occupations**

### 3.2.7 Transnet's Requirements for Infrastructure Management Plan

There are a number of basic requirements that the maintenance personnel require in order to plan for maintenance. The table below highlights those requirements in full:

No.	Item	description
1	Business information and requirements	Annual revenue, traffic volumes, projections; what is affordable as % of revenue.
2	Production / Operational requirements	Traffic volumes and Speed
3	Rolling stock and other technical requirements	Axle loads, suspension types and train lengths
4	Infrastructure current and required RAAS information	
	Reliability	Derailments; service failure of equipment; trends
	Availability	% available when required; speed restrictions due to conditions
	Affordability	Expenditure (monetary and % revenue)
	Safety	Derailments, accidents

5	Details of infra assets	Types, quantities, location and condition of infra assets
6	Age profile of infra assets	How long in the asset in service?
7	Condition of infra components	How many are good, bad or just ok (Quantify)
8	How is the condition of infra components assessed?	Measuring cars, visual inspections or other
9	Required standards for infrastructure components.	Safety standards; maintenance standards
10	Gap analysis	Condition compared to required standards
11	Maintenance needs	Based on the data received after inspections.
12	Current maintenance philosophy / approach	Time based, condition based
13	Maintenance history for the last three years.	Physical work done and expenditure (what, where and when)
14	Current maintenance plan	Budget and asset to be maintained (what, where and when)
15	Resources available for maintenance	Personnel, tools, budget and contractors
16	Infrastructure asset components deterioration history	How is condition changing over time
17	Future infrastructure requirements for future increase in volumes.	Long term planning for tonnage increases

**Table 10: Requirements for Infrastructure Management Plan**

### **3.2.8 Classification and Standards for Running Lines: 1067 mm Track gauge**

Transnet's maintenance philosophy is also dictated by the tonnages that railway lines carry per annum. Classification and standards for 1067 mm gauge railway lines are depicted in table 11 that follows:

CLASSIFICATION OF RUNNING LINES			TRACK STANDARDS FOR RUNNING LINES				
CLASS OF LINE	MAXIMUM AXLE LOAD (Ton)	GROSS TON PER YEAR (Million)	RAIL TYPE AND MASS	SLEEPER AND SPACING	BALLAST		
					DEPTH (mm)	QUANTITY (m <sup>3</sup> / km)	
						CONCRETE	WOOD / STEEL
S	26	–	60kg/m	FY/PY 650mm	300	1 600	–
N1	20	>15	57kg/m	FY/PY/ #700mm	280	1 500	–
N2	20	5–15	48kg/m	P2/F4 STEEL/ WOOD 700mm	200	1 200	1 100
N3	–	<5	REQUIRES THE PRIOR APPROVAL OF THE CJIEF ENGINEER (INFRASTRUCTURE MAINTENANCE).				

REMARKS:

1. ANY DEPARTURE FROM THESE STANDARDS REQUIRE THE APPROVAL OF THE CHIEF ENGINEER (INFRASTRUCTURE MAINTENANCE).

2. CLAUSES 6.2 AND 6.7, AS WELL AS ANNEXURES 4 AND 15 SHEET 2, MUST BE READ TOGETHER WITH THIS TABLE.

3. # P2, F4 AND WOODEN SLEEPERS ARE ALSO ACCEPTABLE. SEE ANNEXURE 4 SHEET 1 FOR BALLAST QUANTITY.

**Table 11: Classification and Standards for Running Lines: 1067 mm Track gauge. (Source: Manual for Track Maintenance, 2012)**

### 3.2.9 Ultrasonic Measuring Car (UMC) Data

Ultrasonic testing is used to detect a large variety of subsurface defects on the rail and is a versatile inspection technique, which can be used to inspect rail cracks and welds. Transnet has embarked on a massive rail replacement programme that spans over seven years from year 2013 to year 2019. Data analysis as input into the maintenance strategy is not fully utilized with baseline routine maintenance.

The condition based maintenance is the applicable strategy for exploiting data generated for decision making. Condition based maintenance requires that the data generated should be the cornerstone of maintenance decision making. There should be somebody in the structure of maintenance personnel at a depot level that analyse the data and give it to responsible decision makers for incorporation into the maintenance planning schedule.

### 3.2.10 IM 2000 Measurement Frequencies

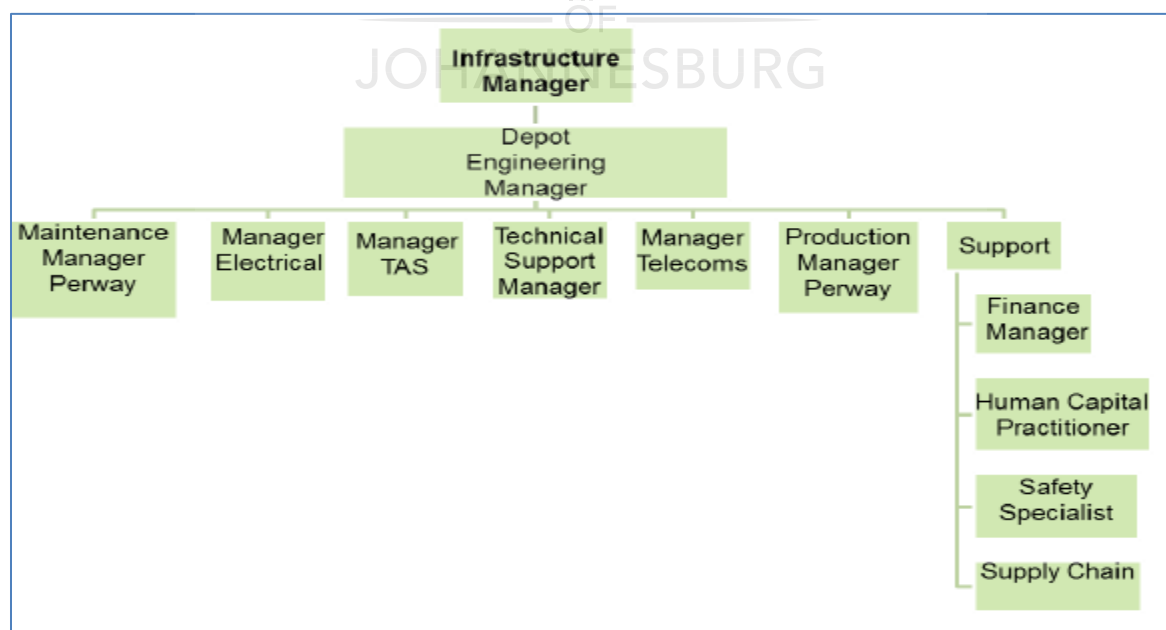
Frequency of maintenance largely depends on the previously mentioned tonnages. For example, the IM 2000 Track Infrastructure Measurements Car measuring frequencies for geometry and rail wear parameters are as follows:

Name of Line	Measuring Frequencies	Class of Line and Tonnages per annum
Heavy Haul Line : Richards Bay Coal Terminal Line	Three times a year	S Line, $\geq 60$ million gross tons
Heavy Haul Line : Iron Ore and Manganese Line	Two times a year	S Line, $\geq 50$ million gross tons
General Freight Business (GFB) Core Network	Two times a year	N1 Line, $\geq 15$ million gross tons
GFB Core Network	Two times a year	N2 Line, $\geq 5$ million gross tons
GFB Non-Core Network	Mainly once a year in majority of lines and only two times a year on selected lines.	N3 Line, $\geq 0.2$ million gross tons
GFB Non-Core Network	Once in two years	N3 Line, $\leq 0.2$ million gross tons

**Table 12: Automated Geometrical Condition Assessment of Parameters (Source: Maintenance Engineering: Manual for Infrastructure Condition Assessment: Version 2, August 2010)**

### 3.2.11 Rail Network Organisational Structure

The structure of the depot is depicted below:



**Figure 19: Organisational Structure: Infrastructure Depot (Source: TFR Rail Network Organogram)**



The responsibilities of some of the high-level technical personnel as documented in the Track Maintenance Manual from Transnet are as follows:

### **Responsibilities of the infrastructure manager**

The Infrastructure Manager is responsible for:

- Determining and negotiating for required resources.
- Improving production continuously.
- Checking safety and service excellence on a continuous basis and for introducing remedial measures.
- Identifying and utilising excess capacity.
- Make certain that preparation in case of emergencies is done and will be executed correctly when is necessary.
- Make sure that Depot Engineering Managers are capable to execute their responsibilities.
- Make sure that the requirements of applicable legislation are conformed with.
- Planning and execution of maintenance utilizing the applicable computerized maintenance management system software.

### **Responsibilities of the Depot-Engineering Manager**

The Depot Engineering Manager is responsible for:

- The safe passage of trains, the personnel and public safety and health of personnel.
- Service excellence and making certain that all agreements in this respect are conformed to.
- Managing all maintenance actions and assets efficiently
- Maintaining and operating reliable systems.
- Make sure that sufficient resources are obtainable for all types of track maintenance plus call-out and emergency procedures.
- Carrying out prescribed inspections.
- Make certain that work is managed appropriately and embarked on according to applicable work codes.

- Make sure that prescribed training and on the job training are taking place and that the applicable legislations are conformed to.
- Make certain that planning guiding principles are in place.

### **3.2.12 Transnet Freight Rail's Maintenance Challenges**

Data capturing is a big part of maintenance within Transnet's track maintenance activities. Analysis of this big data for decision making is a challenge as the structure of the organisation does not have a person who analyses this data on a daily basis in an operational area. Only data that is in the c-standard is considered for the IM2000 geometrical analysis. The current depot maintenance structure does not have a person who analyses large volumes of data coming from the IM2000 machine measuring track geometry and UMC machine, which detects rail defects. This leads to maintenance planners relying on traditional methods of doing periodic inspections and considering only critical readings from the on-track machines. The large volume of data is thus left unused for prioritisation in maintenance planning and decision making.

The policies, processes, procedures, standards and guidelines within TFR's Rail network department do not accommodate the utilization of all new methods of doing maintenance as proposed by Tzanakakis (2013), who proposed the following tools to modernise track maintenance which are:

1. Reliability, Availability, Maintainability and Safety (RAMS) Analysis
2. Life Cycle Costing (LCC) Tools
3. Track behaviour analysis
4. Track quality prediction model

Transnet embarked on improving the overall maintenance of its assets in 2013 with project called Roadmap to Safety. Methodology utilised the following concepts as part of the research design; Data Collection, Data Analysis and Workshops, and Site Visits as Validation.

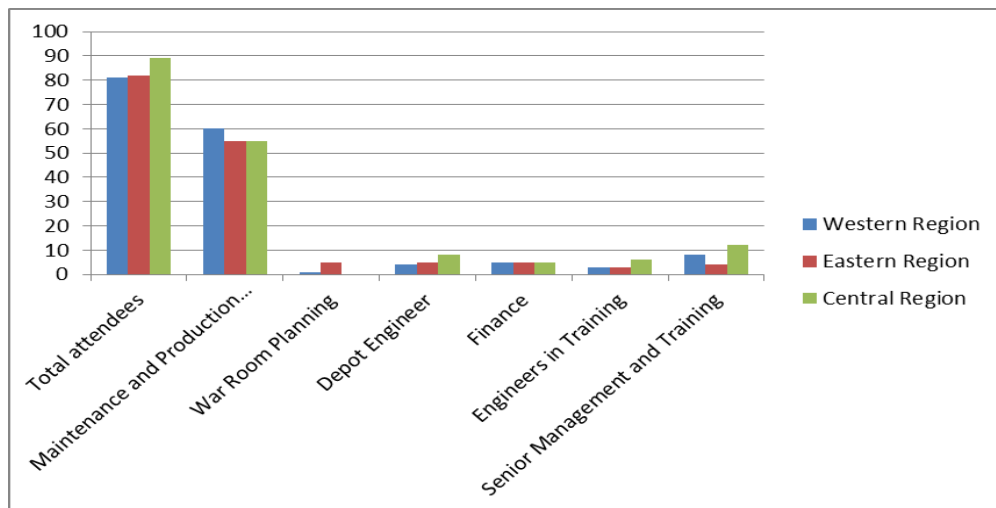
#### **Data Collection and Analysis**

A summary of issues collected from track faults and track related safety incidents attributed to track maintenance were highlighted as follows:

1. Inadequate Infra-maintenance (OHE affected by non-adherence to the Maintenance Engineering Instructions, design issues for cross-overs, overlaps, turnouts and curves).
2. Design issues with Tubular track
3. Unsafe infra conditions (safety critical situations are tolerated – cross discipline)
4. Improper use of SAP for maintenance budget allocation.
5. Non Maintenance on Drainage system
6. Repetitive derailments, condition of track infrastructure and loading facilities (i.e. tippler) and associated infrastructure assets.
7. Procurement processes is often slow impacting maintenance/ repair work and the replacement of parts.
8. Documentation of infra assets (drawings, plans, diagrams etc.). Not all documents are available on site/ depot.
9. Excessive timescale from identification to close out of faults

## **Workshops**

There were over 200 participants from various regions in the workshops that took place within Transnet through the Roadmap to Safety Project. The purpose of the workshops was for various stakeholders to participate in diagnosing the challenges related to general maintenance within Transnet Freight Rail. The diagnosing of maintenance challenges and interventions proposed through these workshops was for the organisation to take a new strategy when approaching maintenance challenges. The personnel who attended the workshops were mainly the perway maintenance personnel responsible for track maintenance, personnel for support structures like finance and operational personnel affected by track maintenance related issues. This was the correct audience as it had experience in the current track maintenance strategy of Transnet and the related internal processes. Figure 20 shows the different stakeholders that participated in these workshops:



**Figure 20: Workshops attendance**

The findings after the assessment resulted in a proposal of four interventions to improve maintenance. Those interventions were improvement of fault management, SAP usage improvement, maintenance planning and maintenance compliance and supervision.

### **Fault Management**

Fault management refers to how an asset owner respond to asset failures and subsequent maintenance or disposal of the failed asset.

Objectives of the Fault Management are to:

- Increase Asset availability and reliability
- Reduce asset down time
- Restore asset failure quickly and effectively
- Documentation of all faults
- Complete documentation of all root causes and fault details
- Management of repeat faults
- Prioritisation of faults with impact and repeat faults
- Prioritisation/ scoring from operational staff
- Efficient allocation and utilisation of maintenance resources (less burning of your resources)
- Process transparency, to define roles and responsibilities.
- Data evaluation and analysis (e.g. Failure rate per asset type and other information)

- Full utilisation of SAP for fault management (Training for SAP)

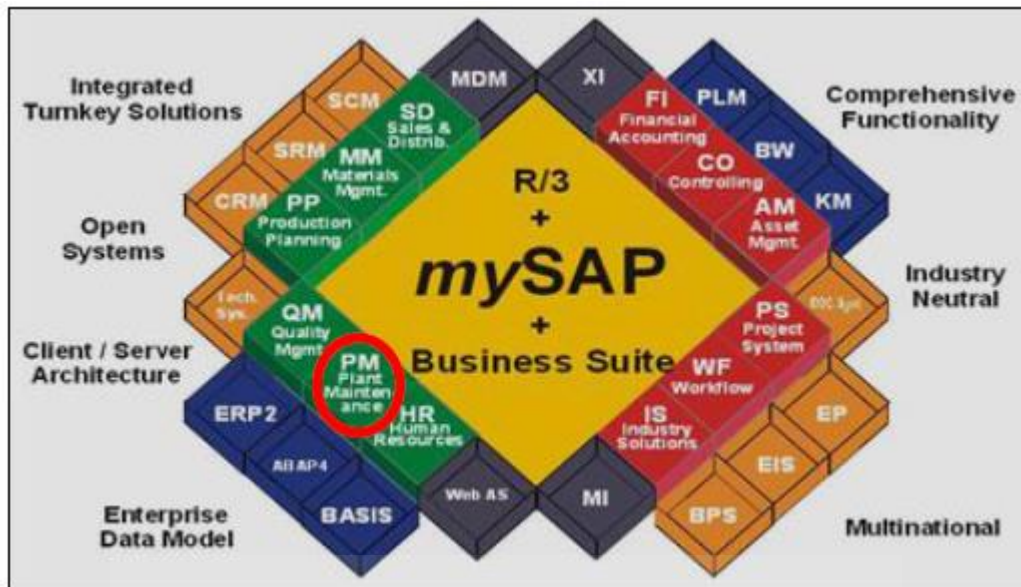
The interventions for the improvement of fault management were as follows:

- Unclear definition of fault management process results in fire-fighting which requires unplanned maintenance instead of preventative maintenance.
- Unplanned maintenance due to infrastructure faults leads to noncompliance to Transnet's Rail Network's routine based maintenance standards.
- Maintenance staff does not get an opportunity to execute preventative maintenance as 95% of faults are priority A.

### **3.2.13 SAP**

SAP is a Computerized Maintenance Management System (CMMS) and maintains a computer database of information about an organization's maintenance operations, i.e. CMMIS – computerized maintenance management information system, e.g.

- To help maintenance workers do their jobs more effectively (determining which assets require maintenance and which storerooms have the spare parts needed).
- To help management make informed decisions (calculating the cost of an asset breakdown repair versus preventive maintenance for each asset, leading to better allocation of resources)
- To measure productivity which allows benchmarking between different depots or business units.
- To verify regulatory compliance (asset compliance).



**Figure 21: SAP Plant Maintenance Module as depicted with a Red circle.**

**(Source: Roadmap to Safety Project)**

Roadmap to Safety Project identified current challenges with SAP Plant Maintenance module in Transnet Freight Rail as the following:

- Different asset databases are used within Transnet Freight Rail, this is due to the limitations of current SAP modules and requirements from various disciplines.
- Information of assets differs as various asset databases are used.
- Captured infrastructure assets in SAP do not include all the existing infrastructure components.
- Existing asset structure limits routine preventative planning for linear assets.
- Existing asset structure is not able to determine main-components or components within the technical asset structure.
- Technical asset Database is not linked to the financial asset data base in the SAP module of asset management.
- Notifications are only used for fault management and not preventative maintenance or other tasks.
- Competency of maintenance staff in exploiting all SAP functionalities requires improvement.

### Benchmarking SAP usage between TFR and Deutsche Bahn (DB)

Item	Transnet Freight Rail	DB
Performance in terms of availability	Downtime 52x per year, 6h – 48h; Shared server with other departments	Downtime max. 2x per year a 6h; Own dedicated server farm for SAP PM
Number of users	600	6500
Maximum assets structure	3 level	6 level + Equipment level
Allocated IT-staff (monitoring, development of functions, etc. for SAP PM)	None	35
Allocated technical staff (standards, maintenance strategies, etc. for SAP PM)	None	15
Information cycle about changes in SAP	No standard	1 – 2 monthly
SAP-object notification used for:	Fault management	<ul style="list-style-type: none"> <li>• Fault management</li> <li>• Maintenance requests</li> <li>• Inspection results</li> <li>• Inspection results by Railway Safety Regulator</li> <li>• Notice for COPEX/ CAPEX</li> </ul>
Drawings available in SAP	None	4 Million
Training for Fault management	2 hours	3 days
Training for notifications	Included in fault management.	8 days
Training for creating of PMO's	2 hours	5 days
Training for reporting	Included in PMO's	10 days
Training in planning & calculation of PMO's	Included in PMO's	10 days
Training in RPM-planning & scheduling	Included in PMO's	15 days

**Table 13: Key Benchmarks: Facts & figures - SAP Module PM – Infra**



### **3.2.14 Maintenance Planning**

Maintenance planning covers the planning of the Routine Preventative Maintenance (for all disciplines on a Depot level) in order to increase reliability and availability of the rail network. The planning also includes data output from track geometry measuring machine (IM2000) and the rail condition ultrasonic measuring car (UMC).

Roadmap to safety project identified the following gaps:

- Training of maintenance staff with regard to economics and financial principles is required.
- Detailed budget and resource planning needs improvement.
- Some key technologies either lack maintenance standards or those existing maintenance standards are not fully developed/designed, e.g wayside readers.
- Routine preventative maintenance is not done in a timely manner according to Transnet's standards.

### **3.2.15 Maintenance Compliance and Supervision**

Maintenance compliance and supervision is important to an efficient and reliable railway system. This is to make sure that scheduled maintenance tasks are executed timeously and efficiently. This also assists in addressing backlog maintenance and its related documentation. Additionally, the roles and responsibilities for maintenance compliance management must be defined clearly.

However, the challenges identified under compliance and supervision are as follows:

- There is no clearly defined maintenance compliance management process.
- The existing infrastructure maintenance compliance standard is generic.
- The technical audit compliance process is a stand-alone process focusing mainly on the safety aspect.
- Key Performance Indicators for measuring of the maintenance compliance performance do not exist.
- Standardised compliance reports are not done.

### **3.2.16 Transnet Freight Rail Interventions by Infrastructure Steering Committee of the Roadmap to Safety Project.**

The corridor interventions to improve maintenance which aimed to close the identified gaps were identified and prioritized. The prioritization list of interventions which was based on value chain benchmark from DB Netze was as follows:

- Organization
- Information Technology (SAP)
- Maintenance Planning
- Fault Management
- Compliance Management
- Supervision
- Resources
- Competence
- Technology Management

Topics that were covered for maintenance improvement in the project were only four as per the project scope. The four topics consisted of fault management, SAP, maintenance planning and maintenance compliance and supervision. The other outstanding topics were reserved for possible future projects.

### **3.2.17 Maintenance Improvements**

#### **Fault Management**

Enable availability of the resources on a Depot level to conduct Routine Preventative Maintenance through optimised process and prioritization of faults.

#### **SAP**

Achievement of an optimal usage of the SAP system (under the current conditions) in order to be the platform for the other interventions and to provide guidance and specifications for the future optimization of the SAP.

#### **Maintenance Planning**

Enabling planning of the routine preventative maintenance (for all disciplines on a depot level) in order to increase reliability and availability of the rail network.

## Maintenance Compliance and Supervision

Purpose of this intervention is to supervise execution and quality of the routine preventative maintenance and to measure the compliance against the RPM plan and TFR maintenance standards. Figure 22 depicts the topics that are covered within R2S project

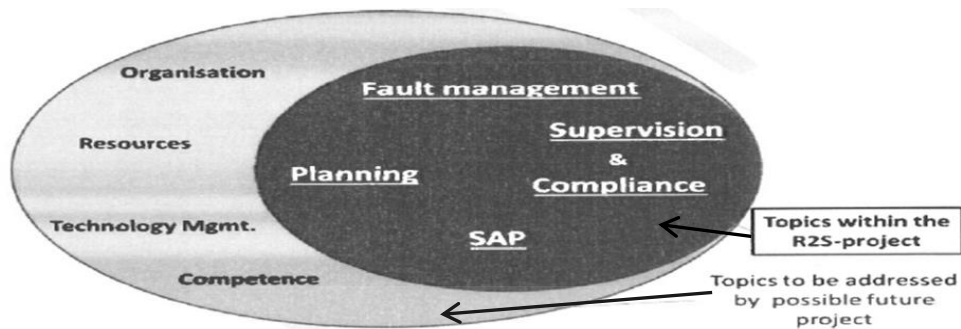


Figure 22: Four Topics for Maintenance Improvement within R2S Project. (Source: Transnet Freight Rail's Roadmap to Safety Project)

### 3.2.18 Scope of Interventions

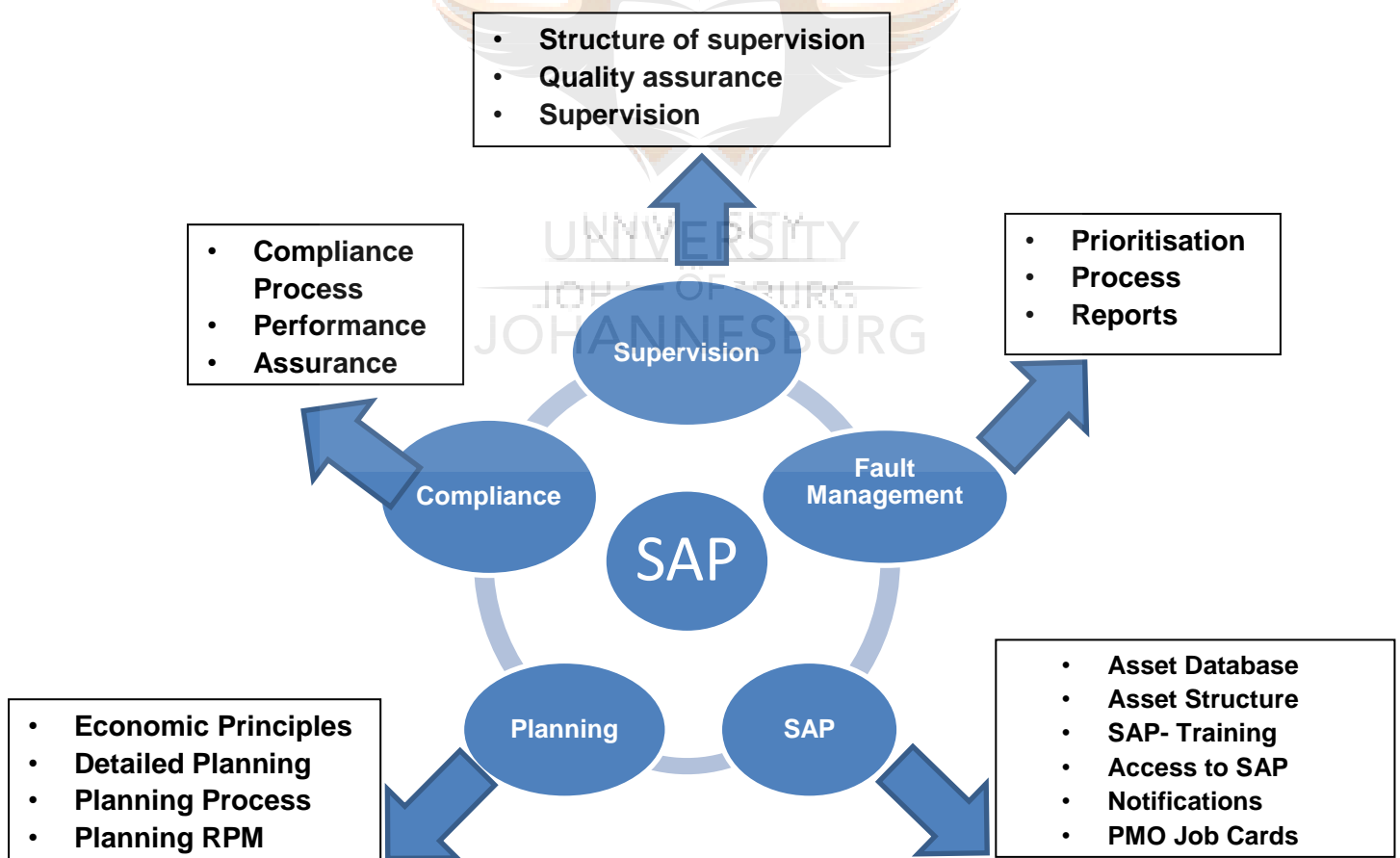


Figure 23: Improvement of Maintenance Interventions covered in R2S Project

(Source: Transnet Freight Rail's Roadmap to Safety Project)

There were over 200 participants in the interventions workshops that took place within Transnet through the Roadmap to Safety Project. Various stakeholders participated in diagnosing the challenges related to general maintenance within Transnet Freight Rail. The diagnosing of maintenance challenges and interventions proposed through these workshops will thus take the organisation in a whole new direction in how it approaches its maintenance challenges. The personnel who attended the workshops were mainly the perway maintenance personnel responsible for track maintenance. This was the correct audience as it had experience in the current track maintenance strategy of Transnet.

### 3.2.19 Advantages of Interventions (Table 12, Source: R2S Project)

Intervention	Advantages
<b>Fault Management</b>	<ul style="list-style-type: none"> <li>• Efficient assignment of staff for fault rectification based on operational requirements.</li> <li>• Plan efficient repair of non-urgent faults (combine with other work).</li> <li>• Documentation of all faults.</li> <li>• Detailed documentation regarding root causes – allows analysis.</li> <li>• Process transparency</li> <li>• TCC-staff will be more knowledgeable &amp; competent</li> <li>• Decrease in faults</li> </ul>
<b>SAP</b>	<ul style="list-style-type: none"> <li>• Faults, costs, material, compliance can be linked down to main-component level.</li> <li>• Competent staff with standardised training &amp; training guides.</li> <li>• Sharing/ ownership of workload.</li> <li>• Storage of MICA/ inspections tasks – shows asset conditions.</li> <li>• Measure productivity</li> <li>• Pool of possible PMO – Job cards allows prioritisation for efficient use of resources.</li> <li>• Transparency about allocated resources.</li> </ul>
<b>Maintenance Planning</b>	<ul style="list-style-type: none"> <li>• Detailed resource planning at depot-level can increase productivity without additional resources.</li> <li>• System based planning/ scheduling for MICA, inspections &amp; maintenance tasks provides transparency for required resources.</li> <li>• Failures reported fully integrated into planned regular maintenance to reduce maintenance costs.</li> </ul>

	<ul style="list-style-type: none"> <li>• Transparency of allocated resources for RPM – shows available capacity for faults &amp; CPM.</li> </ul>
<b>Compliance and Supervision</b>	<ul style="list-style-type: none"> <li>• Legal requirements for a Routine Preventive Maintenance (RPM) and Maintenance Compliance will be adhered to. Relevant clauses are referred to: <ul style="list-style-type: none"> <li>○ SANS-3000-1-2009, Clause: 5.7.1 a) identifies all the legal obligations impacting directly or indirectly on railway safety, b) complies with the requirements contained in legislation c) evaluates compliance with the legislative requirements.</li> <li>○ SANS-3000-1-2009, Clause: 5.8.1 <ul style="list-style-type: none"> <li>a) establish and maintain documented procedures to control all documents and data ...</li> <li>b) ...capturing, storing and processing of data comply with applicable legal requirements;</li> </ul> </li> <li>○ SANS-3000-1-2009, Clause: 14.2 Process control Activities that directly affect railway safety shall be carried out under controlled conditions... a) compliance with the safety standards referred to in 14.1, b) ....., maintenance, equipment and facility usage, installation and construction... c) monitoring to ensure compliance with (a) and (b).</li> <li>○ SANS-3000-1-2009, Edition2, Annex E: The Railway Regulator shall be notified of changes to.... i) changes of inspection procedures, for example track frequencies, bridge examination procedures and frequencies....</li> <li>○ SANS-3000-2-1-2008 <ul style="list-style-type: none"> <li>▪ Life Cycle Phase Maintenance and Monitoring, that covers the period during which the system is maintained and monitored in line with business, operational and safety requirements.</li> <li>▪ Necessary documentation to be generated and utilised for Life Cycle Phase Maintenance and Monitoring is as follows: <ul style="list-style-type: none"> <li>➤ Maintenance standards</li> <li>➤ Maintenance Procedures</li> <li>➤ Maintenance Manuals</li> <li>➤ Drawings</li> <li>➤ Inspection Reports</li> <li>➤ Audit Reports</li> <li>➤ On-going Risk Assessments</li> </ul> </li> </ul> </li> </ul> </li> </ul>

**Table 14: Advantages of Interventions (Source: R2S Project)**

### 3.2.20 Temperature variations

The western part of South Africa has a Mediterranean climate (warm to hot, dry, sunny summer and mild, rainy winters). The eastern part has hot, humid summers with frequent late afternoon thunderstorms, and cooler, dry, sunny winters. In track maintenance this is critical as properties of certain track components like rail are heavily influenced by temperature differences. The strategies of the areas in the Coal line and Iron Ore line are therefore very different as challenges are not the same due to varying environmental challenges that affect the rail.

### 3.3 Gautrain Maintenance Strategy

Gautrain has 80 km of track from Pretoria to Johannesburg and a wide gauge of 1400 mm to accommodate its 160 km/h top speed. Bombela Operating Company is responsible for the operation and maintenance of the Gautrain system under a 15 years' concession contract to the Bombela Concession Company. BMC uses a measurement car with a non-contact inertial measuring system developed by Tecnogamma (MERMEC Group) for the inspection of the Gautrain rail network. The Gautrain network (line speed up to 160 km/h) is usually measured every second month. According to Botha (2012) the Gautrain maintenance strategy is as follows:

- *“Implementing carefully planned inspections (preventive maintenance),*
- *Defining the degree of maintenance necessary for each element,*
- *Keeping adequate spare parts, special tools and test equipment available,*  
*and*
- *Operating an effective fault/failure and maintenance reporting system.”*

*“To achieve the planned system maintenance effectiveness, a Maintenance Management Information System (MMIS) is used for monitoring equipment performance, collecting information, record keeping, controlling spare inventories and projecting maintenance schedules. All vehicle and wayside service reports and maintenance actions, preventive and corrective, are recorded into the MMIS. The data is analysed to identify failure trends and modify preventive maintenance schedules when necessary. Maintenance tasks and schedules are then updated to optimize the maintenance effort.”*

### **3.4 Passenger Rail Agency of South Africa**

PRASA mainly focuses on suburban passenger railway transport. Therefore, the deterioration on the track is mainly influenced by high train frequencies. According to Schmid et. al. (2010), rolling stock for such services is designed to have rapid acceleration and high braking rates because of many frequent stops. This results in rail wear and rolling contact fatigue due to high traction coefficients and rapid acceleration and braking. PRASA and TFR share a common maintenance strategy due to their historical ties and the requirements of their interface agreement.

### **3.5 Other SADC Countries**

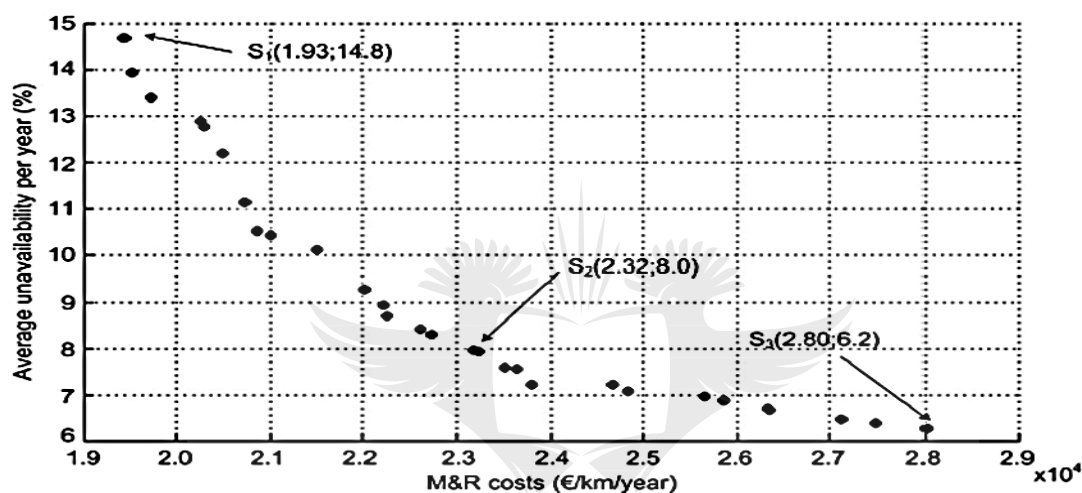
Botswana, Mozambique and Zimbabwe share the same gauge with South Africa. According to one of the Southern African Railways Association's (SARA) constitution, SARA aims to develop benchmarks for service standards and levels of maintenance for infrastructure and equipment to ensure a uniform threshold standard of service delivery by all member railways. The South African Railway Safety Regulator's (RSR) requirements and standards, are similar to those of SARA. Added to that, TFR's interface agreements with neighbouring countries require the same standards and maintenance methodologies when coming to track maintenance. The biggest challenge with some of the countries, like Zimbabwe is enough budget to execute the high cost of maintenance. Some of the operational personnel and maintenance personnel attend their training at TFR's School of Rail and the University of Pretoria's Chair in Railway Engineering. Due to lack of data, it can thus be assumed that the maintenance strategies adopted by these countries, shall be more or less similar to the TFR's approach. All the scheduled maintenance and future planning of reopening some of the closed lines, is in line with what Transnet is doing with their branch lines with its capital investment programme.

### **3.6 Portugal: Lisbon – Porto Case Study**

Caetano and Teixeira (2013) have shown ten years (from 2001–2010) of historical data from track geometry, ultrasonic, and visual inspections of the Lisbon-Porto line were utilised to describe the degradation models. The greatest cause of defects on the Lisbon – Porto line was as a result of rail fatigue defects. The data analysis of ultrasonic inspections of this line found that 52% of rail fatigue defects were as a result



of aluminothermic weld defects, 20% from transversal cracks, 8% from vertical/longitudinal cracks, and 20% are attributable to other fatigue defects. Caetano and Teixeira (2013) continued to show that the total number of welds on a rail section length, and the thermic weld defects on the same rail section length determines the hazard rate. According to one of the findings by Caetano and Teixeira (2013), Figure 24 below indicates that greater investment in railway track maintenance and renewal works guarantees a lower level of unavailability. In practical terms, if there is an average unavailability of 10%, it corresponds with approximately 2.4 hours per day that the railway line is occupied by maintenance and renewal operations.



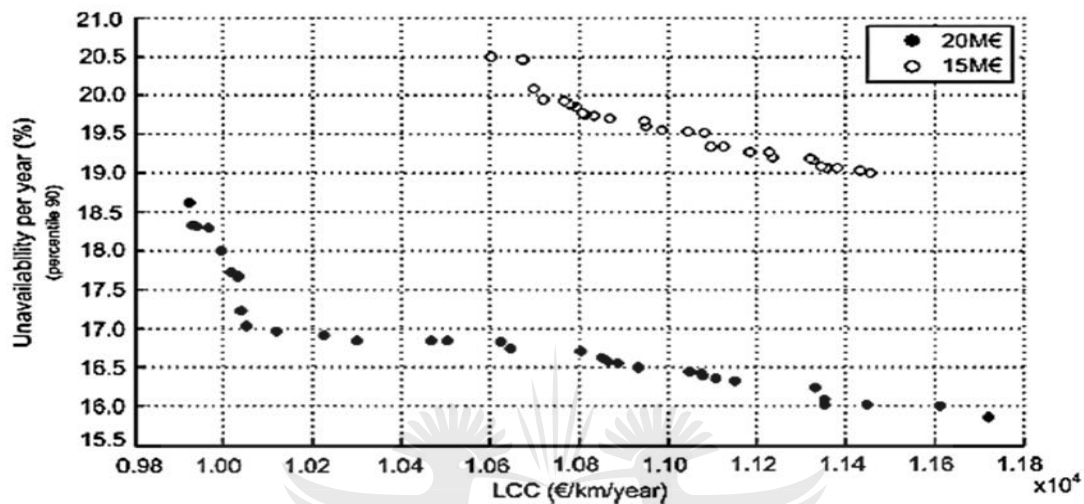
**Figure 24: Pareto Optimal front**  
(Source: JOURNAL OF TRANSPORTATION ENGINEERING, ASCE / SEPTEMBER 2013, 139:941-948.)

### 3.6.1 Multi Objective Optimization Approach

Caetano and Teixeira (2013) utilised the multi objective optimization approach to illustrate that there can be a decision making framework in planning the scheduling of major renewal works with detailed data available for life cycle costs-unavailability trade-off. Furthermore, Caetano and Teixeira (2013) presented a model that allows the estimation of the required yearly budget to accomplish pre-established levels of track availability, which can be used as a tool to support strategic decisions of the Infrastructure Manager. The case study results of Caetano and Teixeira (2013) showed that additional investment in maintenance and renewal operations results in more track availability. Figure 25 as demonstrated by Caetano and Teixeira (2013),

shows the level of unavailability that can be experienced becoming worse as the budget limitation rises. The exact description is as follows:

- For a budget constraint of €15 million, the maximum unavailability ranges between 19.0% and 20.5%; and
- A budget constraint of €20 million, results in maximum unavailability ranges of between 15.8% and 18.6%.



**Figure 25: Comparison of Pareto Optimal front for different budget Scenarios.**

(Source: JOURNAL OF TRANSPORTATION ENGINEERING, ASCE / SEPTEMBER 2013, 139:941-948.)

### 3.6.2 Optimization Results Application

Resulting from the case study summary of findings, Caetano and Teixeira (2013) concluded with the following summarised statements when addressing the issue of maintenance and renewal:

*“If more maintenance and renewal works can be carried out in 1 year, the availability that can be achieved is significantly higher. In a few cases, budget restrictions imply the postponement of renewal works although a high number of systematic maintenance operations are still undertaken. Given that the renewal work cannot be performed within the optimal schedule, the life cycle costs (LCC) increases. For the worst case in terms of unavailability impact, given that the writers are measuring the 90th percentile, 90% unavailability indicates that 10% of the planning timespan will require 20.5% of the downtime for maintenance and renewal works.*

*This is almost 5 hours of daily downtime and exceeds by 1 hour the time window that is usually available for systematic maintenance and renewal works. In these circumstances a train timetable must be implemented that guarantees an additional 1 hour without trains running on the line. Such implications can have a high impact on the quality of service provided to train users.”*

### **3.7 European Track Research Project**

#### **3.7.1 Innotrack**

Innotrack is a research project that was conducted from September 2006 to December 2009. The 25-million-euro project was funded by the European Community (EC), with the involvement of 36 partners from 11 countries. The goal of the project was to reduce the life cycle cost (LCC) of track maintenance and improve its reliability, affordability, maintainability and safety (RAMS) *[Rail Engineering International, Edition 2012, Number 2]*.

The focus on the track component of the railway infrastructure is that they are a major cost driver of track maintenance and those costs have not reduced considerably in the previous 30 years. In contrast, other competing modes of transport have seen considerable reduction in their LCC over the same time period. Competitiveness of rail depends on its ability to reduce its LCC in the same manner *[Innotrack, Project No. TIP5-CT-2006-0314150]*.

Various infrastructure managers, suppliers and research and development institutions were part of the project.

**Innotrack Subprojects** *[Innotrack, Project No. TIP5-CT-2006-0314150]*.

Due to the complexity of the project, 7 subprojects were created, mainly:

- SP1 (Requirements)
- SP2 (Track Support – support structures below the rail level)
- SP3 (Switches and Crossings)
- SP4 (Rails)
- SP5 (Logistics)
- SP6 (LCC assessment and RAMS), and;
- SP7 (Dissemination and Training)

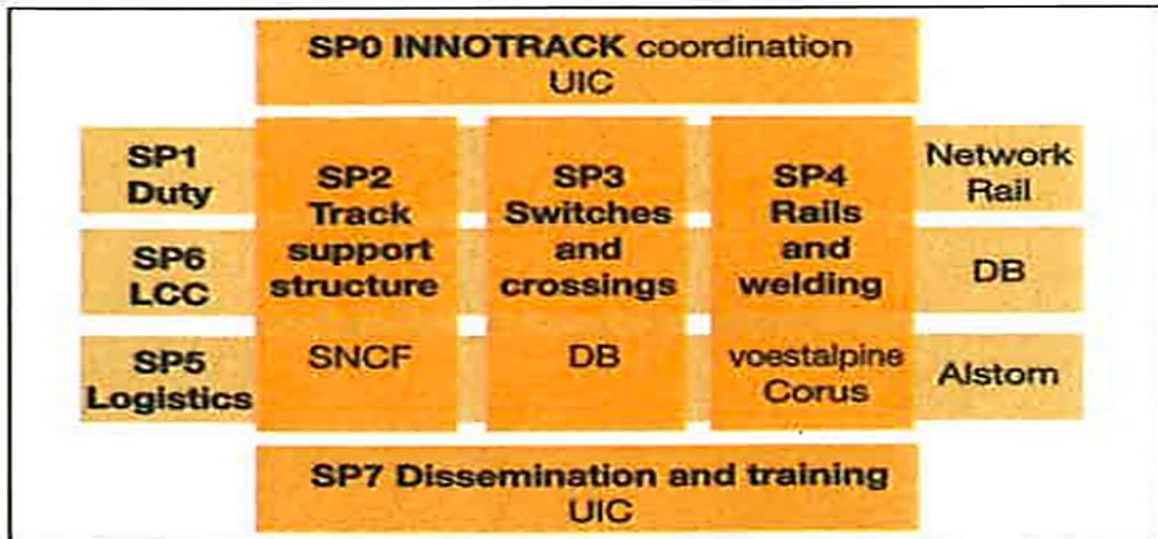


Figure 26: Organisation Chart of Innorack Project.

(Source: *Rail Engineering International*, Edition 2012, Number 2)

The findings of the research are summarised below (see Figure 27):

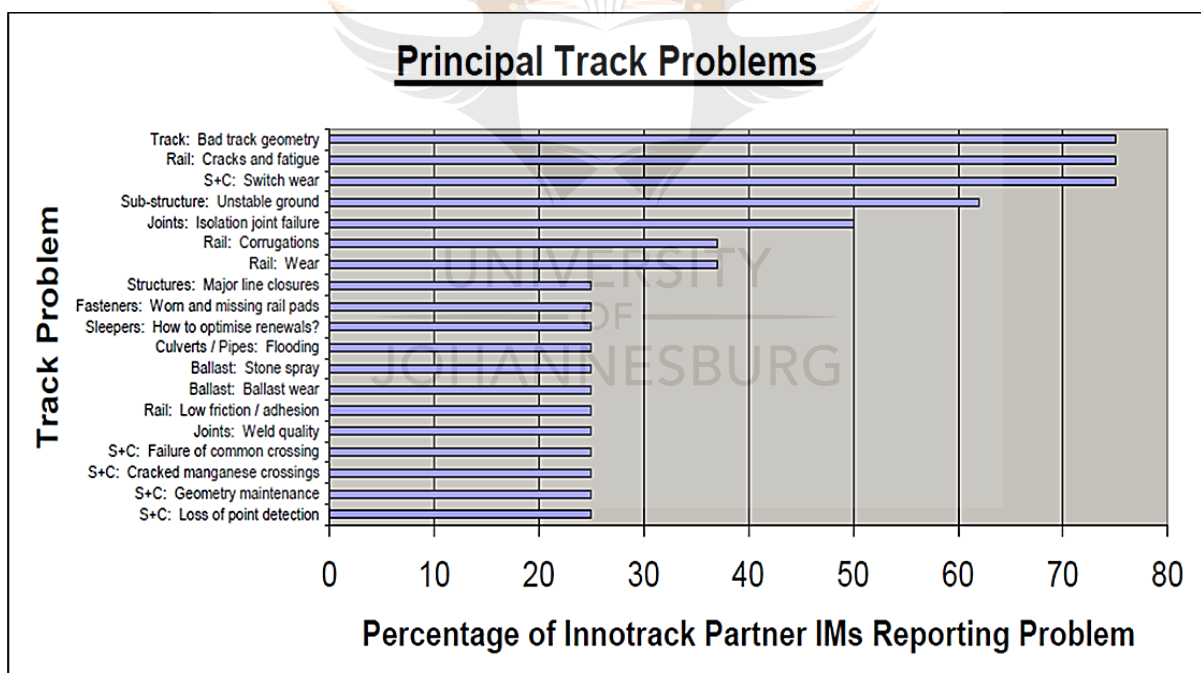


Figure 27: Ranking of Track Faults Based on the Outputs of Infrastructure Managers' Workshops. (Source: *Innorack*, Project No. TIP5-CT-2006-0314150)

### 3.8 Italian and Serbian Comparisons Case Study

#### 3.8.1 Italian Railways

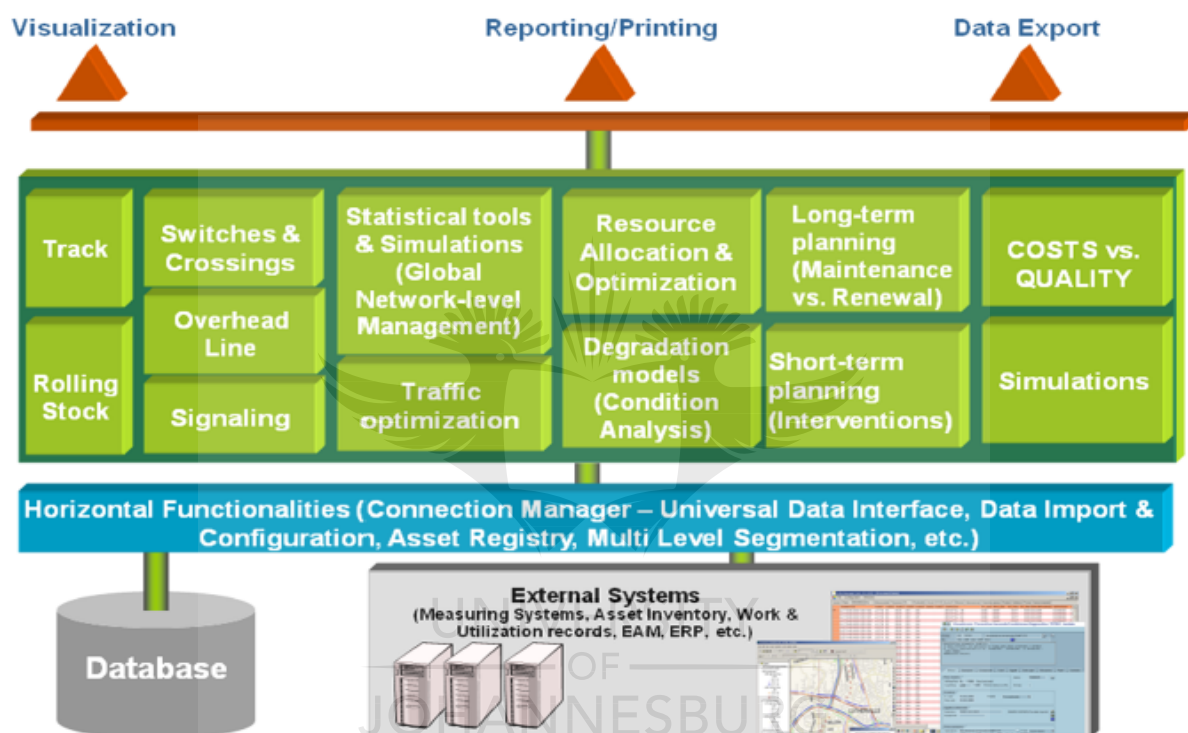
Rete Ferroviaria Italiana (RFI), the Italian public limited company for railway transportation has 22,400 kilometres of track. Bozovic and Jovanovic (2014)

compared the two countries Serbia and Italy in implementing the railway maintenance management system. Their findings in the Italian railways were that RFI started with this process in 2002, by presenting an exclusive modern measuring train, ARCHIMEDE, which incorporates nearly everything within the sphere of monitoring of the infrastructure and measuring its condition. It is made up of one locomotive and five coaches, comprising of extremely intricate monitoring and measuring apparatus. To be able to implement the railway maintenance management system (RMMS), according to Dr. Bozovic and Dr. Jovanovic (2014), the initial two responsibilities RFI had to carry out utilising the new system by filling the database with assets that are applicable. Database information covered included the modelling of the maintenance objects, evaluating and modelling the state and projected life cycles of the objects. Dr. Bozovic and Dr. Jovanovic (2014) further stated that up to October 2004, plans for every week containing actions built on recording and integrating data processed for several infrastructure items were assembled by RFI. (This was prepared through diverse systems in the past). Adding to that, RFI linked the train traffic management system with In.Rete 2000 and the computerised information technology system in the general organisational environment, e.g. logistics, managing rolling-stock, material distribution and inventory, discussions, and replenishing stock. RFI initiated a challenging mission of maintenance and renewal planning, where the initial results were attained at year ending 2005 in October 2004.

For the improvement of the entire Maintenance Management (MM) process, RFI appointed MerMec S.p.A. to create a decision support system called Infra Manager to support their railway maintenance management system. The Infra manager system was established to assist in the planning of condition-based maintenance and repair activities, to offer linkage between diagnosis of defects and a plan for correcting those defects as part of infrastructure maintenance management. InfraManager system primary features consisted of (1) combining of diagnosed data with the In.Rete 2000 system data; (2) establishment of scenarios for enhanced maintenance and renewal scheduling in agreement with infrastructure degree of decline; (3) presentation of predictive algorithms for decreasing the quantity of compulsory corrective maintenance; and (4) observing maintenance and renewal performance.



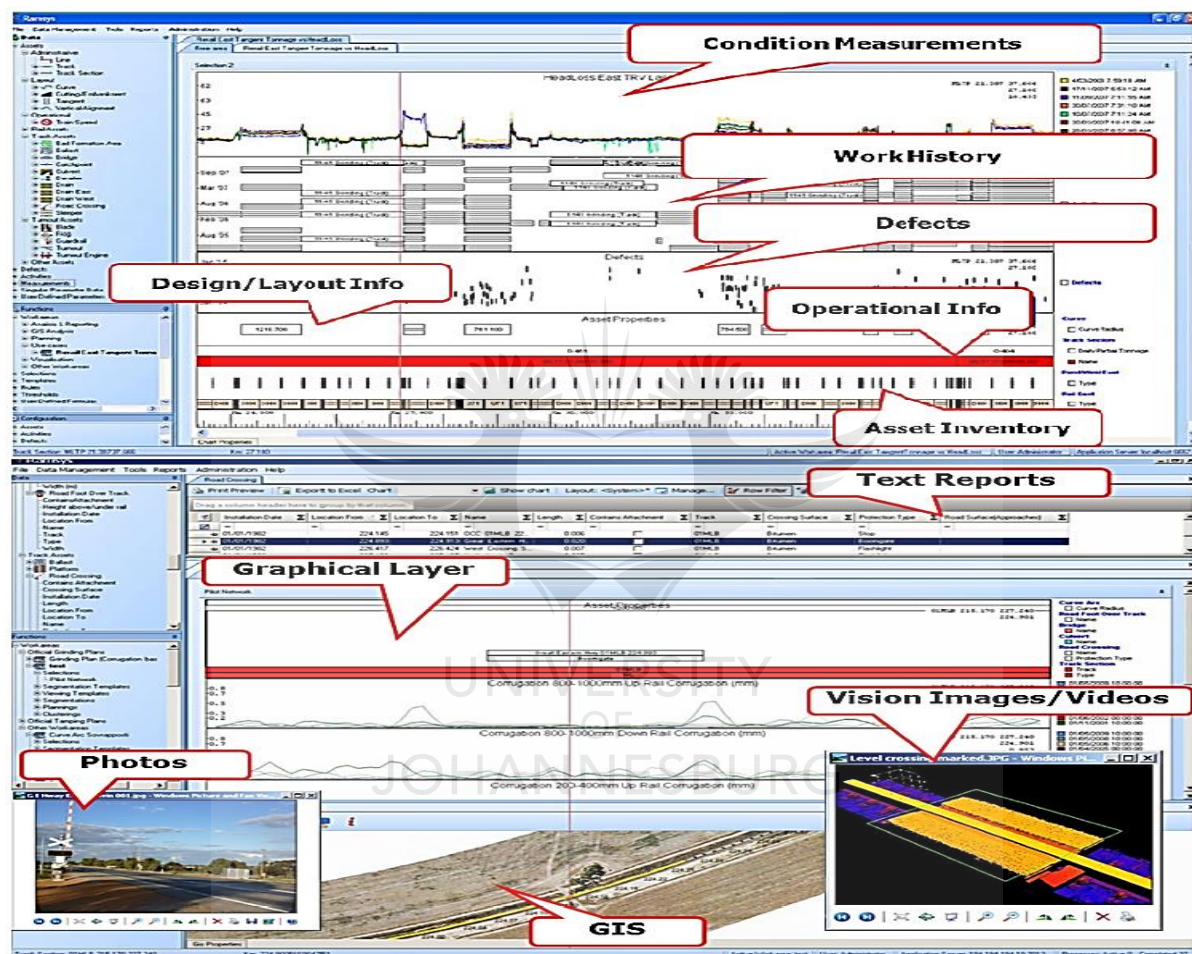
Dr. Bozovic and Dr. Jovanovic (2014) continued to mention that the Infra Manager and RAMSYS software platforms were created from the same idea, except that RAMSYS' scope was created without restrictions. It was also designed to have a wider scope with complete RMMS coverage, flexible enough to fit most circumstances found on the railways. Therefore, RAMSYS was designed such that it is extra dominant and universal in its design than the Infra Manager. Infra- Manager can be perceived as an incomplete type of RAMSYS suitable and deployed for current RFI status quo and requirements.



**Figure 28: Modular Architecture of RMMS**  
(Source: DOI: 10.1061/(ASCE)ME.1943-5479.0000260. 2014 American Society of Civil Engineers.)

The most insightful statement from Bozovic and Jovanovic (2014), was that for enhancement of railway infrastructure maintenance management and elimination of failure risks, the best solution for the planning of maintenance in a condition-based manner, is by determining whether, when, where and how to take action, depending completely on the state of the asset and its observed (measured) change over a certain period. This eradicates premature preventive and/or overdue corrective (after failure event) interventions and promotes enhanced plans for maintenance and renewal work. The main objective of an RMMS is to shift the existing maintenance

management (MM) concept from today's predominantly corrective, prescriptive, and cycle based to one that is preventive, predictive, and condition based. After all the data and their respective sources have been formalized, mapped, and saved into the RMMS database, the analysis can begin starting with the robust visualization tools. The visualization tools must be as powerful as possible, yet flexible, configurable, and capable of handling all usual forms of data (e.g., asset list, asset state, operation, work history on asset, and future work planned for the asset).



**Figure 29: RMMS Visualization (image by Stasha Jovanovic)**

(Source: DOI: 10.1061/(ASCE)ME.1943-5479.0000260. © 2014 American Society of Civil Engineers.)

### 3.8.2 Serbian Railways

Serbian Railways' (SR) network consists of 3,809 km of tracks, where 1,155 km is key lines that belongs to either the European Corridor or Belgrade-Bar (Montenegro) line; 865 bridges, 311 tunnels, 697 stations and sidings. Overall, the electrified network



scale is 1,247 km. The initial relevant maintenance and renewal conception started in the year 1963. The concept was obligatory for the then Yugoslavian railway network. According to Bozovic and Jovanovic (2014), in 1958 Amsler was the first measuring car to be bought. In 1967, the vehicle was fitted with the Neptune system to enable automatic processing of information and assess track sections in a quality manner. The Neptune system can be compared to a former version of the RMMS system and at that time the sections were defined in 500 m stretches. The system was divided further into three ways (1) for critical interventions in the superstructure, (2) for maintenance and renewal (M&R) work scheduling at a departmental level, and (3) for inclusive M&R planning in the whole network.

Bozovic and Jovanovic (2014) continued to mention that condition measurements (track geometry only) were being done regularly for some time, biannually on the main lines and annually on other lines, until 2008, when the EM-80L car broke down and was not repaired. Presently, the state of affairs of the SR network is that 70% of the network has totally depreciated, i.e., the service lives of the components' average life expectancy of 30 years has been exceeded. The SR is faced with an even more critical challenge of lack of funding as such a situation already puts pressure on SR to focus entirely on keeping the network inside the operational/safety boundaries. Other than avoiding accidents, SR cannot do much maintenance and renewal work with their limited funds. SR attempted to solve the financial problem by receiving funding from the international financial institutions such as European Investment Bank (EIB) and the European Bank for Reconstruction and Development (EBRD) and related agencies such as the European Agency for Reconstruction (EAR).

Allocation of the European Union (DEU) to the Republic of Serbia launched a project in 2010 that was the initial stage of the full scale RMMS deployment. LiDAR (Light Detection and Ranging) surveying technology was completed from a helicopter platform covering 1,300 km of the section's 10 main lines. Main infrastructure assets were identified, together with their whereabouts and characteristics drawn out from the ortho-photo images and logged into the database. Additional data was collected where an all-inclusive railway infrastructure condition monitoring study was made, comprising track geometry, rail profile, rail corrugation, OHL geometry and wear. This was concluded by using hi-rail measuring vehicle that is designed to run both on roads and rails.

### **3.8.3 Italian and Serbian Comparison**

During the two case studies, Bozovic and Jovanovic (2014) discovered that some common challenges that were identified as follows:

- Accessing of important data covering asset inventory, condition measurements, infrastructure exploitation, maps, maintenance and renewal (M&R) work history, maintenance and renewal (M&R) policies.
- Interface with the current information technology (IT) environments and user competency level, and
- Interface with the old-style M&R practices and procedures.

Bozovic and Jovanovic (2014) summarised the findings of the two cases as follows:

#### **Italian Case Study**

- Key data was already present in the In.Rete2000 system,
- In.Rete2000 system was designed specifically for railway enterprise asset management (EAM). It was a general-purpose one (not ideal for linear/spatial assets). Some of the critical basic functionalities that did not feature were linear/spatial assets such as visualizations, continuity integrity checks—detecting and resolving overlaps and gaps in the continuity of linear/spatial assets),
- Minor asset data remaining in the In.Rete2000 system needed further improvement.
- InfraManager System had the required functionalities, although data improvement proved to be challenging owing to monotonous manual work that needed tracing of paper records of the incorrect data and finding the right data.

#### **Serbian Case Study**

- No EAM existed, which meant that no direct data handover was likely as only small digital data was available;
- Data that was available was spread across different departments, regional offices and several individuals;

- Available data was not in a combined arrangement as no central information system (e.g., EAM) existed;
- No reliable information was present on the real quality/accuracy/reliability of data. Data varied from place to place, department to department, and asset to asset;
- There was a challenge to establish the overall data quality on the whole network (i.e. data to use and data to reject); and
- Data discrepancies and replications, missing and wrong data required to be evaluated and rectified.

Bozovic and Jovanovic (2014) continued to point out that some inaccuracies were still there. They are regularly and continuously revealed by the everyday use of the RMMS system pilot, where inconsistent circumstances are stumbled upon due to wrong data record, and they are resolved as the need is identified. At that level, the Serbian state of affairs matched with that in Italy as the problems were similar, i.e., data improvement was an overwhelming undertaking of tracing paper records of the incorrect data and find the right data.

### **3.9 Swedish Case Study**

Famurewa et al. (2015) produced a paper on “*Maintenance analysis for continuous improvement of railway infrastructure performance*”. The study was done by the Sweden Lulea Railway Research Centre and the Division of Operation & Maintenance Engineering, Lulea University of Technology. The Swedish railway network section was utilised for the study. The railway line segment investigated was 168 km in length, from Boden to Gallivare. It is a class 2 heavy haul line which is the longest as the track is 39% long. Famurewa et al. (2015) presented a paper after investigating the possibility of implementing a maintenance analysis based on a risk matrix method by identifying track zones that presents obstacles that leads to a constraint in operational capability and excellence. Furthermore, Famurewa et al. (2015) presented a criticality study that suggested to produce a graded enhancement list for that will address the train disruption challenges and a reduction in operational capacity. The arrangement of the paper as presented by Famurewa et al. (2015) was as follows:

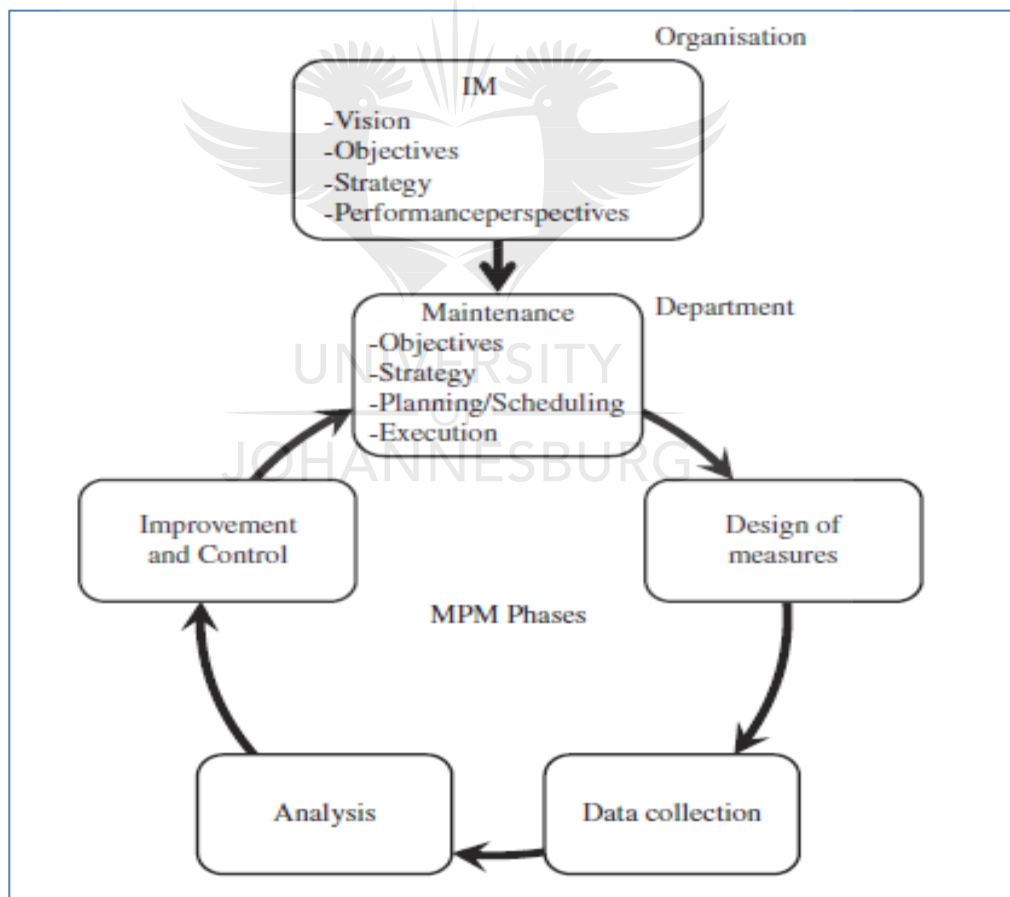
- A short report on railway infrastructure management

- Maintenance performance measurement (MPM) which focuses on maintenance analysis.
- Maintenance analysis methods that are suitable for uninterrupted enhancement at numerous indenture levels of railway infrastructure.

Famurewa et al. (2015) presented the stages of a strong MPM system as follows:

- Introducing measures to be used,
- Collecting data,
- Analysing data,
- Enhancement and control.

The diagram below as presented by Famurewa et al. (2015) summarised the framework for infrastructure management and performance measurement:



**Figure 30: Infrastructure Management and Performance Measurement (Source: Structure and Infrastructure Engineering, 2015, Vol. 11, No. 7, 957–969, <http://dx.doi.org/10.1080/15732479.2014.921929>)**

Famurewa et al. (2015) also presented maintenance performance indicators within the broader maintenance performance system as follows:

Strategic perspective	Maintenance result area	Performance indicators
Process related	Capacity consumption	Total maintenance hour/time period. Correct maintenance hour/total maintenance hour. Response timeliness
Infrastructure related	Dependability	Number of traffic disrupting failures. Number of urgent inspection remarks. Number of failure related incidents (work orders). Train delay (minutes) / total travel time.
Customer related	Punctuality comfort	Train delay minutes. Number of cancelled trains. Track Quality Index (TQI).
Safety related	Safety	Number of derailments and rail breaks. Number of critical incidents.
Finance related	Return on maintenance investment	Maintenance cost per tonnage km and train km.

**Table 15: Synthesised Performance System (Source: Structure and Infrastructure Engineering, 2015, Vol. 11, No. 7, 957–969, <http://dx.doi.org/10.1080/15732479.2014.921929>)**

Famurewa et al. (2015) furthermore emphasised that data collected should be converted into information and knowledge base that will facilitate resolutions and continuous improvement. In addition, Famurewa et al. (2015) mentioned that during maintenance analysis the risk of failure has to be the main driver of maintenance decisions, rather than the failure itself. Therefore, failures impacting negatively on operation, economics or safety are prioritised.

### 3.9.1 Case Study Data: Data analysis and their methods

The Swedish Transport Administration allocated 39 traffic zones or segments for the case study. These segments represented the various technical divisions within the organisation. To facilitate an environment of continuous improvement, the

performance of previous maintenance interventions and resolutions taken utilising different indicators within the system were considered. Data analysed is the record of train delays from 2010 to 2012, focusing on train interruptions and delays that were caused by failure of infrastructure. The table below depicts Trafikverket line classes and their description as highlighted by Famurewa et al. (2015):

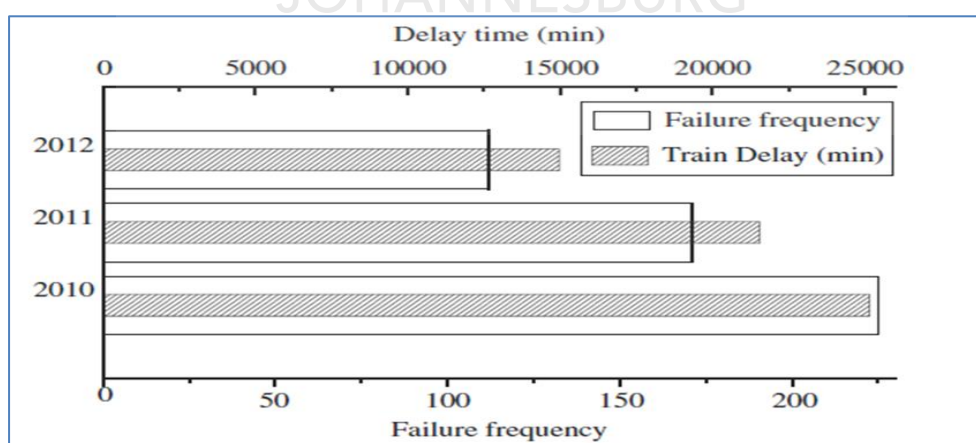
Line class	Transport Value	Capacity Utilisation	Difficulty for track maintenance time	Traffic sensitivity to disturbance	Requirement on punctuality	Requirement on comfort
1	Very important	High	Very high	Very high	Very high	High
2	Very important	Medium to high	High	High	High	Very high
3	Important	Medium	Average to high	Medium	Basic	High
4	Less important	Low	Low	Low	Basic	Basic
5	Less important	Low	Low	Very low	Basic	Basic

**Table 16: Line Classes in Trafikverket and their Description**

(Source: Structure and Infrastructure Engineering, 2015, Vol. 11, No. 7, 957–969, <http://dx.doi.org/10.1080/15732479.2014.921929>)

### Failure frequency and time delays per 3-year period

The Figure below shows a summary of failure characteristics of the line and the operational consequences over a period of three years:

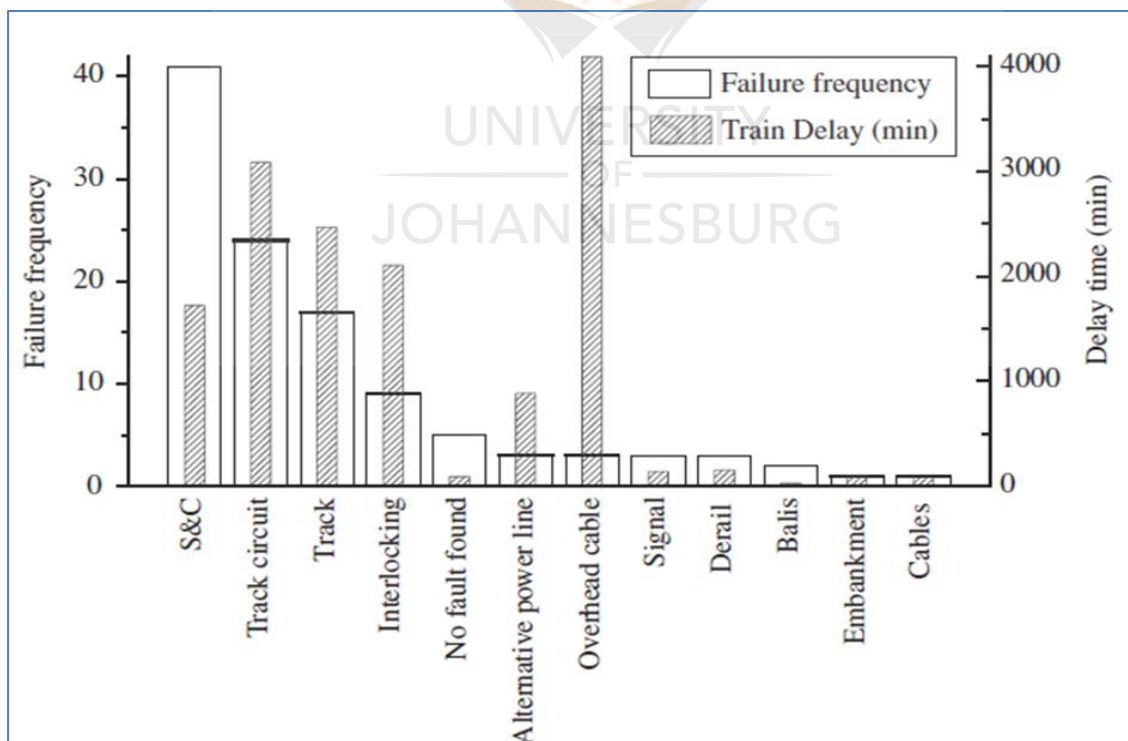


**Figure 31: Overview of failure characteristics of the line and the operational consequences.**

(Source: Structure and Infrastructure Engineering, 2015, Vol. 11, No. 7, 957–969, <http://dx.doi.org/10.1080/15732479.2014.921929>)

### Failure frequency and time delays per infrastructure item

Famurewa et al. (2015) emphasise that to address the problem of train operations disruption and reduced operational capability triggered by poor infrastructure integrity, a data-driven approach should be adopted. To achieve this, infrastructure bottlenecks were identified using a risk matrix and various criticality analysis methods for improvement of line capacity were utilised. Famurewa et al. (2015) further argue that switches and crossings (S&C), track circuit and track have a high influence on the number of mission interruptions or failures on the line section. Whereas overhead cable, track circuit and track have the most operational consequence in terms of the delay time. Famurewa et al. (2015) utilise random events, such as delay times and modelled these events using exponential, gamma, lognormal or Weibull distribution (Yuan, 2006). In the study, it was assumed that the delay time considered (failure-related delay) can be modelled adequately using lognormal distribution as it is general acceptable and simple to use. Furthermore, Famurewa et al. (2015) indicated that it is important to evaluate the performance of historical maintenance actions and decisions using a system of indicators in order to meet the requirements of Table 15. Train operations disruptions due to infrastructure failure are shown in the figure below:

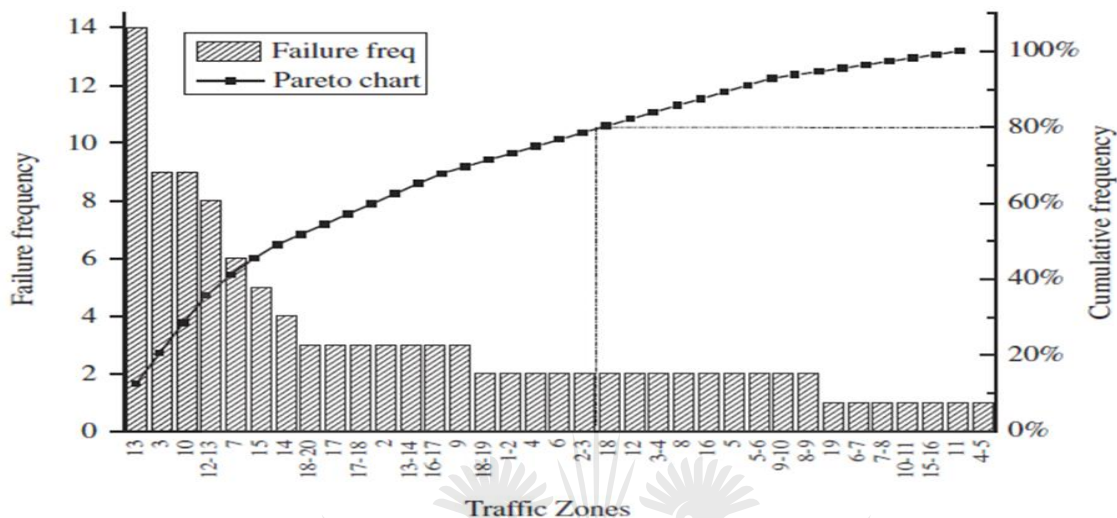


**Figure 32: Contribution of each Infrastructure type to train mission interruption** (Source: Structure and Infrastructure Engineering, 2015, Vol. 11, No. 7, 957–969, <http://dx.doi.org/10.1080/15732479.2014.921929>)



### Frequency of failures and affected traffic zones

The graph below is important for detecting dangerous places that have a negative influence on the capability and reliability issues on the railway line. Famurewa et al. (2015) depicted a graphical illustration of the rate of failures interfering with traffic at 39 zones shown in figure 33 below:



**Figure 33: Pareto chart of higher-level system failure or traffic zones in 2012.**

(Source: Structure and Infrastructure Engineering, 2015, Vol. 11, No. 7, 957–969, <http://dx.doi.org/10.1080/15732479.2014.921929>)

### Categorisation of traffic zones based on risk

Furthermore, Famurewa et al. (2015) depicted a hypothetical grading of the frequency of failure and consequential delay to show the mentioned methodology, which was created through a subjective judgement of a group of experts within the IM organisation. This grading showed both the acceptance limit and quality definition of the organisation. The risk matrix provides data about each traffic zone's risk category in an identified time period and detects dangerous blockages along the linear asset where the capacity of the entire line is limited. The intolerable zones in Figures 37 and 38 are the crucial blockages that restrict the flow of traffic through the line. Famurewa et al. (2015) added that to expedite continuous improvement, it is important to create an implementable time table for extra investigation on maintenance of the zones in the intolerable and undesirable risk categories. The influence of each traffic zone to the overall risk of quality loss is presented in the figures below for the years 2011 and 2012.

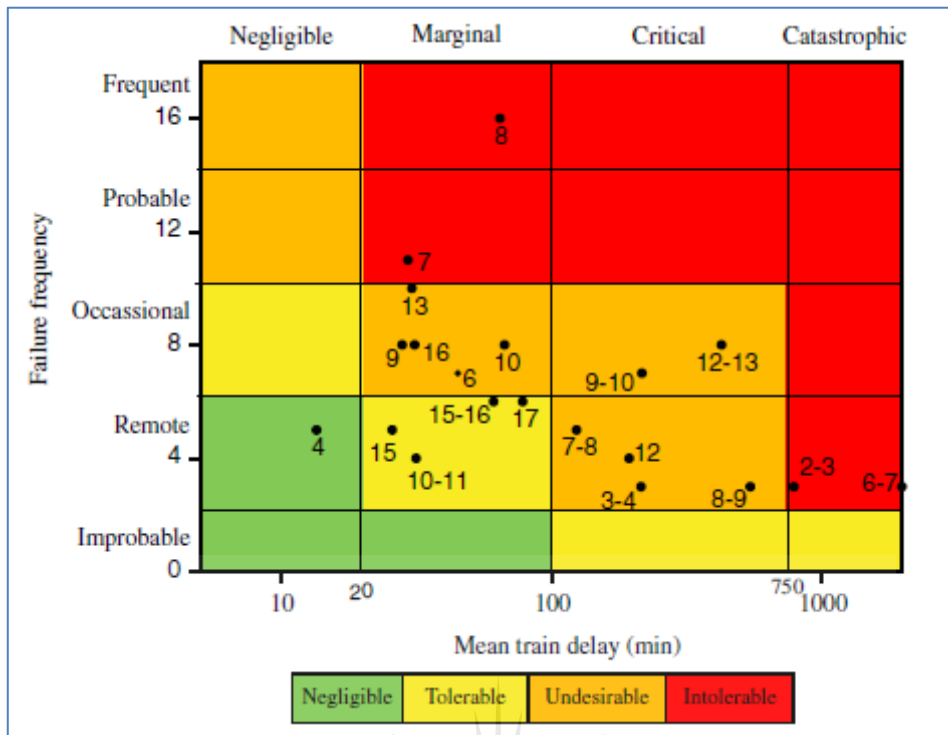


Figure 34: Categorisation of the traffic zones based on the risk of limiting service quality and capacity in 2011.

(Source: Structure and Infrastructure Engineering, 2015, Vol. 11, No. 7, 957–969, <http://dx.doi.org/10.1080/15732479.2014.921929>)

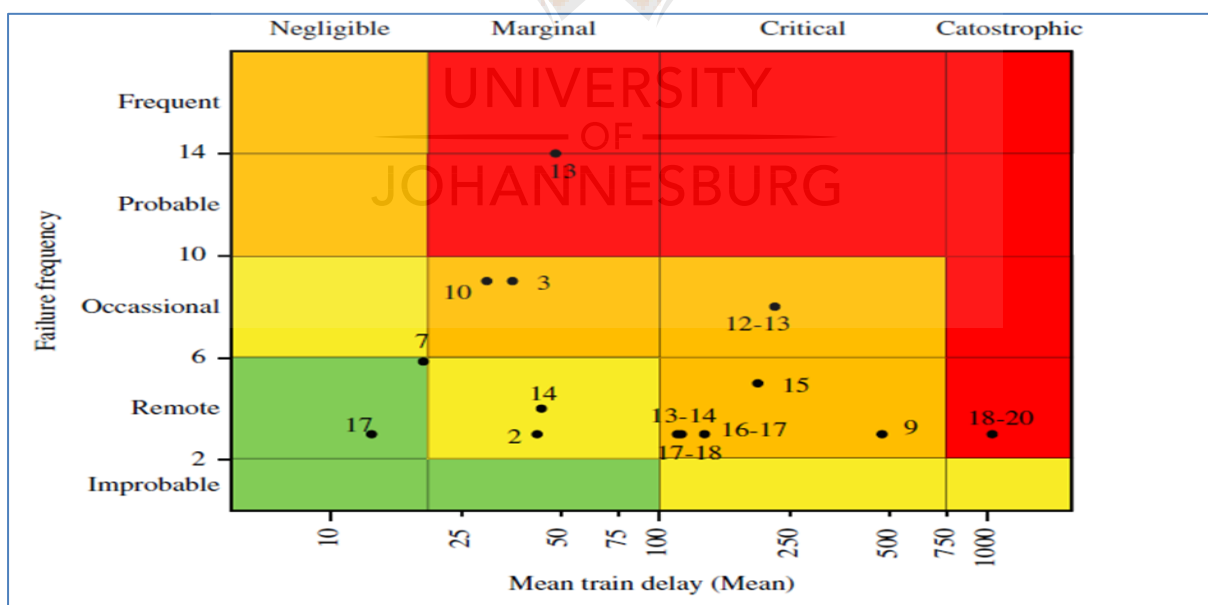
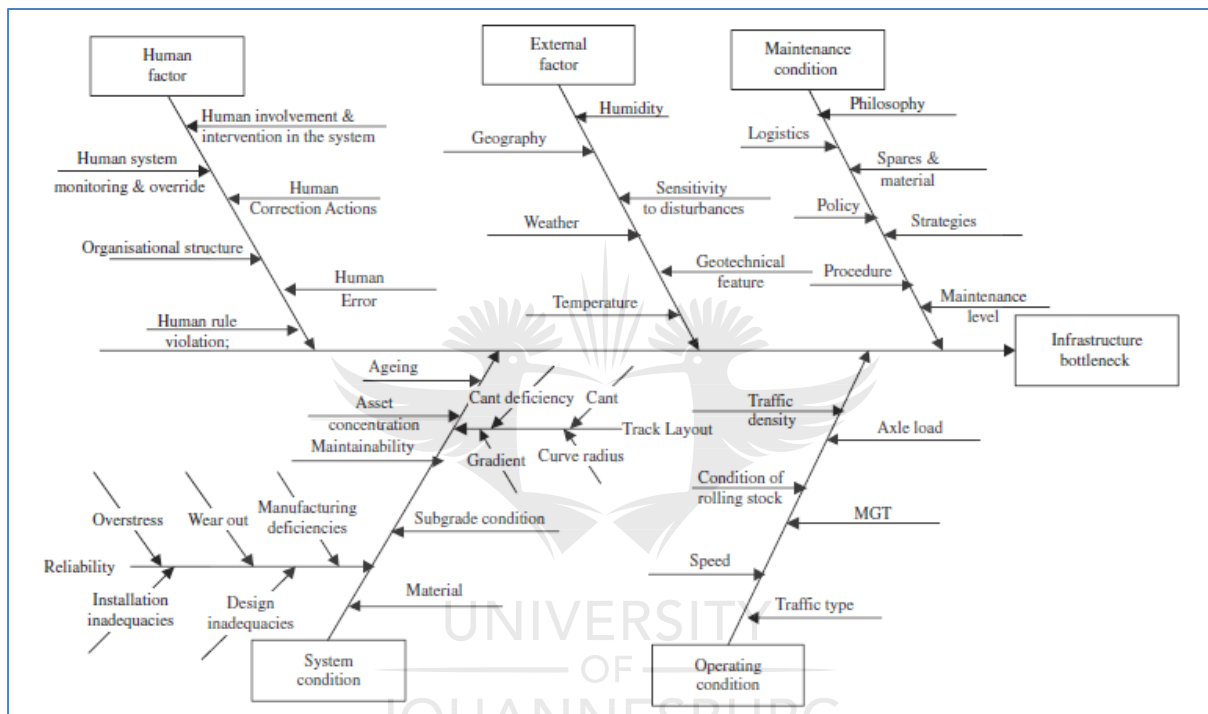


Figure 35: Categorisation of the traffic zones based on the risk of limiting service quality and capacity in 2012.

(Source: Structure and Infrastructure Engineering, 2015, Vol. 11, No. 7, 957–969, <http://dx.doi.org/10.1080/15732479.2014.921929>)

### Undesirable condition of zones and related root causes.

Figure 36 is a cause and effect diagram that can be adopted to highlight the issues that contribute to the intolerable state of the zones and their root causes. According to Famurewa et al. (2015), zones with an undesirable risk contribution can be maintained to reduce their impact. Zones with a tolerable impact should be controlled with required measures, and those with negligible impact should be monitored and their maintenance must be made a standard.



**Figure 36: Root cause analysis of infrastructure bottleneck**

(Source: (Source: Structure and Infrastructure Engineering, 2015, Vol. 11, No. 7, 957–969, <http://dx.doi.org/10.1080/15732479.2014.921929>)

### 3.9.2 Conclusion of the Swedish Case Study

Famurewa et al. (2015) concluded by highlighting the following points regarding the maintenance analyses carried out in the case study:

- Infrastructure failure has a considerably great effect on the capacity of operations and punctuality of the train on the line.
- How much maintenance is needed and graded list of the traffic zones differ when failure frequency and consequential delay impacts are used for

separate analysis. The presented risk matrix is, however, useful for aggregating the two maintenance measures to support decision-making.

- Traffic zones 8, 7, 2–3 and 6–7 are capacity bottlenecks in 2011, and zones 13 and 18–20 fall into the same category in 2012 due to their intolerable contribution to the reduction in service quality and line capacity. The proposed cause and effect diagram can be of use for initiating investigation into the causes of these bottlenecks at the operational level.
- The result of the modified criticality analysis technique for constant improvement shows that the overhead cable on zone 18–20, track circuit in zone 15 and alternative power line in zone 12–13 are the weakest links or restraining assemblies. These should be prioritised in maintenance planning for the year 2013 to improve the operational capacity and service quality on the line section.
- Finally, the decision on the distribution of maintenance and reinvestment budgets can be supported with these analyses. For future research, a holistic approach that extends the maintenance analysis from the topmost indenture level to the lowest maintainable items on a network will be considered. Other relevant MPIs will be included as criteria in the analysis. This will not limit the perspective and application of the analysis to punctuality and capacity improvement at the operational level but rather extend to the safety and economic aspects.

### **3.10 Track Strategy Project of the Austrian Federal Railways**

Veit (2002) in his article of the Rail International Journal mentioned that the dominant role of the various traffic loads that were monitored shows that the track maintenance strategy should be based on increasing the service life of different track components. Useful life reduction and cutting on maintenance will not necessarily be cost effective. Veit's (2002) findings with regards to track, points and crossings therefore concluded with the following points:

- High quality track standards at the outset are the key to success.
- Speed restrictions on the track are extremely uneconomical.
- Extending economic life is useful, even if it means allowing for extra costs.

### 3.10.1 Track Findings

An analysis of track findings took into consideration varying subgrade quality, traffic loads, curve radius distributions and track structures. The following track findings were made during the project:

- Subgrade improvements projects proved to be cost-effective to the overall quality of the track.
- A combination of concrete sleepers and the utilization of heavy UIC 60 rails on busy lines of OBB network is preferable.
- Combining mechanical track maintenance (e.g. tamping) and rail grinding in one track possession period proved to be very economical.
- Minimum maintenance has an adverse effect on the track service life and is not recommended.
- Grinding new rails during renewal of track ensures initial high quality standards.

Table 17 below shows a summary of main track findings:

Daily loading	>30 000 gross tons	5000 – 30 000 gross tons	< 5000 gross tons
Best possible quality at the outset	yes	yes	yes
Subgrade rehabilitation	yes	yes	yes
Heavier track	yes	yes	yes
Rail welding	yes	yes	yes
Integrated Maintenance	Yes	In future: yes At present: no	no
Line speed restrictions	no	no	no

**Table 17: Summary of Main Track Findings**

**(Source: Rail International Journal, June 2002)**

### 3.10.2 Points and Crossings Findings

Factors taken into consideration for this study were subgrade qualities, traffic volumes, turnout radii and rail types. The main findings concerning the points and crossings were as follows:

- Subgrade improvements are more critical than in plain track as points and crossings have lower permissible tolerances that make them vulnerable to

low subgrade quality. Identifying and eradicating causes of poor subgrade should be prioritised rather than eliminating the effects.

- For best outcomes, the type of rails at points and crossings should also be the same as in plain track for the same traffic loads.
- Cutting back on maintenance is strongly opposed because of its adverse effects.
- Combining mechanical track maintenance and rail grinding (i.e. integrated maintenance) in one track possession period proved to be very economical.

Table 18 below shows a summary of points and crossings findings:

Daily loading	>30 000 gross tons	5000 – 30 000 gross tons	< 5000 gross tons
Best possible quality at the outset	yes	yes	yes
Subgrade rehabilitation	yes	yes	yes
Line speed restrictions	no	no	yes
Heavier points	yes	yes	yes
Integrated maintenance	yes	no	no
Extra ballast cleaning halfway through service life (for good quality ballast on good subgrade)	no	no	no
Movable frogs	yes	-	-
Change of sleeper type	no	yes	yes
Concrete sleepers for crossings	yes	yes	yes
Minimum maintenance	no	no	no

**Table 18: Summary of Points and Crossings Findings.**

**(Source: Rail International Journal, June 2002.)**





**Figure 37: Picture of Main Track Components**  
 (Source: Technical University of Graz I Institute for Railway Engineering and Transport Economy Univ.-Prof. Dipl.-Ing. Dr. Peter Veit, 2013)

### 3.11 Track Maintenance Cost Allocations Strategies

Jovanovic (2014) quoted Esveld (2001) by saying that typical yearly costs per 1 km of tracks for West-European networks are about €50,000. For cost effective maintenance practices, Jovanovic (2014) stressed the importance of improving the way track performance is monitored and a dependable technique of forecasting and planning, as these are key objectives of a railway maintenance management system (RMMS). As Caetano and Teixeira (2013) have shown, budget limitations may necessitate delaying renewal works from the optimal schedule and consequently escalating the life cycle cost value. The efficiency of ballast tamping operations has a tendency to reduce as tamping cycles accumulate. Railway Track Components' Degradation Modelling shows the decreasing capability of tamping to improve the geometrical parameters as ballast deteriorate due to traffic loads and every single tamping operation that follows (crushing of the ballast particles). Railway Track Components' Degradation Modelling of rail and sleeper failure revealed that rail fatigue faults and sleeper failure follow a Weibull law (Shyr and Ben-Akiva 1996; Nilsson and Olofsson 2002; Yun and Ferreira 2003; Stirling et al. 2006; Zhao et al. 2007).

In track maintenance planning, stochastic modelling of component deterioration is almost constantly represented by hazard rate (Lyngby et al. 2008). Shah et al (2014)



mentioned that a lot of countries are becoming explicit in their directing of capital investments in sectors such as: Energy, Transportation, Communications, Flood Management, Water and Waste infrastructure (e.g. UK Treasury Report, 2012). According to The Infrastructure Cost Review Report (HM Treasury, 2010) projections, from 2010 to 2015 about £15 billion to £20 billion per annum will be expended in the UK on infrastructure projects and programmes mostly consisting of civil engineering works and capacity improvement, renewals, repairs and maintenance. But in Europe, Australasia and North America a considerable amount of major infrastructure is getting old and the condition declining fast. Minimal budgets of these countries evidently explain the need for resourceful asset management systems (OECD, 2001).

In UK, £30 billion annually was devoted to maintaining and managing the infrastructure, which expected to escalate to £50 billion by 2030 (HM Treasury, 2010). Shah et al. (2014) also mentioned that as all infrastructure assets are directly or indirectly sustained by geotechnical assets, and managing of these geotechnical assets efficiently is important in the whole infrastructure asset management system. Shah et al. (2014) continued to say that straight acknowledgement of influence that geotechnical assets has on the overall asset structure, is not directly visible to the users. Furthermore, Shah et al. (2014) stressed that poor management and maintenance of geotechnical assets escalate the total life cycle costs of the infrastructure assets. Therefore, to cost effectively prolong the lifecycle of the infrastructure asset management systems, it is vital to create a geotechnical asset management system that is robust. In the US alone, \$1.75 trillion have been spent on the development and upkeep of the transportation infrastructure due to the constant and ever-growing demands, and other natural forces, which causes deterioration of the transportation assets (FHWA, 2005). In UK, Highways Agency spent over 30% of its 2010-11 budget allocation on maintenance of infrastructure networks.

### **3.12 Asset Management in Practice**

#### **3.12.1 Network Rail Case Study**

Lloyd and Edward (2012) mentioned that Network Rail in the United Kingdom (UK) spent £12.5 billion pounds on renewals expenditure between 2009 and 2014, which is the total equivalent investment by the 23 water and sewerage companies. This amount

also represents an investment greater than 11 electricity distribution companies and National Grid's UK electricity and gas transmission businesses combined. Network Rail is the not-for-profit company that purchased the majority of the UK mainline rail infrastructure and took over the responsibility of maintaining assets from Railtrack plc following its collapse in 2001.

Edwards (2012) mentioned that Railtrack Plc was placed into administration in 2001, and in 2002, Network Rail, a company limited by guarantee, bought the infrastructure assets and took on the role of asset steward. Network Rail's first priority was to reverse the decline in performance and restore investments in assets to a more sustainable level. The mainline of the rail regulator, Office of Rail Regulation (ORR), set Network Rail a series of demanding output and efficiency targets, but at the same time there was less focus on some of the longer-term aspects of asset management. According to Lloyd and Edwards (2012), an asset management framework review was carried out by the Independent Reporter of Asset Management, whose role was to examine Network Rail's capabilities in asset management and to provide the Office of Rail Regulation (ORR) and Network Rail with a level of assurance that the tools, processes and asset information used to underpin Network Rail's strategic business plan are fit for purpose. Another role of the Reporter was to ensure that Network Rail complies with asset management requirements of licence conditions. The main six areas of performance monitoring, capability and maturity of asset management in six areas were as follows:

- Asset management strategy and planning
- Whole life cost justification
- Lifecycle delivery
- Asset knowledge
- Organization and people
- Risk and review

Lloyd and Edward (2012) go on to further highlight the Reporter's responsibility for maintaining and tracking the recommendations from the best practice reviews and other audits. The Reporter also reviews progress against these regularly in making certain that Network Rail is making progress on development of asset management

systems and data for the business. One of the results of the transformation programme was to restructure the company around an asset management delivery model. This was designed to advance asset management performance by bringing into line maintenance routes with route asset management teams to allow the development of integrated route asset management plans.

Lloyd and Edward (2012) illustrated the fact that Network Rail used the road map to establish an asset management improvement plan for developing its asset management capabilities over the longer term as shown in its 2011 asset management policy document (Network Rail, 2012a):

*Our aim is to meet our asset management obligations in a manner that is demonstrably world class, with asset management capabilities appropriately matched with our needs and our industry partners. Our capability improvement programme has been developed to meet this aspiration. By the end of the current control period (March 2014) our commitment is to have developed capabilities in asset management that are demonstrably comparable with best practice elsewhere in Britain. Over the following five years we are committed to improving our business capabilities further, so that we provide the benchmark against which organisations throughout the world assess their own asset management capabilities.*

The company plan in its fullness includes the following from policy creation to execution in the following progressive order:

- Asset management policy
- Asset management strategy
- Asset policies
- Route asset and route delivery plans
- Work execution

According to Lloyd and Edward (2012), asset management is now regarded as integral to Network Rail's ability to rise to the challenges it faces, namely:

- Continuing to achieve significant efficiency savings.

- Securing future funding in a harsh economic climate.
- Developing and implementing plans to improve value for money of the rail network.
- Accommodating high traffic growth.
- Taking the lead role in developing long-term national rail plans, including involvement in planning the high-speed rail network.
- Improving its ability to deliver significant investment to the rail network with reduced disruption to train services.

Lloyd and Edward (2012) concluded by saying Network Rail learned important lessons from Railtrack's collapse by realising that the railway network is a value chain. Under Railtrack maintenance contracts and renewal levels were not sustainable, although introduction of minute delay as a financial directive was a proper measure as it recognised the interrelatedness of the systems, activities and organisations underpinning network performance.

England (2014), who is Network Rail's Group Asset Management Director added by saying that Network Rail's Asset Management Policy plays an important part in constructing an overall 'line-of-sight' between asset interventions and the general Network Rail objectives. England (2014) added by saying that their asset management policy also provides a structure and document hierarchy that is utilised for distribute the overall output and funding specification, into both an effective asset management plan and the related interventions on applicable assets.

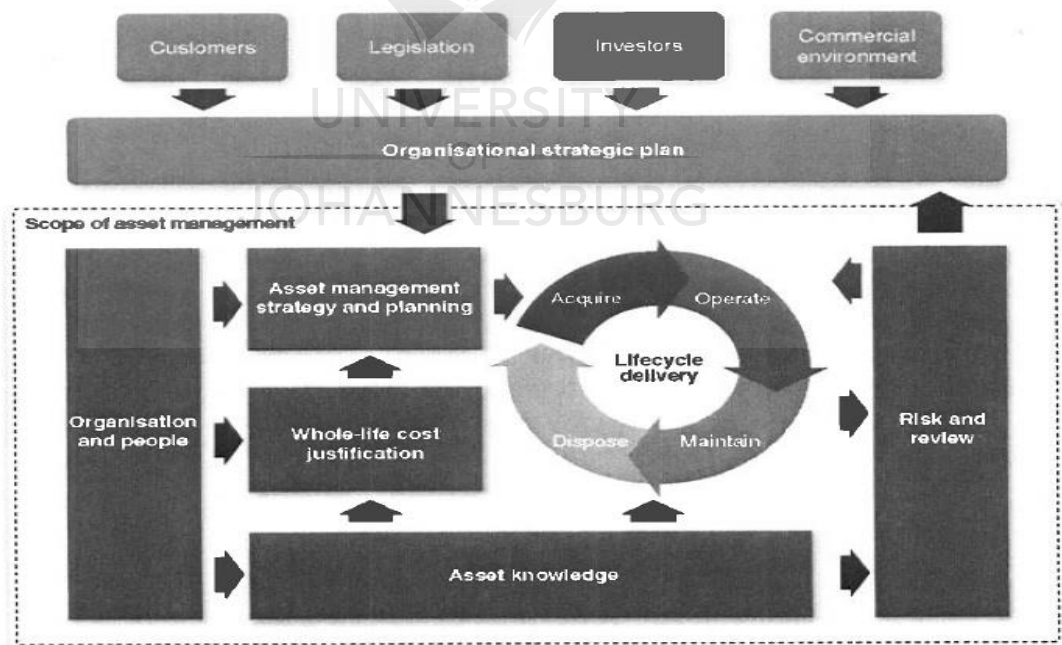
### **3.12.2 Rail and Utilities Sectors**

Edwards' (2012) definition of asset management in its simplicity was that asset management allows asset-intensive businesses to use limited resources to achieve their stated business objectives in the most cost-effective way. Edwards (2012) continued to highlight six key areas of technical, human and organisational capability. The six key areas are:

- Organisational Strategic Plan
- Asset Management Strategy and Planning
- Organisation and People

- Whole life cost justification
- Asset knowledge
- Risk and review

Edward (2012) acknowledged that most aspects of asset management are not new; they are integrated activities within six areas that asset management is seeking to achieve. All the activities in these six areas must be aligned with the overall business strategy for ensuring that funds spent on the assets are contributing to the overall goals of the business. The overall process from policy creation and strategy formulation down to lifecycle delivery activities is called the 'line of sight'. Edward (2012) highlighted the fact that asset management is not really a maintenance manager or engineering manager's sole responsibility. It should be championed by a whole range of people, from director to front line personnel. According to Edwards (2012), the adoption of asset management approach often starts in the middle management of the organisation. It is the responsibility of the middle managers to communicate the benefits of asset management both up and down the organisational levels for achieving the 'line of sight'. Figure 38 below depicts the core six areas:



**Figure 38: Asset management conceptual model**  
(Source: Asset Management Consulting Limited)

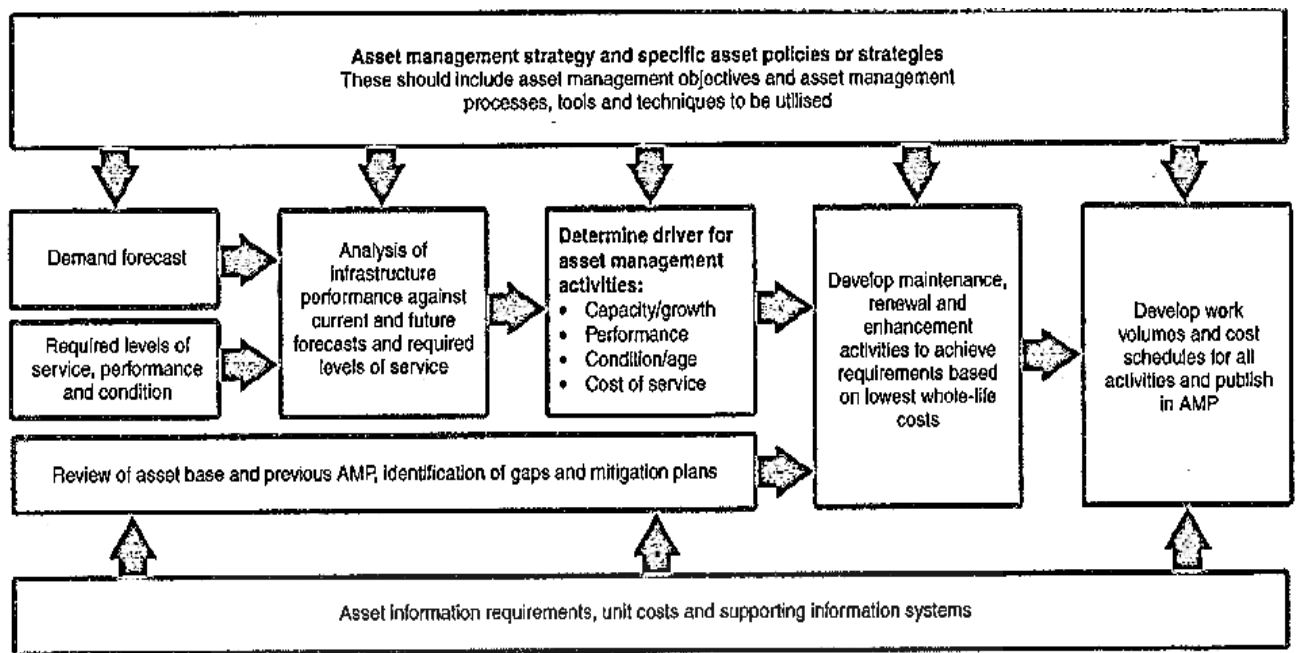
### **3.12.3 Background of Asset Management in the UK utility and rail sectors**

The formation of United Kingdom Institute of Asset Management (IAM) in the early 1990s as a professional body for the development and distribution of good practices in asset management, contributed to the rail and utility sectors' early adoption of asset management methodologies. Edwards (2012) acknowledged that one of the difficulties of trying to change renewal and maintenance regimes was that the requirements for some of the regimes were embodied in standards and procedures, for which there was neither a justifiable clear definition nor the definition to justify the standard or procedure, have been lost over time. It was difficult to change the maintenance and renewal regimes in the rail or electricity sectors as the risks associated with those changes were unknown. Edwards (2012) continued to say that, under those circumstances, it became increasingly important to understand, quantify and manage risks related to optimisation of renewal and maintenance regimes. As such, regulators became increasingly concerned about the longer term risks of introducing short term efficiencies at the expense of higher costs and future risks associated with asset management. IAM started to develop BSI PAS 55 for better guidance on the holistic management of risk. Risk management was a key driver for this development.

#### **Strategy and Planning**

The output of strategy and planning is the asset management plan (AMP), which outlines the asset management activities necessary for the development, implementation and improvement of assets in line with business objectives and also considering the changing demands over time on the asset portfolio. Edwards (2012) highlighted that some rail and utility companies have found that an AMP developed for regulatory purposes can become disconnected from the day-to-day activities of the organisation, as these can be managed by different parts of the organisation. This result in inefficiencies, and through duplication and misalignment, it makes the plan difficult to validate. What is required is better integration of day-to-day asset management activities with business planning processes that will ensure that AMPs reflect actual activities being undertaken. This will lead to better validation of AMPs and their continuous improvement. Figure 39 below shows a process for developing the asset management plan:





**Figure 39: Plan for Developing the Asset Management Plan**  
(Source: Asset Management Consulting Limited)

### 3.12.4 Railcorp Case Study

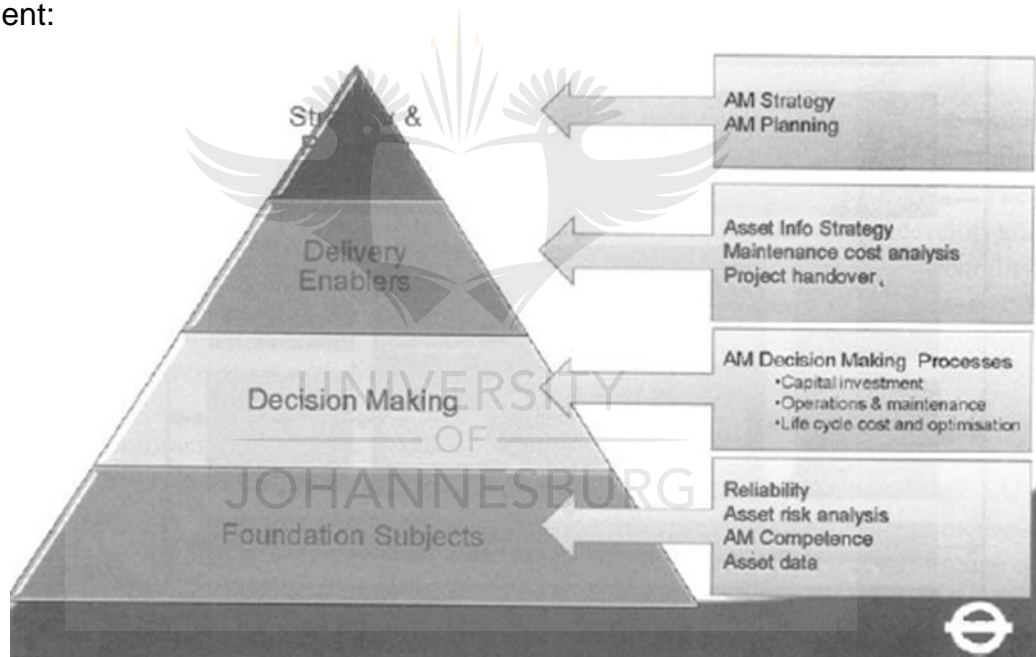
Lloyd and Wallsgrave (2012) discovered that in Railcorp, an observation that was made by asset management champions was that chief engineers who had a lot of experience were given the accountability of making safety critical decisions. The asset management champions believed that this worked against good asset management practice because how decisions were made was not spelled out and there was no explicit or implicit cost-benefit trade off. Lloyd and Wallsgrave (2012) continued to highlight the fact that asset management is more about repeatable, auditable decisions, following agreed lines of analysis, backed up by data and models. Lloyd and Wallsgrave (2012) mentioned that unclear organisational structure was not good for proper asset management as it had a maintenance split across two or more groups, chief engineers in charge of design and a lack of integrated decision making process. In particular, there was no discernible process for investment prioritisation in 2005. Lloyd and Wallsgrave (2012) concluded by saying that the infrastructure division within Railcorp was able to perform better than other operating departments in its business as it made an effort to implement an asset management strategy using PAS 55. It did so because of good leadership and the willingness to change more than other departments. The infrastructure department was also the only part of Railcorp which



could make its case for funding with New South Wales (NSW) treasury. NSW never queried maintenance or replacement spending on track as the asset management strategy outlined the risks of not investing in track maintenance.

### 3.12.5 London Underground Case Study

Lloyd et. al. (2012) mentioned that in 2011, London Underground was certified against PAS 55 by Lloyds Register. An additional gap analysis – structured utilising Infrastructure Asset Management (IAM) asset management conceptual framework and 39 related subjects – has been carried out to determine the next stages in the development of its asset management capabilities. The outcome of this is that a number of improvement areas have been identified, and actions against them are now managed as a programme. Figure 40 below shows the development areas of Asset Management:



**Figure 40: Asset Management Development Areas**  
**(Source: *International Case Studies in Asset Management*, 1<sup>st</sup> Edition, Institution of Civil Engineers Publishing. London, England. 2012, Courtesy of London Underground.)**

Foundational aspects of asset management are reliability, asset risk analysis, asset management competence and asset data. In addition, Lloyd et. al. (2012) stated that the programme reports to The Management System (TMS) Board, on which sit five directors. A steering group has also been formed that consists of senior staff

members, and its duty is to offer pragmatic results-oriented advice to the improvement programme. It is expected of senior personnel to show commitment to the asset management agenda and its value to the business. Lloyd et. al. (2012) goes further to say that at London Underground (LU), asset management is no longer a department it once was, but it is a set of activities that has been built in across traditional boundaries between functions and disciplines. The key objectives for everyone within the organisation is the continuous improvement, establishment of how everyone contributes to LU strategy and objectives, and how all this is beneficial to the business. The LU organisation is trying to move beyond the requirements of PAS 55. In conclusion, Lloyd and Moore (2012) acknowledged that asset management is more relevant today because of improving the quality of information held on the asset portfolio and the reliability of capital and operating expenditure forecasts is now essential to any organisation that needs funding from the UK government through a business case. For infrastructure assets nearing the end of their lives and need replacement, asset management makes it simple to have that proof. In addition to that, Lloyd and Moore (2012) mentioned that asset management is no longer seen as a project or a one-off initiative. Instead, it has to be on-going and improve continuously. Processes are easily streamlined through the new asset management framework. Motivating for funds for infrastructure renewal and/or for maintenance becomes simple if the asset management framework is in place.

### **3.13 Conclusion**

Data collection method utilized was in terms of case studies from different railway organisations. The case study method was opted for as it is the one that can ensure consistency in collecting data from different countries. Transnet has a number of approaches with its current maintenance strategies. In Transnet, the current maintenance strategies utilised are the baseline routine maintenance strategy and condition based maintenance strategy. The Transnet maintenance policies, processes, procedures, standards and guidelines form the basis of the current maintenance approach. Data collected regarding condition of the track shows that the tonnages are having an effect on the quality of the track. Transnet responded by initiating the Roadmap to Safety Project where improvement in maintenance was one of the project deliverables. Workshops were held around the various operational areas

within Transnet Freight Rail were over 200 employees took part. The aim was to diagnose the real maintenance related challenges starting from planning, software issues, competency, organisational structures and execution. The findings from these workshops were accompanied by intervention proposals that were benchmarked against the project partners of DB from Germany. These findings after the assessment resulted in the four interventions to order to improve maintenance. Those interventions were as follows: Improvement of fault management, SAP usage improvement, maintenance planning and maintenance compliance and supervision. SAP plant maintenance module and competency of employees to utilise SAP are central to all the other interventions. Just like Jovanovic (2014) stressed the importance of improving the ways of how track performance is monitored by applying reliable means for forecasting and scheduling, which are the key objectives of a railway maintenance management system (RMMS). Thus resulting in improvement of track maintenance costs allocations for cost effective maintenance practices.

In terms maintenance strategies of other railway organisations around the world, case studies were taken from the European countries as their material was readily available and well structured. According to a research done by Caetano and Teixeira (2013), the case study findings of Lisbon-Porto line highlights the importance of timely maintenance and renewal of the track with adequate budget. It shows how budget limitations influence the unavailability of the track due to track failures. Another important finding highlighted by Caetano and Teixeira (2013) is that data analysis of ultrasonic inspections found that 52% of rail fatigue defects is a consequence of aluminothermic welding faults. On the European Track Research Project called Innotrack, majority of track problems being reported by infrastructure managers were listed. Bad track geometry, rail cracks and rail fatigue, and switch and crossing wear were the first three highly reported defects. In another case study for comparing the maintenance strategies and maturity of Serbia and Italy, Bozovic and Jovanovic (2014) discovered that some common challenges which were identified were as follows:

- Accessing critical data [asset inventory, condition measurements, infrastructure exploitation, maps, maintenance and renewal (M&R) work history, maintenance and renewal (M&R) policies] and interface with the current information technology (IT) environments and user competency, and

- Interface with the legacy M&R practices and procedures.

Furthermore, Bozovic and Jovanovic (2014) highlighted that although data was available already in the In.Rete 2000 computer system for the Italian case study, the data was not reliable and it had to be cleaned first before migration into the railway maintenance management system (RMMS). The key aim of an RMMS is changing the current maintenance management (MM) practice from primarily corrective, prescriptive, and cycle based to maintenance that is preventive, predictive, and condition based. In the Serbian case, Bozovic and Jovanovic (2014) mentioned that no data was transferable as little data existed. Available data was not in a combined arrangement as there was no central information system (e.g., EAM). The most insightful statement from Bozovic and Jovanovic (2014) was that for enhancement of railway infrastructure maintenance management and elimination of failure risks, the best solution the planning of maintenance in a condition-based manner, by determining whether, when, where and how to take action, depending completely on the state of the asset and its observed (measured) change over a certain period. This eradicates premature preventive and/or overdue corrective (after failure event) interventions and promotes enhanced plans for maintenance and renewal work. The Swedish case study as presented by Famurewa et al (2015) emphasised the importance of using a combination of risk assessment and a system of maintenance performance measurement in analysing data that will assist in maintenance decision making. Furthermore, Famurewa et al. (2015) mentioned that during maintenance analysis, the risk of failure has to be the key driver of maintenance decisions instead of failure itself. This is a very different approach from the often reactive approaches that are used by most railway infrastructure owners in maintaining some of their assets. As Gräbe and Van der Westhuizen (2013) already mentioned that the advantages of progressing from reactive or corrective maintenance to condition based maintenance, results in increased effectiveness, as well as a decrease in maintenance costs. Another important point that was highlighted by Famurewa et al. (2015) was that data collected should be converted into information and knowledge base that will facilitate decision making and constant improvement. This is an important topic since in the Serbian case study it shows that too much data which was not reliable and was scattered all over did not help in decision making.

In a case study of Track Strategy Project of the Austrian Federal Railways, one of Veit's (2013) findings regarding track maintenance was that minimum maintenance has an adverse effect on the track service life and is not recommended, as previously mentioned by Caetano and Teixeira (2013). Furthermore, with regards to findings for points and crossings, Veit (2013) emphasised that subgrade improvements at points and crossings are more critical than in plain track as points and crossings have lower permissible tolerances that make them vulnerable to low subgrade quality. Identifying and eradicating causes of poor subgrade should be prioritised rather than eliminating the effects. The other important findings by Veit (2013) were that, with regards to track, points and crossings, high quality track standards at the outset are the key to success; and another point is that combining mechanical track maintenance (e.g. tamping) and rail grinding in one track possession period is very economical. This integrated maintenance will assist in improving service offering to freight and passenger clients due to reduced time for track possession. Regarding track maintenance costs allocations, for cost effective maintenance practices, it has already been mentioned that Jovanovic (2014) stressed the importance of improving the ways of how track performance is monitored by applying reliable means for forecasting and scheduling, which are the key objectives of a railway maintenance management system (RMMS). Shah et al. (2014) mentioned the importance of prioritizing geotechnical assets as poor management and maintenance of geotechnical assets escalate the total life cycle costs of the infrastructure assets. In the United States, higher demands also contribute to the ever increasing infrastructure budget for maintenance.

Network Rail's case study as presented by Edwards (2012) was more about the asset management approach in railway maintenance. Performance monitoring, capability and maturity of asset management were identified as important outputs in asset management. The six key areas that were identified as important inputs in asset management are as follows:

- Asset management strategy and planning
- Whole life cost justification
- Lifecycle delivery
- Asset knowledge
- Organization and people

- Risk and review

Edwards (2012) acknowledged that the activities of the above six areas must be aligned with the organisation's business strategy. The 'line of sight' should be achieved progressively by starting with asset management policy creation, followed by strategy formulation and then concluding with front line activities. Furthermore, Edwards (2012) highlighted that although the asset management plan is important it should not disconnect with the day to day activities of the organisation. Both the case studies of Railcorp and London Underground base their success in proper asset management to the implementation of PAS 55 which was spearheaded by their respective leadership. From their cases it is important to note that risk assessments and decision making based on solid set of data were paramount in the successful implementation of day to day activities of asset management. According to Gräbe and Van der Westhuizen (2013), in Transnet Freight Rail, most tamping requirements on a network level are routine based. In the SADC region, the maintenance strategy is mostly corrective maintenance based on outcomes from routine inspections. With some other track components like rails, preventive maintenance is practiced through rail replacements. The results of ultrasonic measuring car trigger the renewal of rails as it shows the fatigue cracks and other railway defects. When there are subsurface drainage problems in tracks, the design is only modified when the problem starts to affect the subgrade to lower the water table. Another approach from Transnet freight rail's perspective according to Rothman (2004) is to apply condition assessments technologies when planning for track maintenance. The interface agreements that Transnet has with other local and foreign operators, require that the same maintenance specifications be utilised for both infrastructure components like railway track and other mechanical railway assets like rolling stock.



## **Chapter 4: Research Findings**

### **4.1 Introduction**

In this chapter, literature review findings and the findings from the case studies; chapter 1, chapter 2 and chapter 3, are discussed. The aim of this analysis is to compare different maintenance approaches from the literature reviews and case studies and select the best practices that can be adopted. Maintenance strategies from different railway track asset owners will be compared against these best practices from the literature reviews and case studies for continuous improvement.

### **4.2 Research Findings Discussions**

The statistics in figure 3 and figure 4 in clauses 1.2.3 and 1.2.5 have shown that there is an increase in railway business for both passengers and freight in South Africa and Europe. The challenge is to provide a reliable, safe and cost effective railway system to the public and governments around the world for economic prosperity. The uncertainty of climate change and contingency planning for such weather changes need to be considered as well.

#### **4.2.1 Maintenance Strategies**

Maintenance is a crucial element of a sustainable railway system. Track maintenance is more critical as its failure can lead to derailments leading to huge financial losses, company closures, fatalities, negative publicity and even litigation and criminal charges. The incidents mentioned can also lead to the failure to obtain the operating licence from the regulators if the railway asset owner is also a railway operator. As mentioned before in the literature review by Profillidis (2012), the railway track is the most critical in terms of safety, influence on maintenance costs, availability and reliability of the train service. Rail is the most expensive element of the track structure. Therefore, the track maintenance strategy must be a foundation and set the tone for the entire railway maintenance management system. The new developments of the new asset management standard ISO 55000 are worth looking at as they provide a holistic approach of how high value assets critical to the operations of the organisations should be managed. Network Rail's case study as presented by Edwards (2012) was more about the asset management approach in railway maintenance. The findings in this document will be based on the application of the



elements of the PAS 55 / ISO 55000 by Network Rail as a benchmark for the future approach of track maintenance and railway maintenance in general. The other literature reviewed relating to maintenance approaches are simply subsets of the various elements within the broader asset management system of PAS 55 / ISO 55000.

Some Railway Track Asset Owners currently are structured in a combination of maintenance approaches that covers preventative and reactive type of maintenance set-up depending on the type of work that is executed. In case of Transnet, there was emphasis on improving the situation by leaning more towards the preventative maintenance strategy through the Roadmap to Safety project that was highlighted in the previous chapter. As the volumes in Transnet keep on increasing annually, the challenge from Transnet will be the rolling out of Roadmap to safety interventions nationally in time to cater for increasing tonnages and volumes before the track structure reach its last stage of deterioration caused by primitive maintenance philosophies. From an operational point of view, Famurewa et al. (2015) presented a Swedish model for maintenance in a case study, which has performance measures, and tactical approaches that can serve as a benchmark to other Railway Track Asset Owners. Even though the ISO 55 000 advocates that there should be an asset management policy in organisations, most organisations that are continuously improving their maintenance approaches focus on data collection and analysis without a formalised written maintenance policy in place. The majority of existing organisational policies covers the entire organisation in terms of scope rather than functional departments of the organisation.

#### **4.2.2 Approach**

##### **Data: Collection, Analysis and Decision Making**

As already mentioned by Lloyd (2012) in Chapter 2 literature review, one of the key battlegrounds in organisations on the lower rungs of the asset management maturity scale is information and data sharing. According to Lloyd (2012), asset management decisions feed on detailed data on condition, resources, demand and performance. A Serbian case study conducted by Bozovic and Jovanovic (2014) discovered that data collection was a challenge as data available was spread across different departments, regional offices (of various departments), and across several individuals.

In literature review, Veit (2012) from Graz University of Technology mentioned that analysing the trends of all track data allows for forecasting the future maintenance demand. In Portuguese Railways: Lisbon – Porto Case Study conducted by Caetano and Teixeira (2013), past data utilised was from track geometry, ultrasonic, and visual inspections of the Lisbon-Porto line, in order to describe the deterioration models in the last ten years (from 2001–2010). This approach is supported by Famurewa et al. (2015) while conducting the Swedish Rail Case Study as he indicated the importance of evaluating the performance of past maintenance activities and resolutions by means of indicators in order to meet the requirements in Table 15.

### **Computerised Maintenance Management System**

For maintenance strategy to be planned and executed optimally, Haider (2017) in Chapter 2 highlighted the following three major roles in terms of information systems. Firstly, information systems are utilised in collection, storage, and analysis of information spanning asset lifecycle processes. Secondly, information systems provide decision support capabilities through the analytic conclusions arrived at from analysis of data. Thirdly, information systems provide for asset management functional integration.

In Chapter 3 case studies, Transnet utilises SAP and it is not fully utilised by personnel due to competency issues. Another challenge is the capturing of infrastructure assets on SAP that does not include all the existing infrastructure components. When comparing the Italian and Serbian case studies, the differences were that for the Serbian case study there was no central information system where asset data was stored, thus the data was scattered in different departments. For the Italian case study, main data storage platform already existed in the In.Rete 2000 system, which was later improved to Infra Manager system. Infra Manager system's primary features consisted of (1) combining of diagnosed data with the In.Rete 2000 system data; (2) establishment of scenarios for enhanced maintenance and renewal scheduling in agreement with infrastructure degree of decline; (3) presentation of predictive algorithms for decreasing the quantity of compulsory corrective maintenance; and (4) observing maintenance and renewal performance.

## **Asset Management Policy**

Transnet and other Railway Track Asset Owners in this research (except Network Rail) currently, do not have an asset management policy but they have historical standards, procedures, processes and guidelines for maintenance of the infrastructure. The challenge with the historical approach is that the departments are working in silos. There is no sharing of information and the specialists do not know what the other department is doing in order to maximise the cost-effectiveness, safety and reliability of the track components. England (2014) mentioned that Network Rail's asset management policy provides a structure and document hierarchy that is utilised to distribute the overall output and funding specification, into both an effective asset management plan and the related interventions on applicable assets.

## **Asset Management Strategy**

Network Rail's asset management strategy emphasised the link between business strategy and asset management strategy and planning. The current strategy in Transnet is the maintenance strategy that is routine preventative maintenance. Transnet currently is not structured to maximise the full potential of analysed data through software that will enhance maintenance lifecycle of the railway track components. As per the findings of Roadmap to Safety project, there is a limited number of SAP users and the need for improvement in SAP competency levels. Most of the literature regarding track maintenance highlights track geometry as one of the most critical parameters to measure, it is no surprise that in the case studies of different railway organisations, the tamping operation, whose task is to adjust the longitudinal profile, the cross level, and the alignment of the track is the most regular activity for maintenance. As mentioned in the previous chapter of literature review that according to Profillidis (2012), geometrical parameters evolve much faster than mechanical properties by 5 to 15 times. Profillidis (2012), further referred to International Union of Railways (UIC) group 4, which mentioned that for railway line with average traffic of 20 000 to 40 000 tons per day, maintenance of track geometry by tamping operations will be done after 40 to 50 million tons, while rail (i.e. mechanical degradation) replacement can be done after approximately 500 to 600 million tons.

Even though there is move towards slab track designs for new high-speed lines, the existing ballasted track can be modified to increase track stiffness by specifying soft rail pads, under sleeper pads, under ballast mats or stabilizing a certain thickness of the substructure with one of the following stabilizers: bitumen, portland cement, lime and fly ash. Transnet's ballasted railway track can benefit a lot by introducing the under sleeper pads and under ballast mats to reduce the dynamic loads on the railway track. Ferreira and Pita (2013) mentioned that the track dynamically improves with these solutions. The problem of differential settlement because of varying composition of subgrade materials causes track geometry deterioration. The existing track subgrades where there is no stabilization will mostly require tamping operation to solve the differential settlement issue. From this, it can be deduced that most track maintainers undertake tamping operations because dynamic train loads traverse on varying subgrade material with different track stiffness. Problem soils at Transnet are found in different areas and needs solutions that are applicable to the type of soil material in that area. It is not always possible to solve subgrade material issues as it takes time to undertake those repairs which impacts the train operations negatively. Therefore tamping is very popular in Transnet for restoring track geometry issues caused by differential settlement. The challenge is to strike a balance between total track rehabilitation and regular tamping by analysing the cost implications of the decision that is taken. Table 8 clearly shows that as Transnet is leaning more towards corrective maintenance, the cost of maintenance is more as compared to preventative maintenance. In Transnet's case, when the budget is limited, the input of corrective maintenance is more dependent on visual inspections feedback and reports than on on-track machines outputs that can provide data of defects much earlier, thus saving on corrective maintenance.

Guler (2013) and Veit (2007) advocated for the importance of taking decisions based on sound data. The Serbian and Italian case study and other railway lines demonstrated the importance of credible data. The finding is that data is collected and stored in different IT systems for the same organisation, the quality of the data and its credibility is still a challenge. Guler (2013) proposed a series of inputs parameters for decision making in track maintenance planning, these parameters covered from renewal of ballast, sleepers, rails or fastenings, rail grinding and lubrication, tamping,

and general maintenance and spot maintenance. In case studies that were analysed, even though the IT system was designed for a specific railway track maintainer, not all parameters for decision making were covered in the data that was available. The scope of data collection was rather skewed towards certain track components like rail condition for example. When considering maintenance practices within Transnet, the track component which tends to have the least data during maintenance is the subgrade due to the non-destructive technology which is still in its infancy stage compared to other non-destructive testing methods for other components like rail and the track geometry. The trending analysis using gathered data is lacking at strategic level from the case studies conducted.

Although Veit (2012) highlighted that the trends analysis of all track data allows forecasting the future maintenance demand, the reality is that in case studies that were considered, developing economies (Serbian Railways and Transnet in South Africa), routine based and corrective maintenance are still the order of the day (see Transnet study in clause 3.2.1 and Serbian Railways case study in clause 3.2.7.2). In figure 12, Tzanakakis (2013) depicted the topics that are included in the conversion from the past strategy to future maintenance strategy. Tzanakakis (2013) further explains that maintenance strategy can be defined as the best fitting combination of maintenance categories, which applies a balanced combination of preventive, corrective, detective and adaptive tasks, allowing a perfect balance between maintenance costs and availability/reliability of the infrastructure. The two concepts from Tzanakakis (2013) are still a challenge to almost all the railways sampled in these case studies.

At a strategic level, expert judgement is mostly relied on within the case studies conducted. In Railcorp case study, Wallsgrove (2012), as cited by Lloyd (2012) highlighted that asset management is more about repeatable, auditable decisions, following agreed lines of analysis, backed up by data and models. Furthermore, Wallsgrove (2012) discovered that in Railcorp, an observation that was made by asset management champions was that chief engineers who had a lot of experience were given the accountability of making safety critical decisions. The asset management champions believed that this worked against good asset management practice because how decisions were made was not spelled out and there was no explicit or

implicit cost-benefit trade off. As such, UIC's document called "*Guideline for the Application of Asset Management in Railway Infrastructure Organizations*", places greater emphasis on evidence-based decision making, using knowledge of how assets degrade and fail to optimise maintenance and renewal interventions.

Maintenance costs pressure and railway accidents due to maintenance failures caused regulators in the UK to put pressure on the British Standards Institute to formulate a standard for asset management. Then PAS 55 was produced. PAS 55 is a Publicly Available Specification, which enhances the manner in which physical assets are being managed. PAS 55 was written by the British Standards Institute in 2004, and then revised in 2008. According to Woodhouse (2014), organisations involved in the development of the PAS 55 specification were The Institute of Asset Managers and other 49 organisations from 15 industries in 10 countries. The creation of this specification was as a result of responding to industry and regulator request for an Asset Management Standard. Due to wide adoption of PAS 55 by industry stakeholders, and after consultation with industry and professional bodies globally, the PAS 55 specification was presented before the International Standards Organisation in 2009 as the foundation for a new ISO standard for asset management. The approval was granted and that led to the development of ISO 55000 family of standards over the last 3 years with 31 participating countries.

In the case studies, Network Rail is the only organisation which actively sought to adopt the asset management principles because of their local regulatory environment, in this case, Office of Rail Regulation (ORR). According to Edwards (2012), as cited by Lloyds (2012), an asset management framework review was carried out by the Independent Reporter of Asset Management, whose role was to examine Network Rail's capabilities in asset management and to provide the Office of Rail Regulation (ORR) and Network Rail with a level of assurance that the tools, processes and asset information used to underpin Network Rail's strategic business plan are fit for purpose. Another role of the Reporter was to ensure that Network Rail complies with asset management requirements of licence conditions. The main six areas of performance monitoring, capability and maturity of asset management in six areas were as follows:

- Asset management strategy and planning
- Whole life cost justification



- Lifecycle delivery
- Asset knowledge
- Organization and people
- Risk and review

One of the results of the transformation programme was to restructure the company around an asset management delivery model. This was designed to advance asset management performance by bringing into line maintenance routes with route asset management teams to allow the development of integrated route asset management plans. Furthermore, Edwards (2012), as cited by Lloyds (2012) illustrated the fact that Network Rail used the road map to establish an asset management improvement plan for developing its asset management capabilities over the longer term as shown in its 2011 asset management policy document (Network Rail, 2012a). The company plan in its fullness includes the following from policy creation to execution in the following progressive order:

- Asset management policy
- Asset management strategy
- Asset policies
- Route asset and route delivery plans
- Work execution

Edwards (2012), as cited by Lloyds (2012), highlights that asset management is now regarded as integral to Network Rail's ability to rise to the challenges it faces, namely:

- Continuing to achieve significant efficiency savings.
- Securing future funding in a harsh economic climate.
- Developing and implementing plans to improve value for money of the rail network.
- Accommodating high traffic growth.
- Taking the lead role in developing long term national rail plans, including involvement in planning the high-speed rail network.
- Improving its ability to deliver significant investment to the rail network with reduced disruption to train services.



From the above Network Rail case study and other maintenance strategies brought forward by different authors, the most holistic approach of maintaining the track structure and other assets influencing its deterioration is the asset management strategy. Some maintenance strategies like the RCM and RBM are sub components of the overall maintenance management strategy within asset management. Within the RCM, you can still get the condition based maintenance strategy, which is the most preferred approach for cost effectiveness and an increase in assets reliability.



## Chapter 5: Conclusion and Recommendations

Maintenance of the track requires a systems approach that will factor in railway infrastructure, rolling stock and train control or operations. This systems approach was depicted by Famurewa et al (2015) in Table 15 when introducing the Synthesised performance system during the Swedish case study. Sharing of information for planning and decision making is of paramount importance for these departments. This was highlighted by Lloyd (2012) in Chapter 2 when he mentioned that one of the key battlegrounds in organisations on the lower rungs of the asset management maturity scale is information and data sharing. Working in silos is discouraged as it can hamper the efforts of maintaining the track assets optimally with the desired results. As different companies have approaches that differ when doing track maintenance, the most important factors are the company strategy with regards to their asset-centric business. The asset-centric model was introduced by Gräbe and Van der Westhuizen (2013) in Chapter 2, whereby operations and maintenance are integrated elements of a system and need to be managed as such, as it was illustrated in Figure 14. Maintenance should not only be viewed as a cost, but the value it brings into the organisation in enabling track availability, reliability and safety in a cost effective manner. When that track is not available, how many trains are cancelled and how much revenue is lost? This factor was highlighted by one of the findings for the case study of Lisbon-Porto line done by Caetano and Teixeira (2013), where the importance of timely maintenance and renewal of the track with adequate budget was emphasised. The findings showed how budget limitations influence the unavailability of the track due to track failures.

The asset management philosophy using PAS 55 or ISO 55000 should be adopted in order to see the benefits of a comprehensive approach to maintenance management, starting from policy creation, strategic planning and operational execution. Compliance with the regulatory requirements of Railway Safety Regulator will be easier as the lifecycle approach to asset maintenance will be realised. Clause 4.5.2 of SANS 3000-1: 2016 Edition 3, requires that elements of life cycle phases should be taken into account when managing assets. To support this view, on the Network Rail case study, Edward (2012) acknowledged that most aspects of asset management are not new; they are integrated activities within six areas that asset management is seeking to

achieve. All the activities in these six areas must be aligned with the overall business strategy for ensuring that funds spent on the assets are contributing to the overall goals of the business. This overall process from policy creation and strategy formulation down to lifecycle delivery activities is called the 'line of sight'. If the organisation is not ready for such a radical change, the basics of having an information system with registered assets should be there. Case studies from Transnet in South Africa and Serbian Railways highlighted the challenges that can be expected when asset data is not properly managed on a chosen computerised maintenance management system. Condition-based maintenance should be a preferred approach rather than corrective maintenance. RCM can assist organisations in selecting the best maintenance approach for an asset. Risk based maintenance approach should also be factored in to concentrate maintenance activities for high risk assets first before you consider lower risk ones. Methodologies like FMECA and FMEA can be applied for the risk based approach. For track maintenance, Guler (2013) provides a perfect example of the data that should be collected from various track components to serve as an input in risk assessments. Data analysis and trending should take centre stage in these approaches.

In the case studies conducted, Transnet should implement the recommendations of the Roadmap to Safety project in their entirety as the beginning of the changing approach in track maintenance and the overall infrastructure maintenance where topics such as fault management, SAP utilization planning and competency are improved upon. Through the continuous improvement process, other strategies that can be adopted at an operational and tactical phase are the approaches as presented by Famurewa et al. (2015) in a Swedish Rail case study which produced a paper titled *"Maintenance analysis for continuous improvement of railway infrastructure performance"*. Railway Track Asset Owners can benefit from the approach of Famurewa et al. (2015) as he emphasised that during maintenance analysis, the risk of failure has to be the key driver of maintenance decisions instead of failure itself. Famurewa et al. (2015) added by saying that failure itself impacts negatively on operation, economics and safety, therefore it should be prioritised. At the strategic level, the track asset maintenance strategy can be produced by Railway Track Asset Owners in order to prepare the track maintenance plan. This was supported by

Tzanakakis (2013), who noted that maintenance planning is only linked to renewal activities and preventive / predictive maintenance, as it is not possible to plan for corrective maintenance ahead of time. Furthermore, Tzanakakis (2013) presented a transition from modern maintenance strategy where the approaches are empirical, pre-determined and extinguishing fires in most cases, to the future maintenance strategies where track behaviour analysis models and track quality behaviour models to improve reliability, availability, maintainability and safety as cost effectively as possible through a structured life cycle cost analysis, as is depicted in figures 12 and 13. The modern maintenance strategy as presented by Tzanakakis (2013) is more applicable to other track components like subgrades for Railway Track Asset Owners. If the subgrade maintenance is more corrective than preventive or predictive in a particular Railway Track Asset Owner Organisation, then high cost of maintenance can be expected. As highlighted in the literature review, according to Campbell and Reyes-Picknell (2006), as cited by Marten (2010), unplanned running repair work costs 50 percent more than planned and scheduled work and emergency work will cost three times as much.

Therefore corrective maintenance strategy, which mostly consists of emergency unplanned work, will not be sustainable for any railway track asset owner. Budget for implementation of asset renewal projects (Capitalised operational expenditure (copex) e.g. rail replacements) and expansion projects (Capital expenditure (capex) e.g. building of new railway track, new loops etc.) will be a challenge due to budgetary constraints as most of the budget will be committed to corrective maintenance activities.

For the overall improvement of the whole infrastructure network, a continuous improvement approach can enable Railway Track Asset Owners to emulate Network Rail's creation of asset management policy and strategy utilizing the PAS 55 framework. Railway Track Asset Owners can go on to prepare for ISO 55000 certification as it will be easier to implement if the solid foundation has been laid on at the strategic level through asset centred policy creation aligned to ISO 55000, now adopted by SABS as SANS 55000. This will enable the implementation of the asset management system to be seamless at tactical and operational level. Maintenance strategies that can be applicable in this regard area combination of reliability centred maintenance (RCM) and risk based maintenance (RBM) strategy. Finally, one of the

points proposed by Veit (2007) in the literature review is that in order to maximise the maintenance strategy, it is inappropriate to separate a capital works and renewal strategy from the maintenance strategy: optimisation can only be achieved with a single comprehensive strategy. Thus in this stage, as highlighted by Haider (2007) in Chapter 2 with regard to information systems for asset management, the bottom up approach for Railway Track Asset Owners will be feasible considering the level of maturity of the organisation's maintenance approach and its continuous improvement process.

Lastly, Table 8 clearly shows that early detection of faults by utilizing on-track machines, will eventually lead to cost effective maintenance instead of depending on traditional visual inspections where defects are detected late.



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## APPENDIX A: Research Questions Answered from Mini-Dissertation

### **RESEARCH QUESTIONS AND ANSWERS FROM MINI- DISSERTATION**

#### **1. *What are the maintenance trends and strategies applied globally and locally for maintaining the railway track infrastructure?***

According to a research done by Caetano and Teixeira (2013), the case study findings of Lisbon-Porto line highlights the importance of timely maintenance and renewal of the track with adequate budget. It shows how budget limitations influence the unavailability of the track due to track failures. Another important finding highlighted by Caetano and Teixeira (2013) is that data analysis of ultrasonic inspections found that 52% of rail fatigue defects is a consequence of aluminothermic welding faults.

Fleming (2006) as cited by Marten (2010) added by saying that RCM methods are more effective compared to other maintenance processes and methods. On the other view, Sakai (2010) discussed the risk based maintenance (RBM) strategy. In Transnet, the current maintenance strategies utilised are the baseline routine maintenance strategy and condition based maintenance strategy (reference required).

In terms maintenance strategies of other railway organisations around the world, case studies were taken from the European countries as their material was readily available and well structured.

Tzanakakis (2013), Profillidis (2012) and Veit (2010) presented different strategies of track maintenance for consideration.

In terms of holistic asset management, the ISO 55000 asset management system elements provide a framework and platform for asset management policy creation, formulation of asset management objectives and strategies and asset life cycle management plans.

The Transnet maintenance policies, processes, procedures, standards and guidelines form the basis of the current maintenance approach. Data collected regarding condition of the track shows that the tonnages are having an effect on the quality of the track. Transnet responded by initiating the Roadmap to Safety Project where improvement in maintenance was one of the project deliverables. Workshops were held around the various operational areas within Transnet Freight Rail where over 200 employees took part. The aim was to diagnose the real maintenance related challenges starting from planning, software issues, competency, organisational structures and execution. The findings from these workshops were accompanied by intervention proposals that were benchmarked against the project partners of DB from Germany. These findings after the assessment resulted in the four interventions to order to improve maintenance. Those interventions were as follows: Improvement of fault management, SAP usage improvement, maintenance planning and maintenance compliance and supervision. SAP plant maintenance module and competency of employees to



utilise SAP are central to all the other interventions. Just like Jovanovic (2014) stressed the importance of improving the ways of how track performance is monitored by applying reliable means for forecasting and scheduling, which are the key objectives of a railway maintenance management system (RMMS). Thus resulting in improvement of track maintenance costs allocations for cost effective maintenance practices.

In the case studies conducted, Transnet should implement the recommendations of the Roadmap to Safety project in their entirety as the beginning of the changing approach in track maintenance and the overall infrastructure maintenance where topics such as fault management, SAP utilization planning and competency are improved upon.

Through the continuous improvement process, other strategies that can be adopted at an operational and tactical phase are the approaches as presented by Famurewa et al. (2015) in a Swedish Rail case study which produced a paper on maintenance analysis for continuous improvement of railway infrastructure performance. Transnet (Railway Organisations) can benefit from the approach of Famurewa et al. (2015) as he emphasised that during maintenance analysis, the risk of failure has to be the key driver of maintenance decisions instead of failure itself. Famurewa et al. (2015) added by saying that failure itself impacts negatively on operation, economics and safety, therefore it should be prioritised. At the strategic level, the track asset maintenance strategy can be produced by Transnet (a Railway Organisation) in order to prepare the track maintenance plan. This was supported by Tzanakakis (2013) as he goes on to say that maintenance planning is only linked to renewal activities and preventive / predictive maintenance, as it is not possible to plan for corrective maintenance ahead of time. Furthermore, Tzanakakis (2013) presented a transition from modern maintenance strategy where the approaches are empirical, pre-determined and extinguishing fires in most cases, to the future maintenance strategies where track behaviour analysis models and track quality behaviour models to improve reliability, availability, maintainability and safety as cost effectively as possible through a structured life cycle cost analysis, as is depicted in figures 12 and 13. The modern maintenance strategy as presented by Tzanakakis (2013) above is more applicable to other track components like subgrades in Transnet (many railway organisations). If the subgrade maintenance is more corrective than preventive or predictive in Transnet (a railway organisation's maintenance strategy), then high cost of maintenance can be expected. As mentioned in the literature review, according to Campbell and Reyes-Picknell (2006), as cited by Marten (2010), unplanned running repair work costs 50 percent more than planned and scheduled work and emergency work will cost three times as much.

For the overall improvement of the whole infrastructure network, a continuous improvement approach can enable Transnet (other railway track asset owners) to

emulate Network Rail's creation of asset management policy and strategy utilizing the PAS 55 framework. Transnet (Railway track asset owners) can go on to prepare for ISO 55000 certification as it will be easier to implement if the solid foundation has been laid on the tactical and operational level of maintenance. Finally, one of the points proposed by Veit (2007) in the literature review is that in order to maximise the maintenance strategy, it is inappropriate to separate a capital works and renewal strategy from the maintenance strategy: optimisation can only be achieved with a single comprehensive strategy.

Thus in this stage, the bottom up approach for Transnet (a Railway track asset owner) will be feasible considering the level of maturity of the organisation's maintenance approach and its continuous improvement process.

## **2. Which maintenance strategy can maximise the asset life cycle of the railway track for international and local railway organisations?**

The improvement of the reliability and availability of track can also be realised with the application of the holistic asset management strategy.

Woodhouse (2013) as cited by Lloyd (2014) presented background information that led to the creation of PAS 55. PAS 55 then led to the creation of ISO 55000, where the asset management system elements were introduced in an internationally recognised standard. In terms of holistic asset management, the ISO 55000 asset management system elements provide a framework and platform for asset management policy creation, formulation of asset management objectives and strategies and asset life cycle management plans. Management plans should be aligned to the daily operation and control of life cycle activities (i.e. acquire/create, utilise, maintain/improve and renew/dispose).

Shah et al. (2014) mentioned the importance of prioritizing geotechnical assets as poor management and maintenance of geotechnical assets escalate the total life cycle costs of the infrastructure assets.

Network Rail's case study as presented by Edwards (2012) was more about the asset management approach in railway maintenance.

Performance monitoring, capability and maturity of asset management were identified as important outputs in asset management. The six key areas that were identified as important inputs in asset management are as follows:

- Asset management strategy and planning
- Whole life cost justification
- Life cycle delivery
- Asset knowledge
- Organization and people
- Risk and review

**3. What effect does different maintenance trends and strategies have on the reliability and availability of railway track and its related maintenance costs?**

Backlund and Akersten (2003) as cited by Marten (2010), Tzanakakis (2013) and Fleming (2006) as cited by Marten (2010), highlighted the importance of reliability centred maintenance.

The improvement of the reliability and availability of track can also be realised with the application of the holistic asset management strategy.

Maintenance should not only be viewed as a cost, but the value it brings into the organisation in enabling track availability, reliability and safety in a cost effective manner. When that track is not available, how many trains are cancelled and how much revenue is lost?

Furthermore, Tzanakakis (2013) presented a transition from modern maintenance strategy where the approaches are empirical, pre-determined and extinguishing fires in most cases, to the future maintenance strategies where track behaviour analysis models and track quality behaviour models to improve reliability, availability, maintainability and safety as cost effectively as possible through a structured life cycle cost analysis, as is depicted in figures 12 and 13.

According to a research done by Caetano and Teixeira (2013), the case study findings of Lisbon-Porto line highlights the importance of timely maintenance and renewal of the track with adequate budget. It shows how budget limitations influence the unavailability of the track due to track failures.

Calçada et al (2012) highlighted the importance of preventative maintenance on the track as it takes a bigger portion of maintenance management costs, besides its importance on safety and comfort.

As Gräbe and Van der Westhuizen (2013) already mentioned that the advantages of progressing from reactive or corrective maintenance to condition based maintenance, results in increased effectiveness, as well as a decrease in maintenance costs.

Regarding track maintenance costs allocations, for cost effective maintenance practices, Jovanovic (2014) stressed the importance of improving the ways of how track performance is monitored by applying reliable means for forecasting and scheduling, which are the key objectives of a railway maintenance management system (RMMS).

Shah et al. (2014) mentioned the importance of prioritizing geotechnical assets as poor management and maintenance of geotechnical assets escalate the total life

cycle costs of the infrastructure assets. In the United States, higher demands also contribute to the ever increasing infrastructure budget for maintenance.

Maintenance should not only be viewed as a cost, but the value it brings into the organisation in enabling track availability, reliability and safety in a cost effective manner.

Furthermore, Tzanakakis (2013) presented a transition from modern maintenance strategy where the approaches are empirical, pre-determined and extinguishing fires in most cases, to the future maintenance strategies where track behaviour analysis models and track quality behaviour models to improve reliability, availability, maintainability and safety as cost effectively as possible through a structured life cycle cost analysis, as is depicted in figures 12 and 13.

If the subgrade maintenance is more corrective than preventive or predictive in Transnet (a Railway track asset owner's maintenance strategy), then high cost of maintenance can be expected. As mentioned in the literature review, according to Campbell and Reyes-Picknell (2006), as cited by Marten (2010), unplanned running repair work costs 50 percent more than planned and scheduled work and emergency work will cost three times as much.

**4. Which is the most suitable maintenance strategy that addresses the challenges of reliability, availability and related maintenance costs of the railway track?**

Calçada et al (2012) highlighted the importance of preventative maintenance on the track as it takes a bigger portion of maintenance management costs, besides its importance on safety and comfort.

As Gräbe and Van der Westhuizen (2013) already mentioned that the advantages of progressing from reactive or corrective maintenance to condition based maintenance, results in increased effectiveness, as well as a decrease in maintenance costs.

Regarding track maintenance costs allocations for cost effective maintenance practices, Jovanovic (2014) stressed the importance of improving the ways of how track performance is monitored by applying reliable means for forecasting and scheduling, which are the key objectives of a railway maintenance management system (RMMS).

Shah et al. (2014) mentioned the importance of prioritizing geotechnical assets as poor management and maintenance of geotechnical assets escalate the total life cycle costs of the infrastructure assets. In the United States, higher demands also contribute to the ever increasing infrastructure budget for maintenance.

Maintenance should not only be viewed as a cost, but the value it brings into the organisation in enabling track availability, reliability and safety in a cost effective manner.

Furthermore, Tzanakakis (2013) presented a transition from modern maintenance strategy where the approaches are empirical, pre-determined and extinguishing fires in most cases, to the future maintenance strategies. This is where track behaviour analysis models and track quality behaviour models are utilised to improve reliability, availability, maintainability and safety as cost effectively as possible through a structured life cycle cost analysis, as it is depicted in figures 12 and 13.

If the subgrade maintenance is more corrective than preventive or predictive in Transnet (a Railway track asset owner's maintenance strategy), then high cost of maintenance can be expected. As mentioned in the literature review, according to Campbell and Reyes-Picknell (2006), as cited by Marten (2010), unplanned running repair work costs 50 percent more than planned and scheduled work and emergency work will cost three times as much.

