



AN INVESTIGATION INTO THE CAUSES OF FAILURES IN RAILWAY INFRASTRUCTURE AT TRANSNET FREIGHT RAIL – A CASE OF THE STEEL AND CEMENT BUSINESS UNIT

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ABSTRACT

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The purpose of the study was to investigate the causes of railway infrastructure failures in the case of Transnet Freight Rail's Steel and Cement business unit and suggest methods to increase the reliability of the business unit's railway infrastructure and recommend policies to increase the reliability of the railway infrastructure. A reliable railway infrastructure will grow the market share of the business unit, reduce operating costs, grow the economy of South Africa, create employment, and increase the revenue of the business unit. A quantitative approach was used to conduct the research and questionnaires were distributed to a population of 1048 employees that work for the business unit with the participants chosen based on their railway infrastructure experience and railway exposure. The study revealed that extreme weather conditions, ageing railway infrastructure, vegetation, lack of maintenance, other Transnet departments, poor railway infrastructure maintenance, theft and vandalism, are the major causes of railway infrastructure failures in the business unit. The research made a number of recommendations including that the business unit develop a lifecycle management program for its ageing infrastructure and introduce skills transfer programs in place. Railway maintenance was suggested as being a key performance measure.

Contribution/Originality: The paper's primary contribution determined that management needs to improve on asset protection and security measures and controls, as neglected these can lead to substantial financial forfeiture and loss of life. The study identified the inadequacy of current security measures and makes a number of suggestions to alleviate loss.

1. INTRODUCTION

Transnet Freight Rail's Steel and Cement business unit needs a reliable, affordable, safe and available railway infrastructure to meet their goal of becoming one of the top five railway companies in the world and to deliver integrated, efficient, safe, cost-effective and reliable services to South Africa. The railway infrastructure is made up of the track structures, train authorization assets, overhead traction equipment, culverts, bridges and telecommunication equipment, and the railway maintenance depot must provide a railway infrastructure that is 100% available to allow the train operators to run trains safely. The business unit (BU) has three maintenance depots that ensure that the maintenance goals and objectives of the BU are achieved. The railway network in the

BU is old, some equipment was installed in the seventies and are prone to failures. Each depot has five different departments that are maintaining the different infrastructures in the entire BU.

The railway infrastructure that the BU is using plays an important role when it comes to profit and revenue as failures have a negative impact on the BU's performance and revenue. A railway infrastructure that is unreliable, or that is failing, can cause rail-related incidents that can lead to fatalities, environmental damages, and can also increase the operating budget of the BU. The BU has lost considerable funds, some employees have also lost their lives, and the BU has also paid a number of civil claims due to the failures on its railway infrastructure.

1.1. The Research Problem

The railway infrastructure failures of TFR's SAC BU have increased, thus impacting negatively on the trains that the BU runs. Measures to address infrastructure failures have not been put in place by the BU to reduce or mitigate the railway infrastructure failures. The railway network failures have also increased operating costs and some of those failures have caused major derailments and rail-related incidents. The study seeks to determine the root causes and the contributing factors of those railway infrastructure failures in the BU and come up with ways to reduce the failures.

1.2. Research Questions

- What causes Transnet Freight Rail's SAC BU's railway infrastructure (perway, signal, electrical technical support and telecommunication) to fail?
- What are the employee's perceptions on the causes of railway infrastructure failures?
- What can be done to reduce the number of railway infrastructure failures in TFR's SAC BU?
- What policies can the SAC business unit recommend to improve the reliability of its railway infrastructure?

1.3. Academic Significance of the Study

Till now, TFR has not done any detailed research on what is causing its railway infrastructure to fail. This research will focus on the root causes of those failures and also consider factors that cause the railway infrastructure to fail. Recommendations will be made and those recommendations will help the SAC BU to treat the root causes and not the symptoms as it has traditionally been done. The research will also assist the technicians, electricians, track masters and other technical people understand and know the causes of the railway network failures. TFR's other business units will utilise the research to address their railway infrastructure failures and other railway companies can utilise the recommendations to address the railway infrastructure problems that they have. The business unit has a role to play as the country's economic driver and the business unit can only do that if the railway infrastructure is reliable.

2. LITERATURE REVIEW

The section will cover a number of published documents on the causes of railway infrastructure failures, causes of infrastructure failures, what published documents recommended on ways to minimize the perway, train authorisation, technical support, telecommunication and electrical components. The SAC BU maintenance depots have a purpose to provide a business centred and world-class maintenance service which the BU needs to ensure maximum infrastructure equipment availability and performance at an optimum cost. TFR's SAC BU consists of three railway maintenance depots with each depot having five departments and each department has a maintenance manager.

2.1. Perway

The subsection will cover the breakdown of the main perway components that consist of rails, ballast, sleepers and turnouts, an overview of the main perway components and the previous research that was conducted on the causes of perway failures. Berawi (2013) states that the components mentioned above are grouped into the superstructure and substructure.

2.1.1. Rail

Rails, being vital parts of the railway infrastructure and rail defects or failures represent a serious safety hazard that can lead to derailments leading to serious injuries. Bayissa and Dhanasekar (2012) advise that rail companies use rails to guide trains and the rails are subjected to severe contact stresses at the wheel-railhead interface. Train operators cannot run an effective railway if the perway department that is maintaining the rails is not providing a safe and reliable rail infrastructure. An unreliable or a defecting rail component can lead to derailments or train collisions and some railway employees across the globe have lost their lives due to rail-related incidents. Rails are not like other railway infrastructure components that can allow rail operators to run trains even when they are defective.

Berawi (2013) states that a track can degrade due to axle load, traffic speed, climate, track characteristics and topography. Berawi (2013) feel that the deterioration caused by speed is due to an increase by dynamic forces at high speeds and decreasing those at low speed and the axle load contributes to an increased rail wear and fatigue. Companies that haven't invested in technologies to assist them with monitoring the axle loading and speed will experience problems that will be due to track degradations. The BU has been experiencing deterioration-related failures, that has a negative effect on the running of trains and the defects can lead to a derailment.

Oslakovic *et al.* (2013) believe that tracks develop heat kinks causing track misalignments or buckle when they are exposed to high temperatures. Oslakovic *et al.* (2013) also advise that railway companies introduce speed restrictions to overcome the buckling and track misalignment and low temperatures cause the tracks to brittle increasing the risk of rail breaks. Snowfall causes damages to rail tracks, heavy rains also damage rail tracks and wind gusts damage rail tracks (Oslakovic *et al.*, 2013).

Bayissa and Dhanasekar (2012) state that railheads experience cracks that lead to partial or full rail breaks. Routine grinding and re-profiling are part of railway maintenance and proper maintenance of the wheel profile reduces the chances of rail breaks (Bayissa and Dhanasekar, 2012). Bayissa and Dhanasekar (2012) advise that some railway companies are using visual inspections; no-destructive testing technologies such as acoustic emission methods, magnetic field methods, radiography, eddy current techniques, thermal field methods, dyne penetrant and vibration-based 'global' methods are used by railway companies for damage identification and rail condition monitoring.

Anderson (2015) report that bad welds that are caused by poor quality work, wheel burns that are caused by poor train handling and rail wear normally due to age, causes squats defects on the rail tracks. Quality audits/inspections that are done after any rail welding activity, driver's task observations and effective rail lifecycle management can help reduce the number of squats-related defects. Heizer and Render (2011) believe that a successful quality strategy begins with an organizational culture that fosters quality, followed by an understanding of the principles of quality, and then engaging employees in the necessary activities to implement quality. The BU's project management teams can change the performance and the reliability of rails that are failing because of quality-related defects if they understand the principles of quality.

2.1.2. Ballasts

Hassankiadeh (2011) defines ballast as the select crushed granular material that rail constructors place as the top layer of the substructure in which the sleepers are embedded. Railway companies use the ballast to retail track

position, reduce the sleeper bearing pressure for the underlying material and provide drainage for water falling on the track. The BU is experiencing ballast defects, the defects are affecting the smooth running of trains and the BU is cancelling and delaying trains due to the ballast defects.

Berawi (2013) report that the ballast becomes degraded due to the repeated passage of trains and to very intense compression during wheel-track interactions. The degraded ballast combine with water and the ballast loses its primary function to support the track bed, as well as its drainage capability. This can be caused by poor maintenance inspections, poor maintenance, lack of maintenance and poor ballast quality. Degraded failures can be due to the shortage of technical people that are supposed to be doing the normal routine maintenance on ballast, the poor maintenance can also be due to the shortage of training on the current employees that are maintaining the components and the quality might also be the reason why railway companies experience ballast failures. Heizer and Render (2011) caution that poor quality affects the company's reputation, assets liability and global implications. Quality-related failures affects train operations, affects the reputation of the BU and maintainers must understand the implications of poor quality.

Hassankiadeh (2011) advise that environmental factors, freezing and thawing cause vibrations on sleepers, disturbing the support under the sleeper causing white powder to build up and contaminate the ballast. Regular inspections coupled with adherence to maintenance reduces the impact that environment, and high and low temperatures have on the performance of ballasts. Ballast fouling due to progressively contaminated fine-grained aggregate and metal dust fills the void space between ballast stones and fouling prevents the ballast from fulfilling its functions (Hassankiadeh, 2011). Companies are using advanced technologies like the Ground Penetration Radar to scan the ballast and identify the areas that affected by ballast fouling before the defecting ballast can affect other rail components (Hassankiadeh, 2011).

2.1.3. Sleepers

Hassankiadeh (2011) report that sleepers receive the load from the rail and distribute it to supporting ballast and the sleepers fail because of the number of trains that the BU is running on a daily basis. Choudhury (2011) states that railway companies use sleepers to hold the rails in correct alignment and gauge and sleepers also absorb impact and vibration. Choudhury (2011) advise that railway companies are using wooden sleepers, cast iron sleepers which are obsolete, steel sleepers and concrete sleepers. The BU is currently using wooden, concrete and steel sleepers and their unreliability has affected the smooth running of trains in the BU and that has led to derailments, high operational costs, train cancellations, train delays and loss of revenue.

Zakeri and Rezvani (2012) caution that railway sleepers have defects that are related to primary material, concrete, processing and unloading and these are the types of failures that can be prevented by production process monitoring. Zakeri and Rezvani (2012) also report that the type of transport and installation that railway companies use to transport and install sleepers can cause defects or sleepers. Heizer and Render (2011) advise that 85% of quality-related problems have to do with materials and processes and involving employees that are dealing with the sleepers from the designing process of the sleepers until the installation can help reduce the material-related failures. Zakeri and Rezvani (2012) believe that lack of maintenance can cause sleepers to have bending cracks and cutting cracks and railway companies that adhere to their routine maintenance and inspections have sleepers that are reliable. Zakeri and Rezvani (2012) maintain that sleeper maintenance that includes strict adherence to inspection cycles and defect detections has a significant role in the deterioration of sleepers and other rail components.

Hassankiadeh (2011) believes that tamping machine tines strike sleepers causing sleepers to have longitudinal splits and this is due to poor supervision and visibility during maintenance. Poor visibility can be due to shortages of supervisors to supervise the maintenance exercise or due to lack of training. Wrong chair screw sizes or over

tightening the chair screws cause damages on the concrete barriers and this can be due to lack of training or wrong material that the supply chain department has ordered.

2.1.4. Turnouts

Turnouts, being one of the vital components of the railway infrastructure and a turnout divide one track into two or three tracks and turnouts also allow trains to move from one track to another. [Hassankiadeh \(2011\)](#) advise that railway turnouts consist of switches, crossings, switchblades, stock rails, closure rails, sleepers, ballast and subgrade he also reports that a high percentage of railway infrastructure component failures occur on turnouts. Defective railway turnout affect the smooth running of trains and it can lead to derailments, train cancellation and train delays. [Hassankiadeh \(2011\)](#) maintain that railhead cracks are caused by ageing rail tracks and a proper lifecycle management can prevent age-related turnout failures. Poor rail manufacturing during procurement and improper seating of the rail has to do with quality inspection during installation as it could cause cracks in the longitudinal rail foot ([Hassankiadeh, 2011](#)). Quality assures must ensure that the rails that they are buying from suppliers meet all the minimum specifications to prevent longitudinal rail foot cracks and the project managers must also ensure that the turnouts are properly installed.

Cracked fish plates that are on turnouts are caused by the inadequate sleeper support and this is caused by derailments or poor installation of sleepers ([Hassankiadeh, 2011](#)). Project managers must ensure that all turnout sleepers are installed according to specifications to prevent fish plates from cracking. Maintenance of turnouts is essential and [Hassankiadeh \(2011\)](#) advise that poor lubrication of sliding chairs can cause the sliding table to rust because of the desiccated sliding chairs. Poor turnout maintenance has a big impact on the performance and the availability of turnouts. A defect in any of the components can delay trains, cancel trains or cause train derailments. Permanent way components can fail because of weather, lack of maintenance, theft and vandalism, ageing infrastructure, poor installation, poor material quality, other TFR departments or because of external parties.

The Railway Safety Regulator recommended that companies like Transnet recruit retired railway employees who will work as mentors to train young, inexperienced employees and it also recommended that railway companies extend the retirement age to 70 years. The recommendations can assist the BU to address the failures that the skills shortage is causing and training if skills shortage and lack of training is really a problem. The Human Resource department through its skills transfer programs, training and development can address the problem if it is something that is affecting the BU.

2.2. Signalling

The subsection will cover an overview of the train authorisation system's components and the breakdown of the main train authorisation components that consist of track circuits, signals, cables, interlocking, remote control, standby power supply, axle counters, CAS and switches/points. The researches that were done by previous researchers will form part of the subsection. The subsection will also look at the train authorisation main components that the three maintenance depots have.

The train authorisation system's most important objective is to provide a safe and reliable train authorisation system and a defective train authorisation can lead to accidents that can lead to fatalities and environmental disaster. [Bekele \(2015\)](#) caution that train authorisation managers must understand the overall emergent failure behaviour of the train authorisation system. The BU has analysed the raw data that is available and the recommendations that were made haven't improved the availability and the reliability of the train authorisation system in the BU. [Bekele \(2015\)](#) states that railway train authorisation systems have a low tolerance for accidents, because of potentially high numbers of injuries and deaths and the system's main objective is to achieve a high degree of safety. A defective detection circuit, signal or points machine can cause derailments, train cancellation, train collisions and also train delays. The BU's maintenance depots have to ensure that the train authorisation

system that the depots are providing is safe, affordable, reliable and available. Extreme weather condition, lack of maintenance, theft and vandalism, ageing infrastructure, weather, poor installation, poor maintenance, poor material quality, other internal departments and external parties caused the train authorisation system to fail.

2.2.1. Signals

The BU is currently using signals like; multi-aspect signals, mechanical signals, 3 position ground shunt signals, 3 aspect signals, 2 position ground shunt signals, searchlight signals, mechanical dwarf signals and hump signals. The figure shows that there is no standardisation in the BU which is a problem because the three maintenance depots cannot share lessons learned, skills and spares that the depots are using because the signal that the three depots are using are not the same. Some failures that the BU has on its signals are due to other railway components and other departments also affect the operation of the signals. The BU has to ensure that the maintenance plans are integrated in a way that one department's maintenance doesn't affect the other department's components.

2.2.2. Track Circuits

Track circuits are used by railway operators to detect the presence, the position of trains on the rail and train operations cannot run smoothly if there is a detection circuit failure. Track detection circuit failures can affect the operation of signals and points machines. There are different types of railway track circuits that railway companies are currently using today like, ML track circuits, AC track circuits, DC track circuits, Reed track circuits, Jeumont track circuits and Aster track circuits. The BU is currently using ML track circuits, DC track circuits, AC Track Circuits, Aster Track Circuits, Treadle Track Circuits, Reed track circuits and Jeumont track circuits with some those track circuits being operational for more than 30 years.

The South African Institution of Civil Engineers (2011) advise that education of maintenance infrastructure in South Africa has been limited and that resulted in infrastructure components like the railway track circuits failing. The maintenance that the current crop of technical people are doing to the old railway track circuits might be substandard due to the limited infrastructure maintenance education. Some of the old railway track circuits are due for replacement with the BU having reduced its capital expenditure, the tracks that are due for upgrades and replacements might also be contributing to the failures that the BU is having on its railway track circuits. The reliability and the availability of the BU's track circuits is not good, affecting the BU's performance because of the role that track circuits play in the operation of trains. The BU is cancelling and delaying trains daily because the current track circuits that the BU has are not reliable.

2.2.3. Cables

Signalling department uses signalling cables to supply its equipment like electrical points, signals, axle counters, wayside readers, relay rooms, track circuits and interlocking. The department and the BU cannot survive if the signalling cables that are supplying the signalling equipment are unreliable.

The Institution of Railway Signal Engineers (2014) maintain that ideally signal cable should be installed in some form of ducting to protect them from damage, theft and vandalism. Unprotected cables are vandalised daily because some installations do not meet that specification. It goes back to project management where the project managers have to make sure that risk assessments are conducted by the project team to assess the area where the BU is going to install new signalling cables and make sure that the specifications are adhered to. There are projects where the ducting is part of the specifications, but the contractors do not do that due to poor project management, poor project supervision and the incompetency of project managers.

The Institution of Railway Signal Engineers (2014) instructs that underground cable installations must be marked and not be bent. Due to ongoing construction and some maintenance, the BU damages its unmarked

underground signal cables because the maintenance teams cannot locate the unmarked underground signalling cables. Quality inspection, with project quality management, has to ensure that the installations meet the minimum requirements and project managers that do not know what they are doing will not accept underground cable installations that are not marked. The BU also has underground signalling cables that were installed more than 50 years ago and those cables have reached their lifespan and the signalling maintenance managers must ensure that a full condition assessment on the cables is done.

2.2.4. Interlocking

The failure rate on the interlocking that the BU might be higher because the units are old and the mean time to restore the system is also long because of the shortage of spares. A number of railway companies are now moving from the old type interlocking to new type electronic interlocking due to the absoluteness of the equipment. Heizer and Render (2011) believe that periodic examinations of assets are appropriate because the performances of assets change as assets move through their lifecycles and successful assets strategies require determining the best strategy for each asset based on its position in the lifecycle.

2.2.5. Standby Equipment

The signalling department uses standby power supplies to supply power its equipment when there are power failures. South Africa has been experiencing power shortages and power failures in the past few years and the BU cannot operate if the signalling department's standby power supply is not reliable. The BU is using a variety of standby power supplies in its signalling stations and some of the installations were done more than 10 years ago. The BU is cancelling and delaying trains due to power failures and the standby power supplies that are installed are supposed to take over when the main supply goes off and it is not the case in some instances.

2.2.6. Axle Counters

Railway Group Standard Catalogue (2009) defines axle counters as systems that train operators use to detect trains by mounting the equipment on the tracks, the equipment counts the number of axles entering and leaving a track section at each end, and the information is then evaluated to determine whether the track section is occupied or clear. This is one of the most important components in rail operations as a defective axle counter will delay trains, cancel trains and can also lead to train collisions. The BU is currently using a mixture of old axle counters and new axle counters and some of the old axle counters were installed more than 30 years ago. The business is currently using axle counters that are old with the AzS350U being the latest technology that the BU is using. The BU is struggling to buy the spares of other axle counters because the suppliers are no longer offering technical support to the BU and that might also affect the performance of the BU's axle counters.

2.2.7. Condition Assessment Systems

Railway companies use CAS to monitor and assess the condition of their rolling stocks. The performance of the BU's CAS is not satisfactory and the condition assessment's unreliability is affecting the operational performance of the BU and it is also putting the BU's rolling stock at a risk. The BU is currently using Vehicle Identification Systems to track and monitor its fleet, Hotboxes like HTK499, Spoornet hotboxes, Alstom AS02 hotboxes to monitor the hotboxes on trains, Dragging Equipment Detector to detect any foreign objects that train can drag, Derailed Wheel Detector to monitor derailed wheels on trains, Skew Bogie Detectors to detect if there are skew bogies on trains, Trackside Acoustic Detectors and Wheel Profile Monitors to monitor the profiles of wheels on trains.

2.2.8. Points Machines

Switch failures can significantly affect train operations and they can cause major disruptions that can lead to train collisions and train accidents. The BU is using 16 types of switches and standardisation is still a problem. The BU has two depots that are using 11 different types of switches which makes it difficult for the region to share knowledge, learnings and spares. *Ono et al. (2012)* advise that train authorisation systems have adopted microcomputers and other electronic devices in the recent years, yet circuit burnout, system failure and other lightning damage frequently occur in signalling systems because lightning surges easily damage the electronic devices. The BU's signalling department has introduced new technologies that are using microcontrollers and other electronic devices and the BU can do further investigation to check the effectiveness of the lightning protection if lightning is also one of the main causes of signalling failures in the BU.

2.3. Telecommunication

The subsection will cover an overview of the telecommunication infrastructure failures and the section will also look at the high sites/microwave links, fibre optic cables, tele-control, telemeters, Walkie-talkies and the types of high sites failures that have been researched before. The business has added new technology and the ageing workforce that the BU has doesn't want to learn how to maintain the new technology and that can also affect the performance of the new technology that the BU introduced. The current crop of engineers does not want to learn how to maintain the old technology and that can also affect the areas in the BU where the new crop maintains the old technology.

2.3.1. Tele-Control

Tele-control systems provide a remote control capability for the switching of electric power to the railway network and auxiliary services of Transnet. The BU will not monitor or control its substation or auxiliary services if the tele-control system is unreliable and the BU needs a reliable tele-control system to have a smooth train operation. *Leviäkangas et al. (2011)* caution that thunderstorm activities harm rail operations when lightning strikes switching equipment like tele-control. Adequate lightning protection reduces the chances of lightning strikes and regular lightning protection inspections also assist to minimize the chances of lightning strikes.

2.3.2. Radio High Sites

Fard et al. (2011) report that mobile Ad-Hoc network is a collection of mobile nodes which form a self-organising and self-configurable network that has no central administrator. The BU uses the high sites and microwaves for radio communication between train drivers, maintenance personnel and train control officers. Trains cannot run if high sites are defective and the BU will lose its revenue and a radio signal that is not clear can cause communication breakdown between train drivers and train control officers and communication breakdown can lead to train collisions and train derailments.

2.4. Technical Support

The subsection will cover an overview of the technical support infrastructure and the main technical support components that consists of bridges and culverts and the types of failures that other researchers studied before. The department is in charge of the service roads that the BU uses to gain access to the railway infrastructure and the boundary fences that the business uses to demarcate its railway infrastructures and to keep trespassers and animals out of its reserves.

2.4.1. Bridges

Haghani *et al.* (2012) state that bridges are vital parts of the infrastructure in the modern society and some railway and highway bridges were built in the first half of the 19th century and their technical lifespan is deemed to be already completed. TFR's SAC BU constructed its rail bridges in the 19th century, despite the fact that the maintenance teams are maintaining them according to schedule and procedure. The railway bridges that are currently in use by SAC's BU are currently being subjected to rigorous demands due to an increased number of trains that the BU is running. Lifecycle management, which is vital in infrastructure and technical support managers must ensure that they adhere to lifecycle management to improve the performance of the railway bridges that they have in the BU. The BU has railway bridges that are more than 50 years old and the BU is supposed to have a replacement or a refurbishment plan to improve the performance of its railway bridges. The BU has increased the number of trains and the increased number of trains has also compromised the condition of the bridges that the BU has.

2.4.2. Culverts

Bowers *et al.* (2014) state that culverts are critical assets to facilitate drainage and provide structured paths for water to flow under roads and railway installations. The purpose of installing culverts is to prevent wash-away, reduce erosion and to prevent railway maintenance problems (Bowers *et al.*, 2014). Taylor and Marr (2012) advise that culvert pipe material selection has been traditionally been a simple task of using metal and concrete pipes and infrastructure developers have added and coated metals and plastic pipes. Taylor and Marr (2012) maintain that there are several failures modes that influence the performance of a culvert and the BU's culverts have been affected by some of the failure modes. Taylor and Marr (2012) advise that a widespread maintenance problem is sedimentation in the ditches and at culvert ends, companies have reduced the number of maintenance crews in recent years to save on their operational budget and that has affected the cleaning and inspection of culverts. The BU has also reduced its maintenance budget year on year and that can affect the cleaning and the maintenance of culverts. Infrastructure companies are installing concrete or sheet pile cut-off walls when poor soils are present, or placing bands on pipes to prevent water from seeping into the joint or inverting paving in abrasive environments. Taylor and Marr (2012) advise that the designers only receive the soil borings data and the data is not available until after culvert designs are complete. The absence of data during the designing phase of the culvert affects the performance and the reliability of the culvert because the designers will design the culverts based on assumptions and not based on data (Taylor and Marr, 2012).

South Africa experiences a lot of rain and the BU will have wash-away if the three depots have inadequate culverts. Bowers *et al.* (2014) stress that companies turn to ignore culverts because they are underground assets causing them to wear and fail. The BU has culvert maintenance procedures and inspection programs in place that the company must adhere to minimize the failures or to increase the performance of its culverts.

2.5. Electrical and Substations

The subsection will cover an overview of the overhead traction equipment, the main electrical components that consist of substations, OHTE, distribution cables, current transformers, Standby supplies and 6.6kv-11kv distribution system and the types of failures that have been researched before.

Keller and Kroposki (2010) maintain that the main purpose of electrical power is to deliver high-quality, safe and reliable power and the BU's electrical departments have to make sure that their purposes and objectives are achieved. Mahmood (2015) believes that unavailability of traction power capacity leading to train traffic disruptions, trains cancellations and train delays is one of the main challenges that railway infrastructure managers are facing.

2.5.1. Substations (25 kV and 3 kV)

McDonald *et al.* (2013) state that substations are key electrical generation, transmission and distribution systems and more than 50% of the section in the SAC is electrified and the BU needs reliable substations to operate effectively.

Rampersad (2010) feels that a current transformer failure can damage the adjacent high voltage equipment and disrupt system operation due to the fireball that could evolve as a result of a burning oil. Rampersad (2010) states that a survey that was done indicated that some of the causes of failure were related to the actual design of the CT inclusive of the quality of the material used which goes back to the issue of substandard material or spares. An effective supply chain department can minimise the chances of railway companies getting material and spares that are of poor quality. The specifications that the technical officers or the project managers write are also a problem, especially when project managers or technical officers do not know the specifications of the material that they need.

Trainba and Ekonomou (2015) state that external over-voltages caused by lightning strikes can cause several damages to a substation that can lead to insulation breakdowns. The appropriate lightning protection system prevents lightning strikes that occur in substations and substations that are not installed according to specifications will have a problem with lightning strikes. Trainba and Ekonomou (2015) believe that lightning protection systems have to be taken into considering during the designing phase of the substation because it costs a lot to replace or fix a substation that is damaged by lightning. A risk assessment can be performed for substations that are not having adequate lightning protection in order to predict the possible dangers and install the appropriate protection (Trainba and Ekonomou, 2015).

2.5.2. Distribution Cables and Mini Substations

Olusuyi *et al.* (2014) state distribution lines deliver the power from substations to consumers and the BU's distribution system delivers power to departments like train authorisation and other departments that need it. Tolbert *et al.* (2011) define electrical outage as an unplanned loss of power to a load and the BU is using the 11kv to supply the signalling equipment and an electrical outage will mean that the train authorisation equipment will not have power. Train authorisation will not be possible if the 11kv is defective and the operators will not move trains if the train authorisation system is not operational.

Okraszewski and Balzer (2007) advise that distribution cables have been in operation for decades now and the distribution cables are facing many problems concerning ageing or possible technical incapability of some structures. Budget limitation and a reduction in the number of trains that the BU is running resulted in changes in railway infrastructure capital expenditure. The budget cuts have affected railway replacement programs and that has also affected the performance of the ageing distribution equipment. Okraszewski and Balzer (2007) report that infrastructure companies can consider maintenance strategy or prioritization of maintenance to create an effective maintenance algorithm.

Campbell (2012) maintains that the overhead distribution cables are largely exposed and are affected by seasonal storms which is combined with furies of wind, rain, snow and ice. The severe weather events cause the greatest damage to electrical power transmission and distribution infrastructure as damages can result from trees falling on electricity lines (Campbell, 2012). Campbell (2012) reports that trimming of tree branches to maintain a right-of-way free minimizes the chances of trees falling into the distribution lines and some companies have vegetation management programs that look at trees that have a risk of falling into distribution lines. Some companies are installing distribution cables underground which can be costly when it comes to maintenance and the installation costs can also be high.

2.5.3. Overhead Traction Equipment

The catenary wire has a structural function to suspend the contact wire by means of droppers and an electrical function to conduct traction and fault currents and the contact wire provides the electrical live interface with the locomotive for traction purpose. [Leviäkangas et al. \(2011\)](#) believe that overhead catenary wires may fare poorly when exposed to winter storms and snow and regular catenary wire inspections and season preparedness plans that railway companies put in place can help reduce the impact of winter storms and snows on the catenary wire.

2.6. Empirical Review

The section will look at the studies that are currently available that concern the infrastructure failures that are caused by ageing infrastructure, poor maintenance, skills shortage, theft and vandalism and weather.

2.6.1. Ageing Infrastructure-Related Studies

A report on Ageing Infrastructure that was conducted by the Homeland Security in 2010 found out that age is one of the factors that affect the performance of an infrastructure and also its robustness against threats posed by common environmental conditions and extreme natural hazards. [Doyle and Betti \(2010\)](#) state that the age of an infrastructure often acts together with other factors such as design, maintenance and operation in increasing the vulnerability of the infrastructure to these threats.

2.6.2. Skills Shortage-Related Studies

[Richardson \(2007\)](#) defines skills shortage as a source of aggravation to a firm and, when acute, is likely to hamper the quality and the quantity of the organisation's output. The current engineering shortages that the country is facing and the shortages can also contribute to the number of infrastructure failures that the BU is facing. The maintenance depots' duties are to maintain the railway infrastructure to reduce the number of the same infrastructure that the maintenance depots are maintaining and to increase the availability and the reliability of the infrastructure. Skills shortages won't make it possible for the maintenance depots to maintain the infrastructure and an infrastructure that is not maintained is not reliable and it can fail at any given time.

2.6.3. Theft and Vandalism-Related Studies

Theft and vandalism make it difficult for infrastructure maintenance departments to concentrate on maintenance and the performance, safety, availability and the reliability are compromised because of theft and vandalism. Theft and vandalism-related failures amount to millions and companies and departments are losing people and assets due to theft and vandalism-related failures.

2.6.4. Weather-Related Studies

[Leviäkangas et al. \(2011\)](#) caution that extreme weather may cause impacts and consequences affecting these dimensions and lowering the rail transport services. Railway infrastructure weather-related impacts include avalanches, landslides, melting permafrost, and hot and cold waves. [Leviäkangas et al. \(2011\)](#) believe that the increased storm surge is likely to affect highway access and flooding affects grounding of railways and their electricity as well as telecommunication systems across the entire rail transportation network.

3. RESEARCH METHODOLOGY

[Rajasekar et al. \(2013\)](#) state that research methodology is a systematic way of solving problems and it is also a procedure by which researchers go about their work describing, explaining and predicting phenomena. The aim of research methodology is to guide the researcher on how to choose a suitable method for a chosen problem, the efficiency of the method and the order of accuracy of the result of a method ([Rajasekar et al., 2013](#)). [Shukla \(2008\)](#)

defines the research design as a master-plan, blueprint and a sequence of research tasks and activities. This study focused on the view of technical people on the causes of railway infrastructure failures in the Steel and Cement business unit. The study will use a non-experimental, qualitative, exploratory-descriptive and contextual design.

3.1. Quantitative Research (Positivist Research)

Greener and Martelli (2015) explain that quantitative research is likely associated with a deductive approach to testing theory, often using numbers or facts and therefore a positivist or natural science model, and an objectivist view of the objects studied. Shukla (2008) advises that quantitative research methods seek to quantify the collected data and the researcher analyses some of the collected statistics. Researchers put heavy emphasis on using formalized standard questions and predetermined response options in questionnaires or surveys administered to a large number of respondents.

3.1.1. Methodology Used in the Current Study

The quantitative approach will be used to conduct an investigation into the causes of Railway Infrastructure failures in TFR' SAC Business Unit and both descriptive and inferential statistics will be used in this research. The study will use the quantitative research approach by looking at the possible causes of railway infrastructure failures and the participants will give each question a rating on what they feel is the most likely cause of the failures. The sample population has an in-depth knowledge of the possible causes of railway infrastructure failures and can, therefore, provide the possible causes of the infrastructure failures. The sample population has worked on the infrastructure, the population maintains the infrastructure daily and the sample population conducts fault-finding exercises on the subject being studied.

3.2. Target Population

Shukla (2008) defines the research target population as a prescribed segment of the total population that researchers use to collect research data for decision making and a population as the totality of cases that conform to some designated specifications. TFR has a population of plus or minus 44 000 employees with three regions that consist of six business units and the study will be done in the SAC Business unit that has a population of 1048 employees.

3.2.1. Sampling

Shukla (2008) advises that sampling involves a process where researchers select a relatively small number of elements from a larger defined population of elements, expecting that the information gathered from the small group of elements will provide accurate judgement about the larger population. The sample for the study will be 120 of the total 1048 target population members of the SAC business unit. The study will use the probability sampling method because of the experience that the target population has, all the employees in the target population have done maintenance or attended a fault on the railway infrastructure and will understand the questions on the questionnaire. The sampling strategy was also chosen based on the theory of the study where people who have hands-on experience with railway infrastructure can be interviewed. A sample of 120 employees will answer the questionnaire with 65 participants from Polokwane, 30 participants from Isando and 25 participants from Krugersdorp. The study will use stratified random sampling where the population will be divided into 3 depot subgroups. The stratified random sampling was used because the study is only focusing on three Steel and Cement maintenance depots. Six categories are selected to participate in the survey with the perway department receiving 40 questionnaires, signals department receiving 15 questionnaires, telecoms department receiving 19 questionnaires, electrical department receiving 30 questionnaires and other departments 6 questionnaires.

3.3. Pilot Study

A sample of 10 employees participated in the pilot study with 4 participants from Polokwane, 3 participants from Isando and the remaining 3 from Krugersdorp. The questions were the same for the five sections and the participants advised that vegetation is not the main cause of perway infrastructure failures. The pilot study participants also advised that other external departments are not the major cause of signalling infrastructure failures and the question wasn't included in Section C of the questionnaire. The participants also advised that signal interference is a major cause of Telecommunication failures and the question was added in Section D of the questionnaire. Section E of the drafted questionnaire didn't have fatigue on the structures as a major cause of Technical Support infrastructure failures which was added after the pilot study.

3.4. Data analysis

The study used inferential statistics, where the researcher will draw the statistics from the 120 selected employees that will participate in the study. The population consists of 1048 employees and it is not easy to conduct a research from that population looking at the geographical layout of the Business Unit and the technical knowledge of the population. The researcher will analyse the data from the responses that the 120 employees are going to give on the questionnaire provided and Microsoft Excel will be used to analyse the data. The researcher will make conclusions and recommendations based on the answers that the 120 employees will give after answering the questionnaire.

3.4.1. Validity and Reliability

Baumgarten (2010) advises researchers use reliability and validity as quality indicators for quantitative research within a largely homogenous positivist research environment and develop alternative quality standards meaningful concepts. Shukla (2008) believes that reliability in research relates to the consistency of results over a period of time like the type of equipment that the business unit has on its database which will only change when new equipment has been added or existing equipment deleted.

3.5. Limitation of the Study

The study was limited to the SAC business unit employees and the population comprises of Technicians, Technical Workers, Senior Technical Workers, Track Masters, Track Inspectors, Production Managers, Technical Managers, Maintenance Managers, Traction Lines Mans, Electricians, Technical Supervisors, Infra Workers, Maintenance Controllers, Senior Admin Officials, Service Technicians, Senior Service Technicians and Maintainers. The results of the study will be applied in other TFR's business units and the recommendations can also apply because of the standardised business operation. The study is also limited to employees that have either worked on railway infrastructure or have been exposed to the railway infrastructure because of the knowledge that they have about the causes or factors that can affect the reliability and the performance of the railway infrastructure. The questionnaire had six sections and the other five sections required that the participants give a rating on what they felt was the causes of infrastructure failures. Some participants have only been exposed to one department, meaning their responses will only cover one section not the five sections that are on the questionnaire.

3.6. Elimination of Bias

The study remained objective, bias-free and only identified the participants by the depot and the department that they are working for. The questionnaire only looked at the possible causes of railway infrastructure failures and the objectives and the goals of the study were shared with the participants and the participants only participated on their own free will. The language used in the study was well understood by the participants and the questionnaire was thoroughly explained to all the participants, especially the entry-level employees.

3.6.1. Ethical Considerations

Saunders *et al.* (2009) state that no harm should come to the participants who are part of the research study. The study ensured that no employees from the Steel and Cement business unit were harmed during the research.

3.6.2. Ensuring participants have Given Informed Consent

A letter was written and the explanation and the objectives of the research were shared with all the participants and permission was obtained from all the participants.

3.6.3. Ensuring no Harm Comes to the Participants

The researcher made sure that all the participants were safe and no potential risks were identified during the research.

3.6.4. Ensuring Confidentiality and Anonymity

The questionnaire did not ask the employees for their employee numbers or their names.

3.6.5. Ensuring that Permission is obtained

Saunders *et al.* (2009) state that the researcher should obtain permission to do their research via official channels and the three depots that are falling under the SAC business unit are reporting to the Infra Manager and the Infra Manager is reporting to the region's Chief Engineer. The Infra Manager approved the researcher's request to conduct the study within the organization.

4. DATA ANALYSIS, INTERPRETATION AND FINDINGS

Out of a total of 111 employees completed the questionnaire with 34.23% of the responses coming from Perway department, 26.13% of the responses coming from Electrical department, 14.41% of the responses coming from Telecommunication department, 12.61% of the responses coming from Signals department, 7.21% of the responses coming from Technical Support department and 5.41% of the responses coming from other supporting departments. A total of 120 questionnaires were sent out, with the perway department receiving 40 questionnaires and the department returned 38 questionnaires. The signals department received 15 questionnaires and returned 14 questionnaires. The telecommunication department received 19 questionnaires, 16 questionnaires were returned and the technical support department received 10 questionnaires and returned 8 questionnaires. The electrical department received 30 questionnaires and returned 29 questionnaires. Other departments like the supporting departments returned the 6 questionnaires that were sent out to them.

4.1. Summary of the Responses

The section will summarize the responses where the participants agreed with what was asked in the questionnaire.

4.1.1. Section B (Causes of Perway Infrastructure Failures)

The majority of the participants disagreed that lack of maintenance causes perway infrastructure to fail. That means that the SAC business unit's maintenance depots are adhering to maintenance schedules and maintenance procedures. The company's perway infrastructure was installed more than 30 years ago and the participants also agreed that ageing infrastructure is causing the perway infrastructure to fail. The responses show that extreme high and low weather conditions also affect the reliability of the perway infrastructure. The current climate changes are becoming a problem to the business unit due to the fact that the weather patterns are unpredictable. The business unit didn't invest in weather monitoring equipment that warns the operators of incoming heavy storms

that can affect the operation of its perway infrastructure. The survey shows that the participant agreed that theft and vandalism is one of the main causes of perway infrastructure failures. The business unit will need to invest more in its asset protection to minimize and reduce the theft-related failures. The business unit's railway tracks are running next to informal settlements and that makes it easy for the residents to vandalize the perway infrastructure because the business unit doesn't have people that are safeguarding its infrastructure or patrolling the areas that are running next to informal settlements.

4.2. Section C (Causes of Signal Infrastructure Failures)

The employees that participated in the study agreed that signalling theft-related failures are very high with 83% of the participants agreeing. This shows that the business unit spends most of its time attending to theft-related signalling failures which affect the day-to-day running of the business unit and also increases the operational budget of the business unit.

4.3. Section D (Causes of Telecommunication Infrastructure Failures)

The business unit uses radio for communication with some of its communication instruments installed in the mountains and the communication instruments are vulnerable. The majority of the participants agreed that theft and vandalism is one of the main causes of telecommunication failures.

The age of the telecommunication infrastructure that the business unit is using is also a great concern and the majority of the participant agreed that ageing infrastructure is one of the main causes of telecommunication infrastructure failures. The copper cable that the business unit is currently using was installed more than 20 years ago and it has reached its lifespan. A replacement program and migration from copper cable are needed that will improve the performance and the reliability of the telecommunication infrastructure.

The majority of the employees that participated in the survey agreed that extreme weather conditions are affecting the day to day performance of the telecommunication infrastructure.

4.4. Section E (Causes of Technical Support Infrastructure Failures)

The majority of the participants agreed that the business unit's technical support infrastructure is failing because of poor or lack of maintenance. The business unit has been cutting down on its operational budget and that has impacted the maintenance that the infrastructure needs. The current unpredictable weather conditions are worsening the situation because the current bridges and culverts that business unit hasn't been maintained according to schedule and specifications.

The business unit is currently using railway bridges that were constructed more than 50 years ago and the majority of the employees that participated in the study agreed that ageing infrastructure is causing the technical support infrastructure to fail.

The majority of the participants also agreed that extreme weather conditions like floods cause the technical support infrastructure to fail. The current climate changes that the world is facing is making it worse and the changes are affecting the performance of the infrastructure.

4.5. Section F (Causes of Electrical and Substation Infrastructure Failures)

South Africa is losing over R5 billion a year due to copper cable theft and the business unit's electrical and substation infrastructure uses the copper cable to conduct electricity. The network of the infrastructure is large and that makes it difficult for the business unit to patrol the whole network. The majority of the participants agreed that theft and vandalism is one of the reasons why the electrical infrastructure fails. Theft of copper cable is also affecting companies like Eskom, Telkom, PRASA and other communication companies that use copper to either conduct electricity or transmit information.

The majority of the employees that participated in the survey agreed that the infrastructure that the business unit is old and the age is affecting the performance of the infrastructure. The distribution cables that companies are using have been in operation for decades and some of those cables are no longer technically cable of delivering the services that they are installed to deliver. The ageing distribution cables have increased the operational budget of the business unit because of the number of failures that the maintenance teams have to attend to and the overtime that the business unit has been paying because of those failures.

5. CONCLUSIONS AND RECOMMENDATIONS

The aim of the research was to investigate the causes of railway infrastructure failures in Transnet Freight Rail's Steel and Cement business unit and the study found out that the following were the main causes of Railway Infrastructure failures:

- All the infrastructure departments are affected by theft and vandalism according to the views of the employees that participated in the survey and that is causing the infrastructure to fail.
- The business unit is using an infrastructure that is old and the age of the business unit's infrastructure is affecting the infrastructure causing it to fail according to the majority of the participants.
- Extreme weather conditions like lightning, hot weather conditions, low weather conditions and floods, affect the performance of all infrastructure departments causing the railway infrastructure to fail.
- Lack of maintenance and poor maintenance, due to the skills shortage, lack of training, personnel, supervision and a performance contract, is another cause for railway infrastructure failures according to the majority of the participants.
- Vegetation is also causing the railway infrastructure to fail according to a majority of the employees that participated in the study affecting mostly technical support department.
- The study revealed that departments like perway are causing signalling infrastructure to fail and telecommunication infrastructure is affected by the technical support and the perway department.

5.1. Recommendations

The study has revealed that there are things that the management of the business unit was not taking into consideration and therefore the following recommendations are proposed to improve the availability and reduce railway infrastructure failures:

- The business unit's management improves its asset protection, security measures and security controls. This can be done by the installation of advanced security surveillance cameras, deploying more security personnel to patrol its railway infrastructure and putting effective security controls. The current security measures together with the security controls in the business unit are not adequate and theft-related failures won't be reduced if the business unit doesn't improve its security measures.
- The business unit can also lobby the government to introduce a scrap metal act that requires operating licenses from scrap dealers giving local authorities powers to decline unsuitable applicants and revoke their licenses.
- The government through the police department can have power by court order to close unlicensed scrap yards, all sellers of metal must show verifiable identification and a public national register of scrap metal dealers has to be created.
- The business unit put in place a lifecycle management program for all its railway infrastructure assets, increase its capital expenditure budget, quantify the backlog and upgrade the railway components that have reached their lifespan.

- The business unit can also increase the maintenance frequency of the components that have reached the end of their lifespan but are not going to be replaced soon. The business unit will have to make sure that it has enough spares to replace the failing ageing components.
- The business unit's human resource department must have programs in place to transfer skills from the older technicians to the new technicians so that the new technicians will know how to maintain the ageing railway infrastructure.
- The business unit assesses the conditions of the lightning protection that it has on its electrical equipment and put in place a lightning protection inspection program that will be done every rainy season.
- The management of the business unit put in place a season preparedness plan that will look at programs that will reduce seasonal-related railway infrastructure failures like cold-related rail breaks and heavy rains-related wash-away.
- The company invest in technologies that will assist in detecting possible weather-related failures before the infrastructure fails.
- The business unit's Human Resource department draws up a recruitment plan to fill all the vacant positions to reduce the maintenance backlog that the business unit has.
- The management of the business unit revises the performance contracts that are in place to include maintenance as one of the key performance measures and to ensure that maintenance performances are reviewed regularly.
- The management of the business unit put in place quality audits to check the quality of the maintenance that the teams are doing on the railway infrastructure.
- The management of the business unit introduces regular competency assessments to assess the competency of technical people that are doing regular railway maintenance.
- The management of the business unit conducts regular spot checks on maintained infrastructure, improve their visibility and ensure that task observations are conducted on all maintenance-related tasks on a regular basis.
- The management of the business unit put in place external quality inspectors that will audit the quality of maintenance that the three maintenance depots are doing and give the external quality auditors the authority to issues stop certificates in areas where maintenance quality is sacrificed.
- The depots put in the date of inspection, the name of the person that did the inspection, the name of the station or kilometre points and also quantify the possible problems that the depots are going to pick up during the inspections.
- The management of the business unit can also invest in advanced vegetation control machines like the Chlorovision, which uses proprietary vegetation detection algorithms to detect every weed regardless of the size and the system can work both at night and during the day.
- The management of the business unit can also invest in brush-cutter mounted railroad vehicles that will only need a driver to operate, saving the business unit time, money and reducing the vegetation-related infrastructure failures.
- The business unit' integrated maintenance plan is adhered to reduce railway infrastructure failures that are caused by other departments.
- The management of the business unit can purchase a stand-alone planning Time-Location Planning Software that can be used with other planning systems like Microsoft Project and Primavera to plan integrated maintenance plans.
- The management of the business unit ensures that all its maintenance departments understand the impact that one department has in another department by ensuring that proper inductions and maintenance awareness initiatives are put in place.

5.2. Conclusion

Ageing railway infrastructure, extreme weather conditions, theft and vandalism appeared to be the major causes of railway infrastructure failures with the three causes appearing as the causes for the five departments that the business unit has. The business unit cannot run an effective, sustainable and profitable business if its infrastructure is unreliable. Technology, proper planning, capital investment and human resources involvement can help the business unit to improve the reliability and availability of the SAC business unit's railway infrastructure. The recommendations will improve the business unit's railway infrastructure performance, reduce the operational expenditure and increase the profit. The research fulfilled all the objectives and the recommendations can be used by other Transnet Freight Rail business units. A study on the impact that the business unit's railway infrastructure failures have on the revenue of the business unit and the revenue of the company should be investigated. Further studies will assist the maintenance teams and other stakeholders to understand the impact that the unavailability of the infrastructure is having on the business unit's revenue and profit.

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