The Reliability of 43D Diesel Locomotives on the Phalaborwa to Richards Bay Corridor

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Abstract

The 43D diesel locomotives reliability performance en route on the Phalaborwa to Richards Bay corridor is bound with challenges, despite the efforts of Transnet SOC Limited, a South African biggest freight rail company responsible for transport within the country and across the borders.

This case study uses a quantitative data analysis to investigate the reliability of 43D model of the locomotive rail freight operating within this route in the areas of maintenance cost, the effectiveness of the preventative maintenance, poor of asset availability., and to identify other operational management issues affecting this critical asset.

The findings show that the inefficiency resulted from lack of training, inadequate maintenance schedules, and inappropriate location where maintenance is conducted.

For remediation and mitigation purposes, it is recommended that proper techniques and preventive practices and schedules be implemented; good frequent training and performance assessment of the engineers and technicians be regularly conducted. In addition, a proper review of the asset service design, and the location of maintenance site be overhauled in the entire value chain.

Keywords
43D Diesel Locomotives, Availability, Maintenance, Reliability.

1. Background

Failure of locomotives is a risk impact that results to not only unquantifiable safety and environment consequences but incurs a huge financial loss to all stakeholders. The probability that an asset will survive for a specified time duration performing its required functions under some predetermined conditions assures customer the products' quality of service (O'Connor and Kleyner, 2012).

Logistics infrastructure is one of the pillars that positively influences the size of the state economy; creates labor force and maintains sustainability. Havenga (2010), identifies high cost, inadequacy and insufficient capacity of the national logistics system as one of the six compulsory constraints preventing South Africa from achieving high and steady economic growth. Perkins, Federke, and Luiz, (2005) emphasized that South Africa's economic infrastructure grew by more than 15% in 2003, and in its five-year forecast plans expectant value of R165bn for transport and electricity will be invested in Transnet (rail transport) and Eskom (Electricity), the state-owned enterprises.

According to Dibakoane (2013), the most important element of the South African's transport industry is the rail transport, that helped the economy to grow 5% for 32 positive consecutive times. Connecting to all cities and neighboring countries (figure 1) through common network mostly using Diesel locomotive, there is a need to ensure its reliability if this economic development trend can continue. Contrarily, many challenges facing this industry are due mostly to maintenance and rolling stock, the safety of the locomotive fleet, productivity, lack of efficiency and reliability (Jones and Miller, 1992).

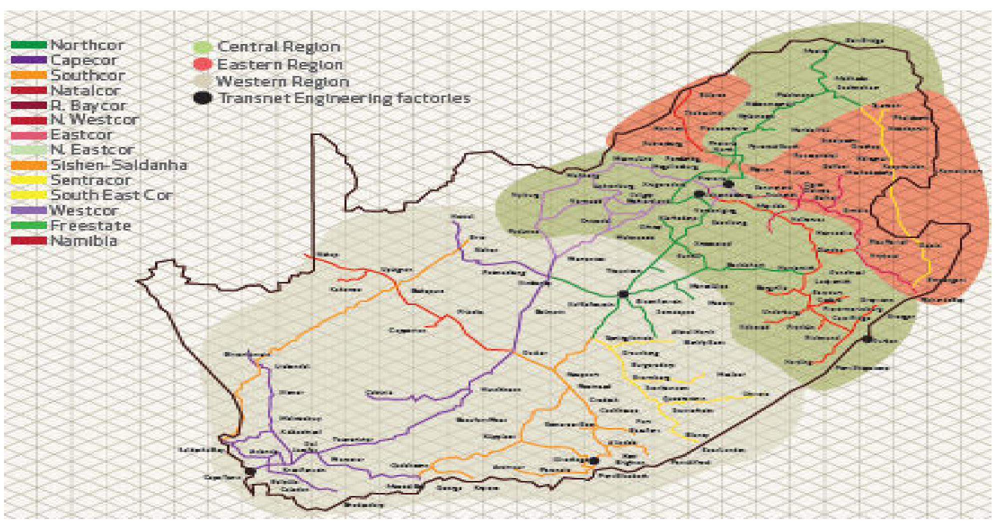

Figure 1. Transnet Geographical Area (**Source**: Transnet Report, 2016)

According to Transnet Integrated Report (2016), Engineering's total revenue for the year was R10,7 billion, which is 13,2% lower than the R12,4 billion achieved in the prior year. During the year, Transnet implemented a capital optimization programme which reduced Freight Rail's demand for rolling stock from Engineering. This resulted in a 12% reduction in revenue from Freight Rail to R9,4 billion (2015: R10,7 billion). Further, the deteriorating economic outlook, both in the country and in the rest of Africa, reduced the demand for Engineering's products, resulting in a decrease in external revenue by 21,1% to R1,4 billion (2015: R1,7 billion).

Through market demand, Transnet Freight Rail has invested over R200 billion for the next five years on numerous projects especially the operational side which rail services suffered from poorly in maintenance and management of rolling stock as well as from poor infrastructure built with low-weight rails and insufficiently designed for present traffic, (Pedersen, 2001). Additionally, Freight rail not only faces stiff competition from other road transport and unreliable locomotives but also suffer undue poor funding from the government due to political bureaucracies (Corman, D'Ariano, Pacciarelli, and Pranzo, 2010; Fourie, 2008).

Reliability of 43D locomotives as a major driver of support to freight transport and in-service cost in Transnet freight services for the Transnet Eastern Region (refer to figure 1) has field failures history that do not generally occur at a uniform rate, but follow a distribution in time commonly described as a "bathtub curve" (Kunar, Ghosh, Mandal, Bose, Sau, 2013). This failure curve assumes the 3 stages of life cycle like any other locomotive; progressive failure rate, failure rate at constant stage and stage where failure begins to increase. However, due to 43D subjection to stress and over/ under maintenance, it results in malfunctions and high maintenance cost, an attribute to maintenance policy of Transnet. Dibakoane (2013) describes 43D diesel locomotive as a self-contained electric driven in the form of traction motors propelling the axles and electronically controlled 43 D series as the locomotive version that produces 35% of the electric locomotive power of similar weight. Additionally, similar to other locomotives in features, it carries its own generating station around it and not connected to a remote generating station connected through overhead wires. This infrastructure under investigation mostly hauls commodities from Richards Bay Cor to Phalaborwa cor, locations grouped as Eastern Region of Transnet.

The 43D locomotive reliability in freight transportation poses a threat to national competitiveness, development initiatives, broad-based upliftment, and sustainability (Havenga, 2010). Reliability as a time-dependent factor monitors unscheduled discrepancies of individual 43D locomotives that affect maintenance workload and cost, (Dibakoane 2013). The 43D series components include diesel engine, Pantograph, wheels, transformers, traction alternators and motors, cut out cocks, electrical system, pipes, compressed and vacuum brakes, compression exhauster, and other accessories. Other features of 43D diesel series include a maximum speed of 120km/h with a maximum axle load of 26000kg (Dibakoane (2013).

3. Review of Literature

This section reviews the maintenance management sysystem, performance requirements, Transnet maintenance standards and philosophy, railway safety, reliability and associated risks in management of 43D locomotives.

3.1. Maintenance Management and Requirements

Considering Health, Safety, cost usefulness, Service levels and other market requirements, Railway infrastructure Management plays a vital role in responding to transportation business pressures (Macchi, et al., 2012). For computerization of data flow, maintenance utilizes sufficient data to accomplish its five principal functions; Work control, Asset Control, spare parts and inventory control, performance reporting and cost accumulation and reporting. Reliability of 43D diesel locomotive cannot be assured without one of types or combinations of maintenance: Condition-based, Time-based and Work-based that determines its operational growth and optimization of a facility. Managing and utilizing a supply of labor, tools, materials, and equipment well ease maintenance. Assessing the service and product against specification and another set of attributes against failure helps to monitor unscheduled discrepancies affecting the cost, workload and maintenance reliability which are cyclical and repeatable, (Campel, 2006). A company identifies best management practices (figure 2) to achieve a competitive advantage over its rivals. (Dibakoane, 2013).

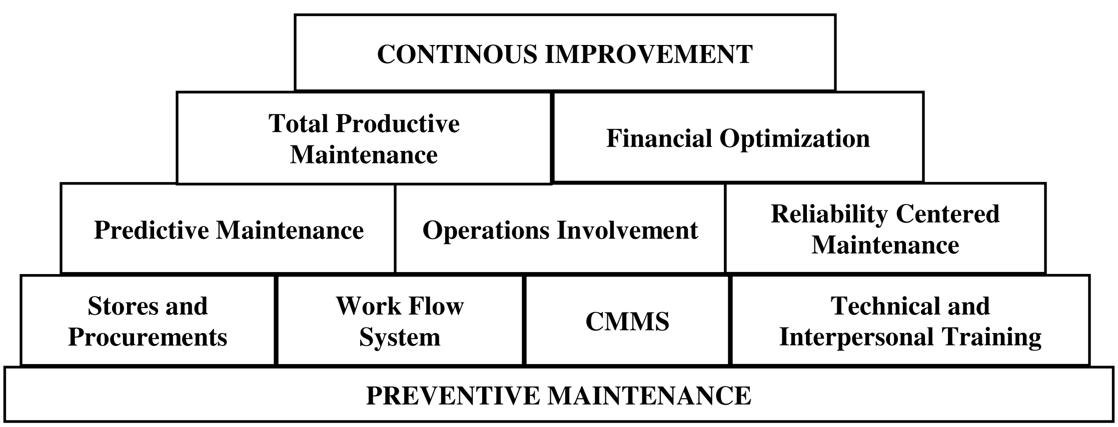

Figure 2. Maintenance Management System (**Source**: Dibakoane, 2013)

3.2. Maintenance Performance Requirements

Maintenance performance accounts for the amalgamation of practical and administrative activities mandatory to keep equipment's and other physical assets in their anticipated operating condition and to reinstate them into a perfect state (Ahire, et al., 2000). Maintenance performance is regarded as an important tool for decision making used by management in industries because of its ability to recognize performance gaps amongst current and desired performance which is able to offer an indication of progress towards terminating the gaps (Cheng & Tsao, 2010).

Requirements are reviewed based on quantitative data analysis, which is essential in accepting the most optimal type of maintenance and time interlude considering the role and failure amount of each component (Mendes & Ribeiro, 2014). The Monte Carlo simulation in railway industries analyses the production and maintenance of rolling stock performance and permits the inclusion and consideration of a variety of important characteristics of all production systems (Mendes and Ribeiro, 2014).

Transnet in its maintenance philosophy indulges in the extension of asset / systems life existence at the same level involving different entities of operation and maintenance, inspection, Data collection, verification and validation as clearly defined for the company's specific sub-contractors (Misra, 2008).

3.3. Transnet Maintenance Philosophy

Transnet Engineering introduced modern and alternate operating philosophies for Transnet's maintenance operations, such as the robust operating paradigm concepts for minimizing impact, fault tolerance and adaptive scheduling and maintenance procedures. Normally Maintenance plan (manufacturer's first guide) initiates the paradigm. The guide includes the running service, overhauls and paint programmes, system upgrades, body repair, replacement of components and disposal of the asset when obsolete.

Extension of a product or systems life preventing it from failure lies with the concept of preventative maintenance; Time Based and condition-based interventions. An effective maintenance system involves different entities such as maintenance, inspection; verification clearly defined by Transnet specifically to sub-contractors (Misra, 2008). The philosophy extends also to run-to-failure components, (semiconductors, cab lights, blocking diodes, thyristors, cab hot plates rectifiers and so on), Workload-based maintenance, root cause analysis (application of Pareto Analysis, Weibull failure distribution, and Fish-Bone techniques), and run-out maintenance. Pareto Analysis is a technique is used mainly to identify equipment failures and to determine total contributions of the whole system. It focuses on solving the largest problems first and reserves other problems to be solved whilst solving those that are contributing 80% of failures in the system.

3.4. Maintenance and Reliability

The process of maintaining a system basically, consist of two known categories (Table 1.); preventive (schedule) and corrective (forced). Carrying out maintenance activities at regular time intervals even when the locomotive is working at a satisfactory state to retain, prolong the life of the asset and to decrease failure rate and increase the mean time to failure (MTTF) is regarded as schedule, (Campbell, and Reyes-Picknell, 2006). Contrary to preventive is maintenance that follows the in-service failures (when a failure occurs). This is followed by series of activities to restore the normal operations; adjustments, replacements, and repair of the components (Dibakoane, 2013).

Table 1. Maintenance Strategy and Approach (**Source**: Campbell, and Reyes-Picknell, 2006)

Maintenance Strategy	Approach	Signification
Corrective Maintenance	Fix it when broke	Large Maintenance Budget
Preventive Maintenance	Scheduled Maintenance	Periodic Component Replacement
Predictive Maintenance	Condition Based Monitoring	Maintenance condition based on Equipment Condition
Proactive Maintenance	Detection of Sources of Failures	Monitoring and Correcting Root cause of failure

The unplanned action and the amount of measure to correct and restore the components to normalcy after forced failure is determined by reliability quantified by Mean Time to Repair (MTTR), while Mean Time Before Failure

(MTBF) is an average time that a component works without failure provided the component has constant failure rate (Kunar, et al., 2013). A common performance relationship existing between maintenance and reliability for a repairable system is the Availability factor; probability that the system is operating properly when it is requested for use showing that a system is not failed or undergoing repair action when it needs to be used AIN = MTBF / (MTBF+MTTR) (Kunar, et al., 2013). The period or the index representing this service unavailability is regarded as the downtime.

3.5. System Reliability Requirements

Dibakoane (2013), emphasize that reliability for freight rail transport is a difficult task to specify as it must exceed customers' expectations, however, the goal depends on specifications; requirements of the products, Engineers, suppliers, subcontractors, and reliability for its customers. Reliability must be measurable, involve customer usage and operating environment of the time, distribution, limits and constant values; clearly defines component failure; specify confidence interval for consideration of the variability of data being compared to the specification.

The requirement analysis including Rails system hardware failure rate and service life, performance, functional, non-functional and architectural constraints must be iterative and recursive in nature and the output of the process must be traceable to and consistent to the stakeholders' requirements.

3.6. Safety in Railways

The National Safety Regulator Act (No. 14 of 2002, as amended by Act 69 of 2008) provides for the establishment of a Railway Safety Regulator and oversees safety in the railway industry, which Transnet and PRASA are signatories (Transnet Integrated Report, 2016). The act amongst others includes: approval of safety permits, conducts of inspections and audits, Investigates railway accidents, compliance with all legal framework and policies, railway safety and non-compliances.

Safety culture procedures and principles in an organization reflect the decisions and policies in place to ensure effective operational performance (Farrington-Darby, et al., 2005). Risks associated with maintenance fall under this act (Farrington-Darby, et al., 2005).

3.7. Reliability Challenges in Railways

Transnet sets a reliability of 90% for all its freight locomotives. Both Locomotives and the railway system is a complex mechanical system influence of various external and internal random factors; rails, wheel malfunction, wet rails, the interaction of wagons, etcetera. (Jastremskas, et al., 2010). A reliable, safe freight and passenger transportation system is well-defined by a properly selected transportation procedure defined by a selected mode of rolling stock usage, and exact discipline of work procedures (Jastremskas, et al., 2010).

3.8. Reliability Testing and Rolling Stock

Testing for reliability is a major field in the world of Engineering as it assists company's like Transnet to manage aging rolling stock by eliminating high-risk possibilities while saving time and resources (O'Connor and Kleyner, 2012). It is a vital system in assisting freight designers to analyze the designs as there is no 100% prediction that failures may not occur in that systems (O'Connor and Kleyner, 2012).

3.9. Reliability Risk Management

The risk in the railway industry is imminent. Accidents and incidents leading to fatalities and injuries to passengers', employees and losses of assets and goods that results in rolling stock damaged take place regularly, and unpredicted (An, et al., 2011). Risk management, therefore, becomes one of the increasingly critical aspects in railway industries as it is used as a mechanism to safeguard railways employees, passengers, and rolling stock while improving safety and reducing maintenance cost (An, et al., 2011).

4. Research Methodology

Locomotives are very complex mechanisms in design with basic specifications which form part of the infrastructures and other mechanical components, that respond to failure. This case studies use quantitative means of data collection and simulation tools for analysis.

4.1. Research Design

This study focuses on answering reliability challenges of 43D Diesel Freight transport from Phalaborwa to Richards Bay (Eastern Corridor). The choice of location stems from the fact that the majority of this diesel series operate in this Eastern Corridor of Phalaborwa precinct. Similar diesel locomotives like 34D's and 35D haul commodities from Komatipoort to Maputo. Other locomotive fleets such as 35D, 34D, and 18E' traveling from Phalaborwa to Richards Bay do not form part of this Study.

A twelve-month period of data was extracted from Transnet locomotives database from April 2016 to April 2017 for the 43D series locomotives both in-service and failed, which reported reasons for failure are taken into account.

Quantitative and Qualitative data analysis are used as research methods to analyses the component failures and answer the research possible questions in a bid to verify findings literature and previous studies in order to reflect different epistemological analogies (Heaton, 2008). Other sources of data collection included semi-structured interviews, responses to open questions, field notes. Qualitative data collected from similar previous studies were utilized but to secondary analysis determined by the instrument used for data collection (Heaton, 2008).

Quantitative data is extracted for a period of 12 months from a Transnet SOC Limited database with a focus on all active and non-active 43D diesel locomotives. Qualitative data is collected through a survey, where employees, who are affected, were given a chance to answer some questions related to locomotives and give feedback.

No sampling was made, as the total locomotive fleet hauling commodities from Phalaborwa to Richards Bay corridor consists of 264 locomotives were included in the analysis to achieve the research purpose. Probability tools such as Weibull and Monte Carlo were used to determine the failure rate and its distribution curve

4.2. Data Collection Methods, Analysis, and Interpretation

Quantitative data formed the means of data collection to draw the findings to conclusions. It seeks to answer the research questions for the best capabilities and experiences without the bias of the researcher. The aim of the quantitative analysis was to clearly articulate the main factors that affect the reliability of locomotives.

The following methods from literature and the collected data were used to analyse the findings: Time-Based Maintenance and Condition Based Monitoring; Reliability Engineering tools (Failure Rate, MTBF, MTTR, and Availability.); Highest Failing Locations; Understanding the Service Design and Operational Methodology; Failure Mode and Effect Analysis (FMEA); and Failure Mode Effect & Criticality Analysis (FMECA); Workload-based maintenance; Root cause analysis (Pareto Analysis) and Run-Out-Maintenance. FMECA technique assists in defining, identifying and eliminating known potential failures from the design, process, or systems before reaching the customer (Hu-Chen Liu, 2014). It further assists in analyzing risks of each possible failure mode and determines the effect of each failure (Hu-Chen Liu, 2014). The focus on this exercise will be on the highest failing components.

To make the most reliable recommendations, the process of data segmentation was used to the highest failing locomotives and the type of failures and compares drawn with normal performing Locomotives in service. This will provide the desired guidelines and responsibility for implementing a failure report and propose corrective actions.

5. Results and Discussion

These are the reliability findings of the 43D Series for Transnet Eastern Corridor

5.1. Failure Type Reliability Analysis

Using engineering reliability analyses, and focusing on the highest failing components; each failure is isolated. A total of nineteen (19) highest failures (table 2) were identified as follows: Noop, Dynamic, Air Pressure, Not Starting, Brakes, Compressor, Motoring, Radio, Oil leaking, Vacuum, Trips, T/Motor, Pipe, Batteries, Lights, Shutdown, Screen, Wipers, and Telemeter. Using the information to calculate Failure Mode and Effect Analysis. The result of this assists in applying a predictive maintenance plan.

Table 2. Failure Type Analysis

Type of Failure	MTBF	MTTR	Failure Rate	Availability

	(Hours)	(Hours)		
NOOP (No Operation)	2290	0.6	0.0005	100%
Dynamic (electrical traction fault)	2290	0.04	0.0005	100%
Air Pressure (Admits air into train pipe through brake valve)	2290	0.03	0.0004	100%
Not Starting	2289	0.41	0.0004	100%
Brakes (braking ability measured through a telemeter)	2290	0.14	0.0004	100%
Compressor	2290	0.15	0.0004	100%
Motoring	2290	0.06	0.0004	100%
Vacuum	2290	0.11	0.0004	100%
Trips	2290	0.12	0.0004	100%
Median	2290	0.12	0.0004	100%

The different types of failures in these locomotives fail within 2290 hours and the time it takes to repair is at a median of 0.12 hours, this means that the restoring the condition does not take time but the failure rate is an average of 3.4 hours of the locomotives total trips.

5.2. Throughput Service Design Times

Throughput service designed times are planned for each train that travels from point A to B, and the dwell times at each station. The service designs reflect the Forward Leg (Loaded trains traveling to Richards Bay) and the Return Leg (Empty trains traveling back to Phalaborwa) at each station respective transit times and dwell times. According to the service design for the forward leg, only two maintenance schedules are planned for the locomotives, at Phalaborwa before the train departs, and at Komatipoort station respectively. The return leg service design indicates that maintenance is conducted at Richards's Bay before the empty train departs, and when it arrives at Komatipoort.

5.3. Highest Failing Locations

The highest failing locations between the transits of the locomotives, gives a better to maintenance team an idea of where the locomotive fails; an indicative on how to resolve the issue. The highest failing locations show high number of failing locomotives predominant at the core locations as per service design. Phalaborwa is the leading failing location with a total of 205 43D locomotives and Komatipoort with 151 failures. The lowest failing locations are in areas of Koorsboom, Fernwood, Kaapmuiden, and so on. These locations are based on the major locations where the train is designed to perform activities.

5.4. Component Failure Analysis

In analyzing component failures, the usage of two methods is applicable, the two methods: the Pareto Analysis and Failure Mode Effect Analysis, which assist in analyzing the causes of failures and which failures need to be compromised as stated in the literature.

5.5. Pareto Analysis

Based on the 80/20 rule, the Component failures (figure 3) are the highest failing components. The analysis shows that the highest failing components are the Noop, Dynamic, Air pressure, Brakes, Compressor, Motoring, Radio, and Oil leaking. This implies that these failures contribute 80% of the failures that are incurred in the 43D diesel locomotive; therefore, preventing these failures will automatically increase the reliability, and will either eliminate or reduce the rest of the components failures.

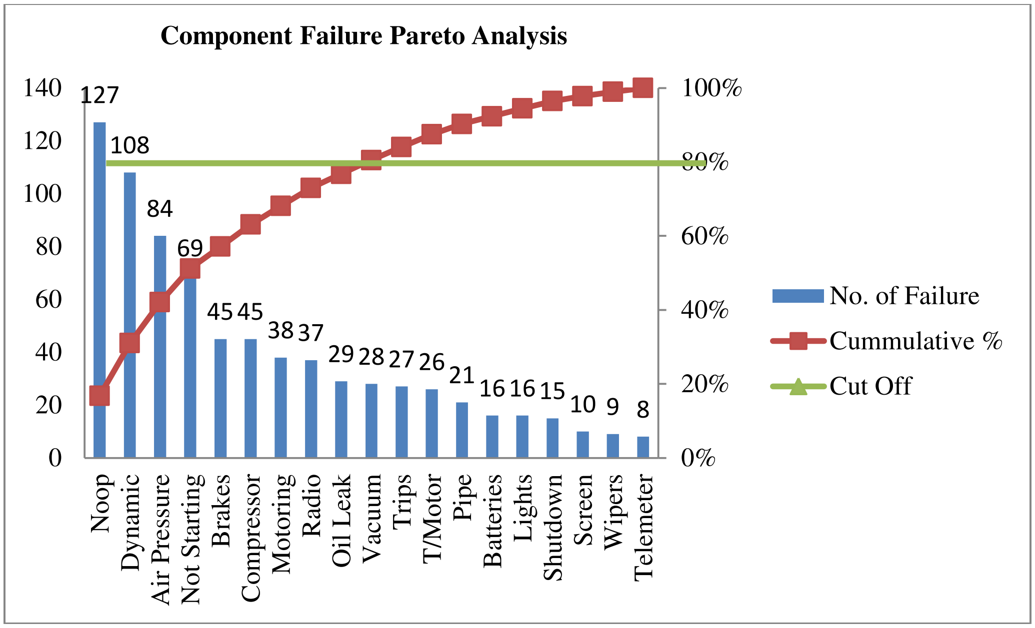

Figure 3. Component Failure Pareto Analysis

5.6. Failure Mode Effect Analysis and Criticality Analysis (FMEA)

The FMEA exercise that was conducted from the highest failing components and the outcome shows that the NOOP, Air Pressure, and Radio are the most risk components prone to failure.

6. Recommendations

Based on the findings, the following are recommended:

1. Reliability and quality to be viewed differently from each other. The South African railway industry must realize that reliable products cannot be achieved without quality and both factors are independent.
2. Maintenance to be scheduled three hours from departure point
3. Maintenance engineers to be placed at the highest locomotive failing locations because MTTR is averaging at 0.12 (7.2 minutes) for each component failure.
4. Conduct proper analysis to be able to eliminate minor failures permanently before planning for major failures. Transnet must prioritize in its maintenance plan.

7. Conclusion

This paper reviewed the maintenance strategy adopted by Transnet. The result show that the strategy in use is good evident by 100% of the availability of components, mean time between failures of 2290 hours per year, mean time to repair of 0.12 hours. This depicts a good run to the failure maintenance strategy management system. The result further show that maintenance of components is not the only challenge but locations and minor service checks are part of the bottlenecks.

Management, all Stakeholders, and design engineers need to ensure that locomotives designed conform with the railway system standards so that the locomotives will be able to perform daily operations without facing much difficulties resulting from either poor infrastructure, design and modelling specifications, or system configurations leading to critical maintenance issues, failures and downtime.

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