South African Rail Infrastructure Maintenance Optimization

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Abstract

Since its inception in 1860 till to date, the South African rail transport sector has had a mixed fortune history. The historical events are separated into different phases, the early development phase, the South African Railways and Harbours (SAR and H) phase, and the current pre-revitalization phase. The primary objective of this study is to identify factors that can be optimized and gaps to ensure execution of maintenance of the railway infrastructure is conducted effectively. This study used a mixed-method approach to collect the information needed to answer the research questions. To collect primary data from the organization, an electronic questionnaire was distributed to 53 practitioners, and South African company maintenance documents were used to collect secondary data. The study identified material availability, skilled person availability, rail track availability and traffic delays, a lack of a properly scheduled maintenance and asset renewal program, a lack of maintenance history data, asset age, and weather conditions as factors influencing maintenance execution. Infrastructure investment, regulations, monopoly protection in the railway sector, and a lack of management training were identified as gaps that require special attention. Furthermore, the organization provided procedures and policies for maintenance execution, according to the research; however, these procedures and policies do not appear to be followed.

Keywords
Maintenance, Railway, Optimization, Factors and Execution.

1. Introduction
Maintenance of railway infrastructure is critical to have an efficient functioning transportation system (Liden, 2015). Lack of maintenance can cause deterioration of the infrastructure which results in the unavailability of the rail network having a detrimental impact on the business revenue. A maintenance strategy is a systematic approach to equipment upkeep that includes identifying, researching, and carrying out repairs, replacing and inspecting equipment, and formulating the optimal life plan for each facility in collaboration with other departments (Bhebhe and Zincume, 2020). A maintenance strategy is seen as an organization's overall direction, which includes one or more maintenance approaches. One or more maintenance strategies are seen as part of the maintenance methodology. It includes tools that can be used to put maintenance initiatives into action.

The historical events that have shaped South Africa's history have had a considerable impact on the rail industry's development, and this, together with other external forces, has resulted in a railway industry that currently faces numerous challenges (Department of Transport 2015). These challenges include ageing, deteriorating, and obsolete conditions of the rail infrastructure and rolling stock, perceived underutilization of parts of the existing rail network, and a capital investment backlog. The associated need for investment funds is a preference by logistics service providers and shippers for transporting many categories of natural rail freight by road. According to George et al. (2018), given South African Company anticipated capacity and volume increases, the freight rail network, particularly rail infrastructure, is expected to be heavily strained. Due to that, adequate rail infrastructure performance is critical for guaranteeing safe and dependable rail operations, tracking the frequency of operational incidents can provide insight into the condition of rail infrastructure (George et al. 2018). In order to address the poor state of the rail

infrastructure condition, South African Company implemented the annual maintenance shutdowns where no train services would operate for five to ten days depending on the corridor or business unit.

According to Rail Safety Regulator (2021), since the 2010/11 reporting year, there has been a 2% decline in all derailments per million railway kilometres. However, since the 2010/11 reporting year, train kilometres have reduced by 53%, effectively cancelling out the improvement in derailments per million train km. This is to some effect due to the deterioration of the rail infrastructure in South Africa. When comparing the 2019/20 reporting period to the 2020/21 reporting there was a 15% drop in total train derailments. However, when normalized to per-million train km, the same data period shows a 38% rise (Rail Safety Regulator 2021).

In 2019, freight trains hauled a total of 215,1 mt, a decrease of 4,9% from the previous year (2018: 226,3 mt) and a 10% shortfall from the estimated budget of 241,2 mt. The current infrastructure maintenance approach is unable to improve railway conditions; thus, this study aimed at providing factors that should be optimized to effectively improve South African railway conditions.

1.1 Objectives
The primary objective of this study is to identify factors that can be optimized and will ensure execution of maintenance on the railway infrastructure is conducted effectively. It will also identify gaps in the optimization of the railway infrastructure maintenance execution in South Africa.

2. Literature Review
In general, maintenance is described as the collection of all technical and administrative tasks, including monitoring, that assures a system's proper operation (Basri, et al. 2017). The need for maintenance will always be present in production machines, equipment, and devices. The growth of the industry is accompanied by the advancement of maintenance. Maintenance has been a necessity for mankind from the dawn of time when it began to create gadgets that met their needs. Maintenance actions such as repairing, replacing, overhauling, inspecting, servicing, adjusting, testing, measuring, and detecting faults are normally associated with maintaining a system to avoid any breakdown that would result in interruptions in production operations (Basri, et al. 2017). According to Poór et al. (2019) maintenance records can be traced dating back to ancient Egypt. An old Egyptian text from 600 B.C. recounts a shortage of cedar wood needed for the upkeep of Amun Ra's sacred boat (Poór, et al. 2019). For many years, maintaining a system's product lifecycle has been an expensive and onerous task (Prajapati, et al. 2012). Various ways to minimize failures or correct historical failures of a system have been examined, the most common of which is increasing the frequency of maintenance actions. To solve the problems and inefficiencies of the previous generation maintenance system, one improvement suggestion after another has been tried. Maintenance was still seen as a greasy, dirty job with little substance. Different realities emerged from the practice of upkeep. Maintenance expenses were rising, and the service availability of the systems that needed to be maintained was at an all-time low.

Throughout the years, the method of maintenance has evolved. It has evolved from reactive (corrective) actions to continuous predictive activities to reduce time, cost, and quality (Poór et al. 2019). Maintenance is thought to be a crucial component of effective production. A proper maintenance approach can help you save money on maintenance execution (Gackowiec 2019). While it is now recognized as a competitive advantage or an area where development can boost profit and provide several benefits, some people still regard maintenance as a need (Poór et al. 2019).

2.1. Maintenance Strategies
Researchers have proposed several maintenance strategies. Their application, however, differs from one organization to the next. The maintenance approach is determined by the organization, available maintenance resources, and capabilities. Different maintenance schedules have a direct impact on the system's reliability and long-term viability (Mhlongo 2021). According to Nazeri and Naderikia (2017), among many other researchers, the most prevalent maintenance strategies are:

2.1.1 Reactive maintenance
This maintenance strategy includes corrective and run-to-failure maintenance techniques. Systems, subsystems, or components are permitted to run until they fail in this type of maintenance strategy. Based on Bhebhe (2020), this type of maintenance strategy is the oldest. This method allows the company to minimize the number of maintenance employees necessary to a minimum. Only defective components are repaired, and usually only to the point where they can be put back into service. Corrective maintenance is cited as the simplest, but most expensive, strategy because it

is utilized in response to breakdowns and all their effects (Gackowiec 2019). Failure-based or unscheduled maintenance is another title for the mentioned technique.

2.1.2. Preventive maintenance

The goal of preventive maintenance is to keep the equipment running while considering the costs of failure. Tasks are scheduled during machine stoppages or shutdowns to replace components before they fail. This maintenance strategy includes time–based maintenance and routine services. One of the goals of preventative maintenance, according to Stenström, et al. (2016), is to assure component reliability, availability, and safety. Simple preventive maintenance and preventive replacement are part of the maintenance approach while the system is functioning. Lubricating, cleaning, adjusting, tightening, and basic repairs are all examples of simple preventive maintenance. Preventive maintenance is an important part of any facility's management. It contributes to equipment longevity, reduced unplanned downtime, and, eventually, lower long-term maintenance expenses.

2.1.3. Predictive maintenance

Predictive maintenance was implemented to reduce failure rates, and repair rates, assess equipment conditions in real-time, detect equipment problems before they break down, reduce downtime, and improve the maintenance department's and organization's readiness (Bhebhe 2020). Predictive maintenance includes condition-based maintenance and inspections. The Rio Grande Railway Company originally introduced the concept of condition-based maintenance (CBM) in the late 1940s, calling it "predictive maintenance."

2.2. Factors Affecting the Implementation of Maintenance in The Railway Infrastructure Sector

The following factors have been identified from the literature to be affecting the implementation of maintenance in the railway infrastructure sector:

Table 1. Summary of factors affecting the implementation of railway maintenance

Factor	Description	Reference
Material availability	Resources like spare parts, tools, and maintenance staff should always be available to minimize the effects of reactive maintenance.	Bhebhe and Zincume, 2020
Skilled people availability	Research has demonstrated over time, according to Organ et al. (1997), that people, not technology or computer systems, are what will determine the success of organizations in the future. The majority of the time, maintenance is performed by unskilled employees, which compromises the standard of maintenance processes and the availability of equipment.	Kumar, et al., 2006 Bhebhe and Zincume, 2020
Rail track availability and traffic delays	Controlling train traffic while conducting an inspection is a crucial concern. It can be exceedingly challenging to stop train movement on some rail routes to conduct rail inspection and maintenance.	Kumar, et al., 2006
Weather conditions	A crucial element is the weather. Rail replacement and rerailing could only be done in the summer in cold nations like Sweden.	Kumar, et al., 2006
Unavailability of a proper scheduled maintenance and asset renewal program.	Long unplanned interruptions in the service to customers due to the unavailability of a proper scheduled maintenance and asset renewal program.	Liden, (2015) Eskandarzadeh, et al., (2019)
Flawed traffic information	The infrastructure manager has no indication of how much traffic is on the track, let alone what kind of traffic, vehicle kinds, axle weight, or speed is being operated	Espling, (2007)
Asset age is not always recorded in the asset system	Determining the current state based on how much traffic it has been exposed to is difficult.	Espling, (2007)
Lack of maintenance history data	The lack of maintenance history data makes it challenging to follow time-based preventative maintenance practices because it is unknown when the asset was last maintained.	Espling, (2007)

2.3. Gaps in the optimization of railway infrastructure maintenance execution in South Africa

Below is a summary of identified gaps in the optimization of railway infrastructure maintenance execution in South Africa:

Table 2. Summary of gaps in the optimization of railway infrastructure maintenance execution in South Africa

Gaps	Description	Reference
Lack of infrastructure investment	The rail networks are no longer able to significantly contribute to economic growth due to their deteriorated conditions.	African Development Bank Group, (2015) (Department of Transport, 2015)
Lack of management knowledge and training	Due to this gap, poor decisions are made by managers.	Phaladi, et al., (2019)
Common technical standards and regulations between public and private railway sectors	In order to ensure successful and efficient infrastructure, a a fully integrated approach to policy, planning, and delivery of infrastructure across sectors is needed.	African Development Bank Group, (2015) (DPME, 2015)
Regulations protecting monopolies in the railway sector	Implementation of regulations that will allow competition within the railway sector.	African Development Bank Group, (2015) (DPME, 2015)
Open access to infrastructure for third parties	Granting concessions to allow private sectors to operate and maintain rail infrastructure.	African Development Bank Group, (2015) (DPME, 2015)

3. Methods

The case study method's benefits include the ability to convey the complexities of real-life situations so that the phenomenon being studied can be studied in greater detail, as well as the collection and analysis of data to make sense of the concept and assimilate structured and unstructured data to be processed using data analysis (Mhlongo 2021).
This study utilized internal secondary data acquired from the company's quality management documentation to gain a thorough understanding of the execution of maintenance on the railway lines.

When doing a case study, care must be taken to prevent the case from being misrepresented and to increase the likelihood of getting access to the data required to gather the evidence. Consequently, the following was done:

- To comprehend the optimization of the execution of railway infrastructure maintenance, a thorough literature review was carried out.
- Getting permission from South African Company to conduct the research allowed access to the appropriate company documents, which contained the crucial and pertinent data for the study.
- Using a variety of data-gathering techniques, improved the accuracy of the results of the data analysis since participants' responses to the questionnaire were contrasted with information gleaned from an examination of company documents.

This part of the research also aims to collect data using a questionnaire. According to Jivan, (2019), a set of questions that are simple to comprehend must be developed and given in a standardized format before a questionnaire can be used. The use of a questionnaire also enables more people to be assessed because it is a faster technique than getting data through oral responses.
A case study was shown to be a more effective method of identifying, exploring, and examining these issues as well as the deficiencies of the existing maintenance execution in the South African railway industry.

4. Data Collection

Data collection is the process of acquiring and analysing information on relevant variables in a predetermined, methodical way so that one can respond to specified research questions, test hypotheses, and assess results (Sreejesh, 2014). Although techniques differ depending on the profession, the importance of ensuring accurate and truthful collection does not change. The collection of data for a case study benefits greatly from the use of multiple sources of

evidence, thus the researcher should avoid using only one (Prins 2019). Data triangulation, the process of using many sources of evidence to support a conclusion, aims to increase the construct validity of the study.

Any data collection aims to gather high-quality evidence, which can then be used to conduct extensive data analysis and create a solid case for answering a given question. Accurate data collecting is crucial to preserving the integrity of research, regardless of the subject of study or preferred method for defining data (qualitative, quantitative). Sreejesh (2014), stated that the risk of errors occurring is decreased by choosing appropriate data-gathering tools (current, modified, or newly invented) and by providing clear instructions for how to utilize them properly. Data was acquired via the questionnaire and the South African Company maintenance reports.

5. Results and Discussion

This study relied on two data sources: a questionnaire and secondary data, as well as the assistance of case study employees. Section 5.1 contains information regarding the questionnaire and sections 5.2 and 5.3 results from the questionnaire, while Section 5.4 has information about secondary data.

5.1 Numerical Results

The questionnaire was distributed to a total of 53 participants, of whom 43 provided complete responses. This results in a response rate of 81%; according to Fincham, (2008) and Legobe, (2020), the typical response rate to an online questionnaire is between 25% and 30%. This suggests that the study's completed response rate (81%) is satisfactory. As part of the research study, the questionnaire gathered general data from the respondents. It was a closed-ended question that provided alternatives for the pertinent roles. Each respondent was asked to indicate their position within the company and the number of years they had worked in a maintenance environment for railway infrastructure, see below Table 3.

Table 3. Respondents' Profile (N= 43)

Roles and Responsibilities	**Counts**	**Percentage**
Maintenance Manager	10	23%
Engineering Manager	4	9%
Track Inspector	2	5%
Engineer (maintenance planning)	3	7%
Engineering Technician	17	40%
Production Manager	2	5%
Foreman	2	5%
Welding Superintendent	2	5%
Technical Supervisor	1	2%
Total	**43**	**100%**
Experience	**Counts**	**Percentage**
6-10 years	17	40%
11-15 years	10	23%
>16 years	6	14%
0-5 years	10	23%
Total	**43**	**100%**

According to above Table 3, engineering technicians (40%); maintenance managers (23%); engineering managers (9%); engineers (7%); track inspectors, production managers, foremen and welding superintendents (5%) and technical supervisor (2%), respectively, had the largest percentage of responses. The results are anticipated in this order because engineering technicians, maintenance managers, and engineers all play a significant role in the planning and acquisition of necessary resources for maintenance, while track inspectors, engineering managers, and production managers play a role in the execution. Table 1 further elaborate on the respondents' number of years of experience, 40% of participants have 6-10 years of experience, 23% have 11-15 years, and 14% have more than 16 years of experience in the railway infrastructure maintenance environment. The participants in this study had a good experience and they were in positions of authority in infrastructure maintenance, so their feedback can be relied on for this study.

5.2 Factors affecting the execution of maintenance

To assess the factors affecting the execution of maintenance, we use eight factors which had a high internal consistency (Cronbach's Alpha = 0.859). Material availability (M=4.698, Std=0.674) was rated very high which was followed by skilled people availability (M=4.116, Std=0.905). But the flawed traffic information (M=3.372, Std=0.952) was identified as one of the least factors affecting the execution of maintenance.

Table 4. Factors affecting the execution of maintenance analysis

Factors	Number of Respondents	Standard Deviation (Std)	Mean (M)	Ranking
Material availability	43	0.674	4.698	1
Skilled people availability	43	0.905	4.116	2
Rail track availability and traffic delays	43	1.017	3.674	3
Unavailability of a properly scheduled maintenance and asset renewal program	43	1.096	3.581	4
Lack of maintenance history data	43	1.036	3.571	5
Asset age is not always recorded in the asset system	43	0.983	3.558	6
Weather conditions	43	1.032	3.488	7
Flawed traffic information	43	0.952	3.372	8

5.3 Gaps in the optimization of the railway infrastructure maintenance execution

We use six items with high internal consistency (Cronbach's Alpha = 0.806) to assess the gaps identified in maintenance execution. Lack of infrastructure investment (M=4.233, Std=0.947) was rated very high which was followed by regulations protecting monopolies in the railway sector (M=3.628, Std=1.155). However, common technical standards regulations between the public and private railway sectors (M=3.302, Std=0.939); open access to infrastructure for third parties (M=3.326, Std=1.190); Lack of management knowledge (M=3.395, Std=1.027) were identified to have little to no impact on the execution of maintenance activities affecting maintenance execution optimization.

Table 5. Gaps in the optimization of the railway infrastructure maintenance execution analysis

Gaps	Number of Respondents	Standard Deviation (Std)	Mean (M)	Ranking
Lack of infrastructure investment	43	0.947	4.233	1
Regulations protecting monopolies in the railway sector	43	1.155	3.628	2
Lack of management training	43	1.142	3.488	3
Lack of management knowledge	43	1.027	3.395	4
Open access to infrastructure for third parties	43	1.190	3.326	5
Common technical standards and regulations between public and private railway sectors	43	0.939	3.302	6

5.4 Secondary data analysis

This part contains the findings from the secondary data analysis, which was carried out using technical specifications, audit reports, maintenance procedure documents, maintenance manuals, MICA (maintenance infrastructure condition assessment) manuals, and on-site reports. These documents contain information about railway maintenance South African Company's compliance with the execution and management of maintenance activities. A checklist based on the literature was developed for secondary data collection to determine and confirm the elements of interest. The primary researcher's major responsibility was to mark the appropriate boxes with an "X" to indicate whether the item

under inquiry was available or not. Table 6 displays the checklist that was created to display whether the items were available

Table 6. Level of Compliance Checklist

Item	Complied		Comments
	Yes (26%)	**No** (74%)	
Asset management procedure	X		The asset management procedure was shared with the researcher.
Maintenance standard procedure	X		South African Company has a set of maintenance standards which every rail network department must comply with the execution of maintenance based on what the standard says.
Meeting minutes between planning and production teams	X		There were records of meetings between the production and maintenance divisions, however, the frequency of these meetings varied.
Maintenance budget	X		Details of approved operational expenditure and capital expenditure the budget was provided. Provide details of the approved budget for the current financial year, i.e., forecast, cash flow, major breakdowns, and minor breakdowns (indicate those that were classified as emergencies).
Maintenance plan schedule		X	The various departments were not able to provide their weekly, monthly and yearly maintenance plan
Compliance with the maintenance schedule		X	The maintenance schedule could not be followed due to the supply chain delays and budget restrictions.
Records of maintenance infrastructure condition assessment inspections		X	Non-adherence to manual for infrastructure condition assessment inspections, no data was supplied on all inspections done on assets
Depot management (Production and Maintenance Managers) in possession of latest Electrical Safety Instructions, Maintenance Manuals, Maintenance schedules, Written Safe Working Procedures and Technical Procedures		X	Depot does not have the latest Electrical Safety Instructions BBF 3690 V2.
latest standards and procedures shared by Production Manager with his/her subordinates	X		Procedures have been shared
Record of planned maintenance vs actual maintenance done		X	Some departments could not provide their records of planned vs actual maintenance plans.
Comply with the manual for infrastructure condition assessment standards		X	It was observed that the manual for infrastructure condition assessment standard for ultrasonically measuring the railway line 4 times a year was not adhered to.
Minimum Measurement Frequencies for the ultrasonic measuring car (UMC) as stipulated in MICA Element 20.		X	Operational expenditure budget constraints before 2019/2020 FY
Comply with the Standard Corrective Actions for UMC Defect removal		X	No contract for the supply of thermite at the beginning of 2019/20FY and no supply of turnout components and rails.
Grinding of the rail profile has been done according to million gross tons (MGT) interval.		X	No Operational expenditure Budget allocation Between 2015 and 2019

Table 6. Level of Compliance Checklist continues

Item	Complied		Comments
	Yes (26%)	**No** (74%)	
Adherence to the stipulated radiographic testing regime.		X	The permanent way department does not comply with radiography testing of new welds as per the manual for radiography testing stipulate. All new welds should be radiographically tested within 7 days of being cast.
The failure rate of welder's adherence to threshold of 5%		X	Most welders' failures are above the 5% threshold as per the welding manual requirement, this finding was indicated in the welding assurance audit report.
Execution of routine preventative maintenance for major assets forms part of the maintenance plan		X	Through discussion with the Perway Maintenance Manager, the was evidence that Routine Planned Maintenance (RPM) for Major Assets did not form part of the maintenance plan
Tracking of the annual maintenance Shutdown project costs against budget and analysis on costs	X		Some of these projects including the major rail replacement projects that was cancelled due to a lack of materials
The strategy of the shutdown is focused on utilizing the maintenance window to inspect, repair, replace and refurbish assets in order to ensure availability and reliability when needed.		X	It was indicated that there was an increase in the number of breakdowns for some assets partially maintained during the shutdown was due to substandard work executed and reworks required to be done i.e., welding joints failed and needed to be recasted.
Technical officer and Electrical Officer needs to be trained.		X	Depot engineering team needs training for infrastructure measuring vehicle for condition assessment.
Data integrity issues and concerns.		X	Results were found to be not complete; the records of other months were not captured in the maintenance system.
Effective sufficient resources		X	Depot does not have sufficient resources to form a complete and effective welding team
Trained personnel for the investigation of occurrences		X	Some departments personnel did not attend the rail incident commander training where they are found competent to conduct investigation of occurrences.
Supply chain management policy	X		The supply chain management policy was shared with the researcher.
People management policy	X		The people management policy was presented to the researcher.
Adherence to Safe Operating procedures		X	There was no Safe Operating Procedure (SOP), or Safe Working (SWP) provided for Radio High Site.
Does the condition of the substation comply with the minimum requirements of the Safety Management System (SMS) Determination		X	The measuring instrument submitted by Company X was last calibrated on 19 October 2016. Therefore, measurements may not be the true reflection and unreliable.
The team responded within the set standard time.		X	Response times are only recorded on job cards. No standard time available.
Corrective actions developed and implemented.		X	High-level plan for Perway available, but no due dates or responsible person, or active status.
The mean time to repair managed.		X	Mean time to repair not measured. Only recorded on job cards.
Approval of Total occupations for maintenance		X	It was observed that tracking occupations for maintenance execution are not approved and there was also no evidence that they were replanned, this indicates that maintenance activities are not executed.

5.5 Validation

The triangulation of data into a matrix is part of the analytical process. Any discrepancies between the data gathered from the questionnaires and documents were found using the triangulation of data. The literature review identified factors that can be optimized and ensure execution of maintenance activities on the railway infrastructure was conducted effectively. It also identified gaps in the optimization of the railway infrastructure maintenance execution in South Africa. The findings of the literature and industry comparison are shown in Table 7 below:

Table 7. Literature Review and Industry Practice Comparison

Variables	Literature Review	Industry Practice
Material availability	Material availability was identified as a factor affecting the execution of maintenance (Bhebhe and Zincume, 2020).	The respondent agreed that material availability was one of the factors affecting optimal maintenance execution in the railway sector. The organization does have a supply chain management policy however it was observed that there is non-compliance with the maintenance schedule due to delays in the supply chain and budget restrictions. In support, some of the projects during the annual maintenance shutdown had to be cancelled due to a lack of materials.
Skilled people availability	Chapter 2 revealed that skilled people availability is a factor affecting the execution of maintenance in the railway sector. (Kumar, et al., 2006) and (Bhebhe and Zincume, 2020)	Respondents agreed that skilled people were one of the issues affecting optimal maintenance execution in the railway sector. The organization does have a people management policy although it was indicated in the checklist that the depot does not have sufficient resources to form a complete and effective welding team.
Rail track availability and traffic delays	(Kumar, et al., 2006) identified rail track availability and traffic delays as a factor affecting the execution of maintenance.	The respondent agreed that rail track availability and traffic delays impacted the execution of maintenance in the railway sector. In the checklist, it was indicated that the mean time to repair is not measured to impact the asset availability and track occupations for execution of maintenance are not approved indicating non-compliance to the maintenance plan.
Unavailability of a proper scheduled maintenance and asset renewal program.	The literature revealed that the unavailability of a proper scheduled maintenance and asset renewal program is a factor affecting the execution of maintenance. Liden, (2015) and Eskandarzadeh, et al., (2019)	Respondents agreed that the unavailability of a proper scheduled maintenance and asset renewal program played a role in optimal execution of maintenance. Although the organization provide the procedure but there was some indication of non-compliance to the procedure because grinding is not done, and maintenance is not executed as per the maintenance plan.
Flawed traffic information	Espling, (2007) identified flawed traffic information as a factor affecting the execution of maintenance in Chapter 2.	The results (M=3.372, Std=0.952) suggested that this is an area that requires further investigation in the South African context, people had mixed views. It was noted in the checklist that there are data integrity concerns as records of other months were not captured in the maintenance system.
Lack of infrastructure investment	The literature identified a lack of infrastructure investment as a gap in the optimization of maintenance. African Development Bank Group, (2015) (Department of Transport, 2015)	Respondents agreed that the lack of infrastructure investment as a gap in the execution of maintenance. The departments provided their capital expenditure budgets although there was an indication in the checklist that there were budget restrictions hence non-compliance with the maintenance schedule.
Common technical standards and regulations between public and private railway sectors	The literature identified common technical standards regulations between public and private railway sectors as a gap in the optimization of maintenance. African Development Bank Group, (2015) (DPME, 2015)	The results (M=3.302, Std=0.939) suggested that this is an area that requires further investigation in the South African context, people had mixed views.
Weather conditions	(Kumar, et al., 2006) identified weather conditions as a factor affecting the execution of maintenance in the railway sector.	The results (M=3.488, Std=1.032) suggested that people agreed that weather conditions do have an impact to the execution of maintenance in the railway sector.

Variables	Literature Review	Industry Practice
Asset age is not always recorded in the asset system	Espling, (2007) identified asset age is not always recorded in the asset system as a factor affecting the execution of maintenance in Chapter 2.	Respondents agreed that asset age is not always recorded in the asset system and impacted the optimal execution of maintenance. The organization does have an asset management procedure although in the checklist it was indicated that there are data integrity concerns as records of other months were not captured in the maintenance system.
Lack of maintenance history data	Espling, (2007) identified a lack of maintenance history data as a factor affecting the execution of maintenance in Chapter 2.	The results (M=3.571, Std=1.036) suggested that people agreed that lack of maintenance history data impacted the execution of maintenance in the railway sector in the South African context, in the checklist it was indicated that some departments could not provide their records of planned vs actual maintenance plans.
Lack of management knowledge	The literature identified a lack of management knowledge as a gap in the optimization of maintenance. Phaladi, et al., (2019)	The results (M=3.395, Std=1.027) suggested that this is an area that requires further investigation in the South African context, people had mixed views.
Lack of management training	The literature identified a lack of management training as a gap in the optimization of maintenance. Phaladi, et al., (2019)	The results (M=3.488, Std=1.142) suggested that people agreed that lack of management training does have an impact on the execution of maintenance in the railway sector. In the checklist, it was indicated that the depot engineering team needs training for infrastructure measuring vehicles for condition assessment and some department personnel did not attend the rail incident commandeer training.
Regulations protecting monopolies in the railway sector	The literature identified regulations protecting monopolies in the railway sector as a gap in the optimization of maintenance. African Development Bank Group, (2015) (DPME, 2015)	The results (M=3.628, Std=1.155) suggested that people agreed regulations protecting monopolies in the railway sector do have an impact on the execution of maintenance in the railway sector.
Open access to infrastructure for third parties	The literature identified open access to infrastructure for third parties as a gap in the optimization of maintenance. African Development Bank Group, (2015) (DPME, 2015)	The results (M=3.326, Std=1.190) suggested that this is an area that requires further investigation in the South African context, and people had mixed views.

6. Conclusion

The primary objective of this study is to identify factors that can be optimized and will ensure execution of maintenance on the railway infrastructure is conducted effectively. It will also identify gaps in the optimization of the railway infrastructure maintenance execution in South Africa. This study used a mixed-method approach to collect the information needed to answer the research questions. An electronic questionnaire was distributed to the chosen participants in order to collect data from the organization's various sources and South African Company maintenance documents analysis was used as a case study.

The literature revealed various factors and gaps that affect the implementation of maintenance execution in the railway sectors as; material availability, skilled people availability, rail track availability and traffic delays, unavailability of a proper scheduled maintenance and asset renewal program, lack of infrastructure investment, weather conditions, asset age is not always recorded in the asset system, lack of maintenance history data, lack of management training and regulations protecting monopolies in the railway sector.

People had mixed views that flawed traffic information, common technical standards regulations between public and private railway sectors, lack of management knowledge and open access to infrastructure for third parties as factors or gaps affecting the execution of maintenance on the railway infrastructure in the South African context. The organization provided procedures and policies for maintenance execution, according to the research; however, these procedures and policies do not appear to be followed. It is recommended that the organisation develop strategies to ensure compliance with the set rules and procedures.

References

Basri, E. I., Razak, I. H. A., Ab-Samat, H. and Kamaruddin, S., Preventive maintenance (PM) planning: a review. Journal of Quality in Maintenance Engineering, 23(2), pp. 114-143, 2017.

Bhebhe, M., Influence of different maintenance strategies on the availability of rolling stock, Stellenbosch: Stellenbosch University https://scholar.sun.ac.za,2020.

Bhebhe, M. and Zincume, P. N., MAINTENANCE STRATEGIES IN THE RAIL ENVIRONMENT. SAIIE31 Proceedings, 5th – 7th October 2020, Muldersdrift, South Africa © 2020 SAIIE, 2020.

Department of Transport, National Rail Policy Green Paper, s.l.: s.n, 2015.

Fincham, J. E., Responce rates and responsiveness for surveys, standards and the journal. American Journal of Phamaceutical Education, 2008.

Gackowiec, P., General overview of maintenance strategies – concepts and approaches. Multidisciplinary Aspects of Production Engineering, 2(1), pp. 126-139, 2019.

George, T. B., Mokoena, R. and Rust, F. C., A REVIEW ON THE CURRENT CONDITION OF RAIL INFRASTRUCTURE IN SOUTH AFRICA. 37th Annual Southern African Transport Conference, pp. 1-12, 2018.

Jivan, K. P., Influence of organisational culture in the adoption of agile, Johannesburg: University of Johannesburg, 2019.

Legobe, K., Requirement verification and validation activities to improve the quality of railway technologies, Johannesburg: University of Johannesburg, 2020.

Liden, T., Railway infrastructure maintenance - a survey of planning problems. 18th Euro Working Group on Transportation, EWGT 2015, 14-16 July 2015,, pp. 574-583, 2015.

Mhlongo, N. G.,Improving the reliability of railway signalling systems, Johnnesburg: University of Johannesburg, 2021.

Nazeri, A. and Naderikia, R., A new fuzzy approach to identify the critical risk factors in maintenance management. International Journal of Advanced Manufacturing Technology, 92(9-12), p. 3749–3783, 2017.

Nxele, N., Public Transit and Crime. An exploratory study on commuter's perceptions of crime in Metrorail trains: A case study of Durban station.. KwaZulu Natal: University of KwaZulu-Natal, 2021.

Poór, P., Ženíšek, D. and Basl, J., Historical Overview of Maintenance Management Strategies: Development from Breakdown Maintenance to Predictive Maintenance in Accordance with Four Industrial Revolutions. Czech Republic, University of West Bohemia, 2019.

Prajapati, A., Bechtel, J. and Ganesan, S., Condition based maintenance: a survey. Journal of Quality in Maintenance Engineering, 18(4), pp. 384-400, 2012.

Prins, S., The measurement of cybersecurity awareness in an industrial control systems company, Johannesburg: University of Johannesburg, 2019.

Rail Safety Regulator, State of Report 2022/2021, Johannesburg: RSR, 2021.

Sreejesh, S.,. In: S. S, ed. Business Research Methods. Switzerland: Springer International Publishing, pp. 143-159, 2014.

Stenström, C., Norrbin, P., Parida, A. and Kumar, U., Preventive and corrective maintenance – cost comparison and cost–benefit analysis. Structure and Infrastructure Engineering. Taylor and Francis, 12(5), pp. 603-617, 2016.

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