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The Level of Maintenance Management Maturity in the South African Rail Network

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Abstract

The South African Institution of Civil Engineering released a fourth infrastructure report, highlighting the deteriorating state of the country's rail network infrastructure. Lack of maintenance has been identified as the root cause of this problem, leading to a decline in the efficiency and competitiveness of the transportation sector. The current state of infrastructure is expected to increase the number of infrastructure failures, maintenance costs, train cancellations and operating costs. To address capacity demand and maintain quality services, it is essential to adopt effective maintenance management tactics. This study aims to evaluate the maturity level of maintenance management in the South African rail network industry and identify deficiencies and opportunities to enhance existing maintenance processes. This will help to improve the maintenance function, leading to a reduction in infrastructure deterioration. This study conducted an exploratory quantitative survey to assess the overall maturity level of maintenance management in the South African rail network industry, and it was found to be at Level 3. Technological knowledge in the organization seems to be in its early stages. The organization needs to change its perspective on technology and invest in technological advancements to improve the maturity level of this element. As part of future work, research can be conducted on how to align rail network maintenance practices with the advancements brought by Industry 4.0, and the application of these technologies in railway maintenance management.

Keywords
Maintenance Management, Maturity Model, Critical Success Factors, and Rail Infrastructure Deterioration

1. Introduction
The South African railway network comprises passenger and freight transportation. The urban rail infrastructure for passenger transport is owned by the Passenger Rail Agency of South Africa (PRASA), whereas general freight and heavy-haul railway lines are owned and operated by the ((TFR). The Gautrain rapid rail link, which is owned through a private-public partnership, is also part of the passenger rail network.

The South African Institute of Civil Engineering (SAICE) found that the railway infrastructure was not in a good enough state to support the country's economic growth. The increased dynamic loading imposed on deteriorating track infrastructure increases the likelihood and severity of train derailments, environmental damage, threats to passenger safety, and revenue loss. Another study (Govender 2019) also emphasized the country's rapidly deteriorating infrastructure; as a result, deficiencies in maintenance practices and strategies threaten economic growth. It focused on analyzing public infrastructure maintenance philosophies to gain a deeper understanding of the causes of infrastructure deterioration and to take lessons from the findings that will enable the improvement of infrastructure maintenance interventions in South Africa. Derailments on mainlines climbed from 65 in 2019 to 88 in 2020 (Transnet Freight Rail 2020). This increase was primarily due to poor track conditions, such as (broken rails, defective crossings, and gauge widening). These failures resulted in a drop in capacity, higher maintenance costs, and failure to reach

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annual targets (Transnet Freight Rail, 2020). Matsaung (2019) stated that TFR and PRASA employ routine maintenance techniques. This means that there are predetermined inspection and maintenance intervals for both mechanical and manual processes. This traditional routine maintenance may result in unnecessary actions that do not guarantee asset reliability, and late maintenance interventions may risk train operations and cause service delays. The South African rail network infrastructure has deteriorated because of these maintenance management strategies.

1.1 Objectives

This study aimed to determine the maturity level of maintenance management in the South African rail network industry. This assessment will assist in identifying existing shortcomings and opportunities for enhancing the railway maintenance processes which will further assist the rail network industry in improving their maintenance function leading to the reduction of infrastructure deterioration and failures.

2. Literature Review

The maintenance paradigm is changing with the growing competitiveness of the market, coupled with the increase in automation driven by the advent of Industry 4.0 (Cardoso and Ferreira 2021). This has resulted in the role of maintenance receiving increasingly more attention as organizations are realizing that to stay competitive, it is necessary for companies to continually increase the effectiveness and efficiency of their maintenance processes (Cachada, Barbosa, Leitno, Gcraldcs, Deusdado, Costa, Teixeira, Moreira and Romero 2018). The concept of critical success factors has been utilized to present and identify the key factors that organizations should concentrate on to successfully implement maintenance management strategies.

2.1 Critical success factors

Soltanali, Khojastehpour, and Khaybar's (2023) study, which focused on maintenance management in agro-industries, found that several factors are critical to the successful implementation of maintenance management, such as commitment and support from top management, employee awareness of maintenance goals and strategies, well-established organizational structure, and monitoring performance through measurement and analysis. According to the findings of Bukhsh and Stipanovic (2020), one of the primary obstacles to the implementation of predictive maintenance solutions is the lack of a vision of digitization and its prospective benefits to the organization from top management. Other significant factors reported in this study include collecting and handling vast amounts of data from the continuous monitoring of assets, as well as the development of innovative technologies. Similarly, Karuppiah, Sankaranarayanan, and Ali (2021) identified a lack of leadership dedication and a need for reliable data and innovative technology that can aid in sustainable maintenance management. Singh and Gurtu (2022) concluded that the critical success factors for implementing total productive maintenance were organizational culture, people involvement, management commitment, implementation plan, information system focus, and quality management, which are all necessary components for successful maintenance. The identified CSF are provided in the first column, followed by the anticipated benefits in the second column and the authors in the final column, as shown in Table 1.

Table 1. Benefits of the critical success factors

Critical success factors	**Expected benefit if fully implemented**	**Author**
People involvement	When employees feel empowered, they are more likely to show higher levels of engagement and motivation toward their work resulting in improved performance, work quality and reduced employee turnover rates.	Singh & Gurtu (2022) ; Soltanali et al., (2023)
Organizational culture	A positive organizational culture fosters an environment where employees are motivated to seek out opportunities for improving business processes.	Singh & Gurtu (2022); Soltanali et al., (2023)
Technology	Through the use of advanced technologies, maintenance managers can be able to predict future	Bukhsh and Stipanovic, (2020); Karuppiah, Sankaranarayanan and Ali (2021)

Critical success factors	**Expected benefit if fully implemented**	**Author**
	asset failures which will enable them to recommend optimal preventive measures.	
Leadership	When senior management is fully committed to maintenance management, the allocation of fundamental resources, such as funding and manpower, will be prioritized for the successful implementation of maintenance strategies. By prioritizing maintenance, management can ensure that maintenance strategies are by the organization's strategic goals.	Bukhsh and Stipanovic (2020); Karuppiah, Sankaranarayanan and Ali (2021); Singh and Gurtu (2022); Kalpande and Toke (2023); Soltanali, Khojastehpour and Kheybari (2023)
Performance measurement	By implementing efficient performance metrics, asset owners can effectively monitor the various factors that impact system performance. This enables them to identify inefficiencies in the maintenance processes and devise strategies to optimize maintenance schedules.	Soltanali, Khojastehpour and Kheybari (2023)
Continuous monitoring	The implementation of condition monitoring techniques can facilitate the timely identification of equipment or system anomalies, thereby preventing breakdowns and expensive repair work.	Bukhsh and Stipanovic (2020)
Data management	When data collection and management are fully utilised by organizations, it can facilitate the identification of recurring patterns and trends in asset failures, enabling the adoption of a proactive maintenance approach instead of reactive interventions.	Bukhsh and Stipanovic (2020); Karuppiah, Sankaranarayanan and Ali (2021)
Information system focus	When organizations have fully implemented information system focus, it can assist maintenance managers in identifying and prioritising maintenance needs and creating targeted maintenance plans. This reduces unavailability and improves performance. It also protects critical data from unauthorized access.	Singh and Gurtu (2022)
Quality management	Through the implementation of quality improvement measures, the elimination of waste such as scrap and rework can be achieved. This leads to increased productivity which subsequently results in reduced costs and happier clients.	Singh and Gurtu (2022); Kalpande and Toke (2023)

2.2 Maturity models

According to Oliveira and Lopes(2019), the determination of the level of maturity in maintenance management has the potential to identify shortcomings in the area and help with benchmarking by showing where business processes can be improved. Linhart et al. (2017) found that, despite the benefits provided by maturity models, these models have been subjected to criticism. They have been described as processes that oversimplify reality and do not have an empirical basis.

While numerous maturity models have been created, there is limited published literature on their application and development in asset maintenance (Chemweno, Pintelon, Van Horenbeek and Muchiri, 2015). According to Oliveira and Lopes (2019), there are some maintenance maturity models found in the literature; however, these models are

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over ten years old and do not reflect recent developments in maintenance management. Similarly, Johannes et al. (2021) mentioned that there has been an increased interest in maintenance management maturity models. However, no maturity model has considered technological advancements in maintenance.

According to Van de Merwe (2021), maturity models are classified into three distinct categories: maturity grids, CMM-like models, and Likert-type questionnaires. The quality management maturity grid (QMMG) developed by Cosby was employed as the basic tool for evaluating an organization's level of maturity in terms of its maintenance processes. QMMG is deemed the optimal approach for acknowledging the significance of human elements, particularly in terms of leadership and employee involvement (Albliwi et al., 2014). QMMG suggests five successive stages in which a company is likely to evolve through uncertainty, awakening, enlightenment, wisdom, and certainty. Table 2 shows the summation of the maintenance cultures.

Table 2. Summation of QMMG adapted from (Fernandez, Labib, Walmsley, and Petty, 2003)

	Uncertainty	**Awakening**	**Enlightenment**	**Wisdom**	**Certainty**
Summation of an organisation's maintenance posture	"We don't know why we have problems in maintenance''	"Is it necessary to have problems with maintenance"	"We identify and solve problems"	"Quality product can't be made with poorly maintained equipment thus quality maintenance is a routine"	"We don't expect a breakdown, on the contrary, we are surprised when they occur"

Figure 1 depicts the five stages that represent the culture of the maintenance function. These stages illustrate the evolution of maintenance from a primarily reactive state in the initial stages to a preventive state and ultimately to a prescriptive state in the final stages. For this to be possible, senior management must understand the significance of maintenance in the organization as a crucial tool that not only minimizes expenses by preventing the occurrence of breakdowns but also contributes to increased availability of assets (Fernandez *et al.*2003).

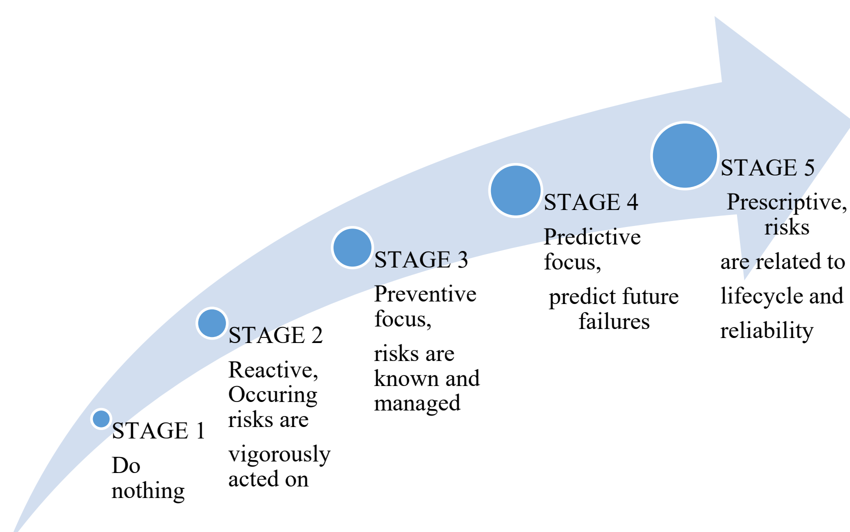

Figure 1. Maturity levels

3. Methods

There are three main research approaches to theory development: induction, deduction, and abduction (Saunders *et al.* 2019). The inductive methodology involves the initial process of gathering observations to obtain data, which is subsequently used to formulate a theory based on the collected data. The deductive approach employs the available literature to identify theories that can be empirically tested (Luphondo, 2020). After thoroughly examining all available research methodologies and techniques, the research meets the stated objective through the application of a deductive approach. A quantitative methodology is concerned with attempts to quantify social phenomena and the collection and analysis of numerical data. It emphasizes the interrelationships among a limited number of attributes across a broad range of cases (Antwi and Kasim, 2015). By contrast, qualitative methodology places greater emphasis on comprehending the significance of social phenomena and concentrates on the connections between a greater number of characteristics across a smaller number of cases (Antwi and Kasim, 2015). Integrating the attributes of quantitative and qualitative research methodologies can enhance their respective advantages, resulting in a more comprehensive investigation. However, this approach also introduces complexity and requires additional time and resources (Neuman 2013). The study employed a deductive research approach and quantitative research, as these were more suitable methodologies for answering the posed research question. This study used the survey research method because of its ability to efficiently gather standardized data from a vast pool of respondents, enabling straightforward comparison (Goldkuhl, 2019). The process of collecting data through a survey involves the use of an instrument and analysis of responses to identify patterns within the sample of participants (Goldkuhl 2019).

Various formats can be employed to conduct surveys, such as interviews, questionnaires, or a combination of both. The survey was conducted using questionnaires, as they can be conducted at a minimum cost and are geographically friendly (Saunders et al., 2019). The researcher submitted the questionnaire to subject experts to verify the validity of the measuring instrument. Unclear inquiries were rectified and inefficient inquiries were eliminated. This assessment resulted in the exclusion of the data management variables from further analysis. The target respondents were railway practitioners involved in the maintenance management of South African railway network infrastructure. The Likert scale allowed participants to select from five options, with 1 indicating strong disagreement and 5 indicating strong agreement with the statement. The survey collected a total number of forty-five (45) responses out of the required sample size of 30. Quantitative data were further analyzed using descriptive statistics.

4. Data Collection

Antwi and Kasim (2015) identified several methodologies for collecting data including questionnaires, interviews, observations and archival techniques. Based on the advantages, disadvantages, and research strategy adopted for this study, the survey-based questionnaire method was the most suitable. The research used both primary data from the survey questionnaire and a literature review comprising conference papers, peer-reviewed journal articles, and books to collect secondary data. The questionnaire was developed with the help of an in-depth literature review and was subjected to face and content validity as well as internal consistency. Reliability and validity are the two most crucial aspects to consider when evaluating any measurement tool used in the research (Saunders *et al.* 2019). Validity refers to what an instrument measures and how accurately it measures it, whereas reliability refers to the confidence one can have in the data obtained from the use of an instrument or the degree to which any measuring instrument controls for random error (Mohajan 2017).

The researcher submitted the questionnaire to the subject expert, with the aim of verifying the validity of the measuring instruments. Unclear inquiries were rectified and inefficient inquiries were eliminated. Owing to the outcomes of the assessment of content and face validity, the data management variable was excluded from further analysis. To meet the University of Johannesburg ethical standards, the researcher enforced beneficence, autonomy, non-maleficence, and justice during the data-gathering and analysis processes. An electronic survey questionnaire was sent to identified railway practitioners involved in the maintenance management of the South African rail network infrastructure. Railway practitioners were asked to extend the questionnaire to other participants in their networks. In total number of forty-five (45) responses were collected.

5. Results and Discussion

This section presents the results of a questionnaire survey conducted as part of the research study to examine the level of maturity in maintenance management in the South African rail network industry. The research data were subjected to in-depth analysis, interpretation, and reporting using tables and graphs.

5.1 Numerical Results

As part of the data-gathering exercise, a demographic information section was included in the questionnaire. Table 3 presents the results. This study benefited from the inclusion of individuals with varied positions within the railway

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business. The findings also suggest that the participants possessed a strong understanding of railway maintenance management and, based on the highest qualification results, the respondents possessed a higher level of knowledge.

Table 3. Demographic information

Items	Participants	% Contribution
Job function		
Maintenance manager	4	9
Production manager	3	7
Engineer	13	29
Engineering technician	25	56
Number of years in railway maintenance		
1-2	4	9
3-5	15	33
6-10	16	36
≥10	10	22
Highest qualification		
National certificate	1	2
National diploma	10	22
Bachelor's degree	28	62
Master's degree	6	13

5.2 Graphical Results

The first phase involved a theoretical study consisting of an in-depth literature review of the critical success factors (CSFs) for effective implementation of a maintenance strategy, which resulted in a successful compilation of nine (9) critical success factors. A questionnaire was created using literature review as a guide. A five-point Likert scale was used to collect the participants' responses to the questionnaire. The Likert scale allowed participants to select from five options, with 1 indicating strong disagreement and 5 indicating strong agreement with the statement. The following section is a representation of how the respondents ranked these variables' sub-items on a scale of one to five.

5.2.1 People Involvement

Three items were employed to assess the construct of people involvement, and the statistical measure of reliability was evaluated using Cronbach's alpha. The three items had a Cronbach's alpha coefficient of 0.757, indicating an acceptable level of internal reliability. A significant proportion (53%) (see Figure 2) of the survey participants indicated that employees played a role in establishing maintenance targets. A large proportion (42 %) of the participants expressed uncertainty or reservations in expressing their opinions, while an equal number of respondents both agreed and disagreed with the notion that they were typically content in their respective occupations.

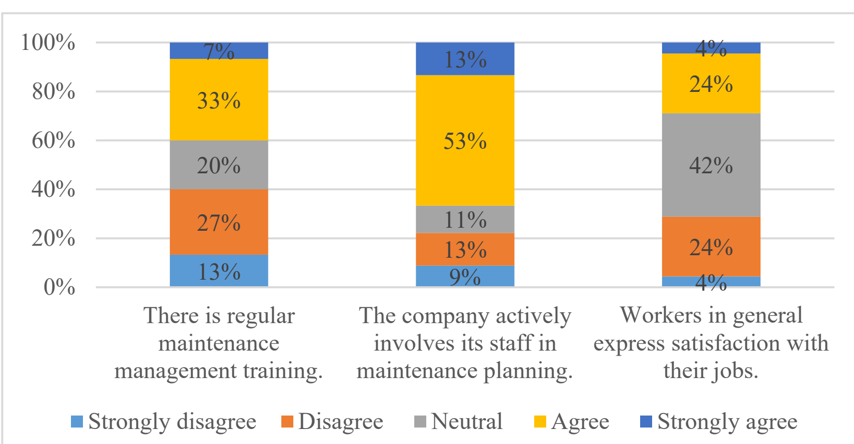

Figure 2. People involvement

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5.2.2 Organizational culture

Figure 3 shows the results obtained for each of the three statements on the importance of organizational culture, and their reliability was evaluated using Cronbach's alpha coefficient. The three items had a Cronbach's alpha coefficient of 0.867, indicating an acceptable level of internal reliability. The survey results shown in Figure 3 indicate that the majority of respondents, comprising 54% of the entire sample, held the belief that firms foster an environment that encourages excellent performance, while a notable proportion of respondents (29 %) expressed disagreement with this perspective. A significant number of participants indicated that formal approaches exist to manage organizational changes, whereas a smaller percentage (29%) expressed disagreement with this perspective.

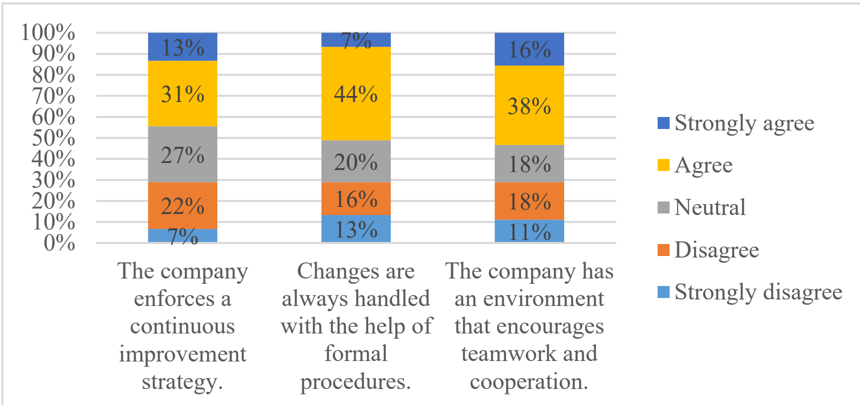

Figure 3. Organisational culture

5.2.3 Technology

Three items were employed to assess the construct of technology and its reliability was evaluated using Cronbach's alpha coefficient. The three items had a Cronbach's alpha coefficient of 0.892, indicating an acceptable level of internal reliability. Based on the survey data graphically represented in Figure 4, 42% expressed the belief that their respective organizations had already initiated digital transformation. The majority of the participants (44%) expressed a lack of consensus regarding the utilization of modern data architectures. A large percentage of participants (33%) expressed uncertainty over their organization's stance on the potential for adopting technological advances.

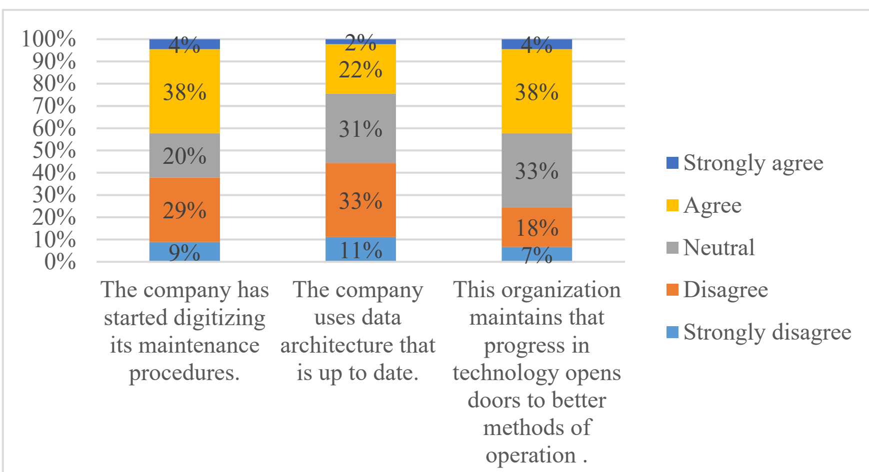

Figure 4. Technology

5.2.4 Leadership

This section shows the results obtained for each of the three statements that were presented on the importance of leadership in maintenance strategy implementation, and its reliability was evaluated using Cronbach's alpha coefficient. The three items had a Cronbach's alpha coefficient of 0.910, indicating an acceptable level of internal

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reliability. A significant number of the survey participants (67%) agreed with the comprehensive understanding of business and operational objectives among all employees, although a smaller percentage (22%) held a contrasting viewpoint, as shown in Figure 5. The findings indicate that forty-nine percent of the participants possessed knowledge of their organization's objectives, but a smaller percentage (31%) expressed dissatisfaction with this notion.

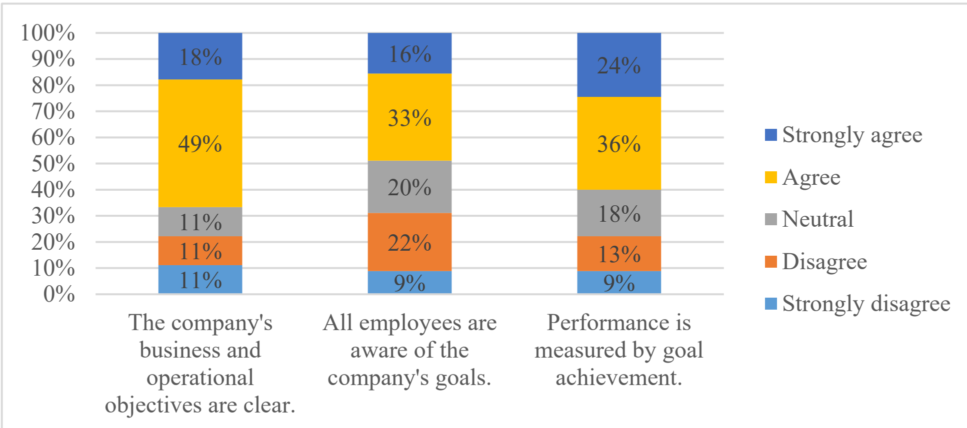

Figure 5. Leadership

5.2.5 Performance measurement

This section shows the results obtained for each of the three items that were presented on the importance of the organization's approach to setting performance objectives, and its reliability was evaluated using Cronbach's alpha coefficient. The three items had a Cronbach's alpha coefficient of 0.913, indicating an acceptable level of internal reliability. The findings shown in Figure 6 indicate that a significant proportion (62%) of participants agreed with the presence and regular monitoring of maintenance key performance indicators (KPIs) while a minority of 20% of respondents held the belief that no such maintenance KPIs existed. Sixty (60) percent of the respondents acknowledged that maintenance tasks were closely associated with business objectives. A majority of the participants (66%) indicated that their respective organizations have a well-defined and organized method for disseminating performance-related data.

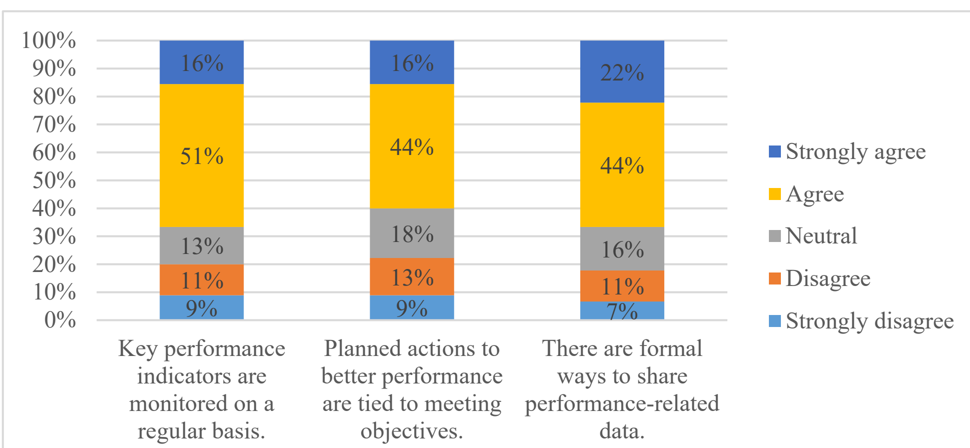

Figure 6. Performance measurement

5.2.6 Continuous monitoring

This section presents the results obtained for each of the three items that were presented on the importance of condition monitoring, and its reliability was evaluated using Cronbach's alpha coefficient. The three items had a Cronbach's alpha coefficient of 0.765, indicating an acceptable level of internal reliability. A large percentage of participants (75%) indicated that maintenance planning is influenced by the condition of the assets, whereas (14%) of respondents do not consider the present state of the assets when making their decisions, as presented in Figure 7. A majority of

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respondents, comprising (60%) of the sample, indicated that their respective organizations continue to employ the firefighting maintenance approach, while 22% of respondents expressed uncertainty regarding the maintenance tactics employed within their organization. A significant proportion of participants (45%) indicated that asset performance monitoring was facilitated through the use of an automated system.

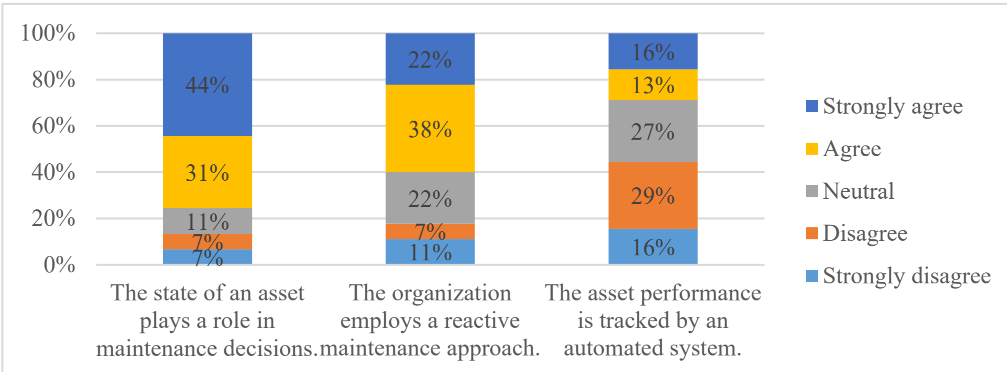

Figure 7. Condition monitoring

5.2.7 Information system focus

This section shows the results obtained for each of the three items that were presented on the importance of all tools that assist in maintaining and managing maintenance data in the organization, and its reliability was evaluated using Cronbach's alpha coefficient. The three items had a Cronbach's alpha coefficient of 0.893, indicating an acceptable level of internal reliability. The findings shown in Figure 8 indicate that a significant proportion of participants, specifically 36%, expressed a disagreeing viewpoint regarding the integration of maintenance management with other business systems. Most participants (42%) utilized management systems such as computerized maintenance management systems. Most respondents (51 %) agreed with the presence of formal mechanisms for distributing maintenance-related information updates within the organization, while 42% held the belief that there is a lack of a structured process in place for this purpose.

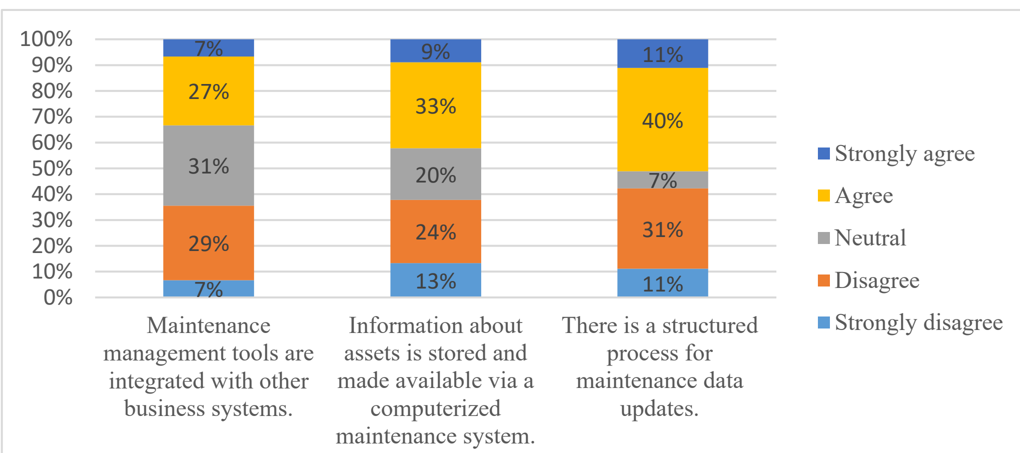

Figure 8. Information system focus

5.2.8 Quality management

This section shows the results obtained for each of the three items that were presented regarding the importance of the application of quality management practices, and its reliability was evaluated using Cronbach's alpha coefficient. The three items had a Cronbach's alpha coefficient of 0.913, indicating an acceptable level of internal reliability. A significant proportion of respondents (38%), as seen in Figure 8, expressed uncertainty or chose to withhold their comments, while 16% of respondents (strongly disagree and disagree) indicated that there was a lack of quality management tasks integrated within the maintenance process. Many respondents indicated that their organizations exhibited an inadequate allocation of funds for maintenance activities. A large percentage (44%) of the participants indicated that their respective organizations possessed a mechanism for investigating instances of non-conformance.

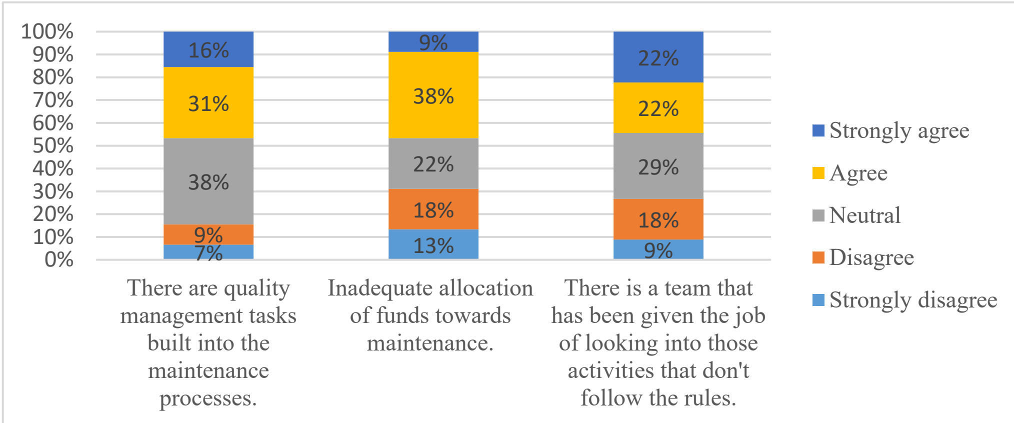

Figure 9. Quality management

5.3 Proposed Improvements

Table 4 shows the weighted average and standard deviation of the identified critical success factors as well as their ranking, which are based on their weighted average. The technology factor possesses the lowest average value which was computed as 2.956 indicating a distinct inclination towards the disagree range. The performance measurement exhibits a notable tendency toward the agreed range as seen by its highest mean value of 3.541.

As presented in Table 4, all the calculated standard deviations have values that are in proximity to 1. This implies that the respondents exhibited a high level of consistency in their viewpoints regarding the critical success factors for effective maintenance management.

Table 4. Descriptive statistics

CSFs	**Number of items**	**Standard deviation**	**Mean**	**Ranking**
Performance measurement	3	1.074	3.541	1
Condition monitoring	3	1.246	3.459	2
Leadership	3	1.141	3.430	3
Quality management	3	1.181	3.274	4
Organisational culture	3	1.174	3.222	5
People involvement	3	1.095	3.141	6
Information system focus	3	1.185	3.022	7
Technology	3	1.040	2.956	8

The factors were rated and analyzed using the weighted average method. Figure 10 shows that most of the critical success factors have a weighted average of four, except for the technology factor, which has an average of two.

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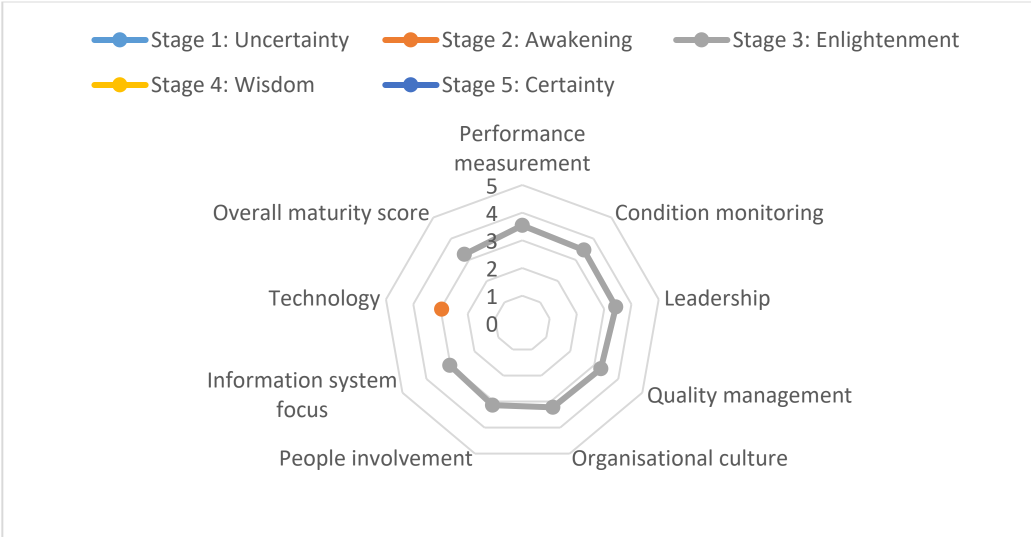

Figure 10. Maturity level

5.4 Validation

The researcher submitted the questionnaire to subject experts to verify the validity of the measuring instrument. Unclear inquiries were rectified and inefficient inquiries were eliminated. This assessment resulted in the exclusion of the data management variables from further analysis. All eight critical success factors had acceptable internal consistencies.

6. Conclusion

The main objective of this study is to assess the level of maturity of maintenance management in the South African rail network industry. The first phase of the research involved a theoretical study consisting of an in-depth literature review of the critical success factors (CSFs) for the effective implementation of a maintenance strategy, which resulted in a successful compilation of nine (9) critical success factors. As a result of the content and face validity assessment, data management was excluded from further analysis, resulting in the use of eight key factors during the data collection phase. Using the literature review as a guide, a questionnaire was created and distributed using snowballing to railway engineering practitioners involved in maintenance management. A five-point Likert scale was used to collect the participants' responses to the questionnaire. The overall maturity level of maintenance management in the South African rail network industry was found to be at level 3. According to the summation of the quality management maturity model shown in Table 2, this is the enlightenment stage whereby organizations identify and solve problems. This assessment helped to identify current shortcomings and opportunities for enhancing the existing maintenance processes in the railway infrastructure, which will further assist the rail network industry in improving their maintenance function, resulting in the reduction of infrastructure deterioration and failures. Future research could be conducted on how to align the current rail network maintenance practices with the advancements brought by Industry 4.0 and the application of these technologies in railway maintenance management.

References

Albliwi, S.A., Antony, J. and Arshed, N. , 'Critical literature review on maturity models for business process excellence', in *2014 IEEE International Conference on Industrial Engineering and Engineering Management*. IEEE, pp. 79–83, 2014. Available at: https://doi.org/10.1109/IEEM.2014.7058604.

Antwi, S. and Kasim, H. , 'Qualitative and Quantitative Research Paradigms in Business Research: A Philosophical Reflection', *European Journal of Business and Management* [Preprint], 2015.

Bukhsh, Z.A. and Stipanovic, I. , 'Predictive Maintenance for Infrastructure Asset Management', *IT Professional*, 22(5), pp. 40–45, 2020. Available at: https://doi.org/10.1109/MITP.2020.2975736.

Cachada, A. *et al.*, 'Maintenance 4.0: Intelligent and Predictive Maintenance System Architecture', in *2018 IEEE 23rd International Conference on Emerging Technologies and Factory Automation (ETFA)*. IEEE, pp. 139–146. Available at: https://doi.org/10.1109/ETFA.2018.8502489 , 2018.

Cardoso, D. and Ferreira, L. , 'Application of predictive maintenance concepts using artificial intelligence tools', *Applied Sciences (Switzerland)*, 11(1), pp. 1–18, 2021, 2021. Available at : https://doi.org/10.3390/app11010018.
Fernandez, O. *et al.* , 'A decision support maintenance management system', *International Journal of Quality & Reliability Management*, 20(8), pp. 965–979, 2003. Available at: https://doi.org/10.1108/02656710310493652.
Goldkuhl, G. (2019) 'The Generation of Qualitative Data in Information Systems Research: The Diversity of Empirical Research Methods', 44. Available at: https://doi.org/10.17705/1CAIS.04428.
Govender, D. , 'Delivering on Infrastructure Maintenance for Socio-Economic Growth: Exploration of South African Infrastructure for a Sustained Maintenance Strategy', in, pp. 495–506, 2019. Available at : https://doi.org/10.2495/SC190431.
Johannes, K. *et al.*, 'Identifying Maturity Dimensions for Smart Maintenance Management of Constructed Assets: A Multiple Case Study', *Journal of Construction Engineering and Management*, 147(9), 2021. Available at: https://doi.org/10.1061/(ASCE)CO.1943-7862.0002112.
Kalpande, S.D. and Toke, L.K. (2023) 'Reliability analysis and hypothesis testing of critical success factors of total productive maintenance', *International Journal of Quality & Reliability Management*, 40(1), pp. 238–266, 2023. Available at: https://doi.org/10.1108/IJQRM-03-2021-0068.
Karuppiah, K., Sankaranarayanan, B. and Ali, S.M., 'On sustainable predictive maintenance: Exploration of key barriers using an integrated approach', *Sustainable Production and Consumption*, 27, pp. 1537–1553, 2021. Available at: https://doi.org/10.1016/j.spc.2021.03.023.
Linhart, A., Klaus, C. and Röglinger, M., 'Maturing maturity models – a methodological extension using the analytical hierarchy process and Google PageRank', *Journal of Decision Systems*, 26(4), pp. 307–327, 2017. Available at: https://doi.org/10.1080/12460125.2017.1422317.
Luphondo, N. (2020) *The impact of quality losses on overall equipment effectiveness: an analysis of the food manufacturing industry in South Africa*. The University of Johannesburg.
Matsaung, M. (2019) *Strategies for maintenance management of railway track assets*. Masters. University of Johannesburg, 2019.
Van de Merwe, L. (2021) *Towards a maturity model for the assessment of data management of healthcare entities in developing countries*. Stellenbosch University.
Mohajan, H.K., 'two criteria for good measurements in research: validity and reliability', *Annals of Spiru Haret University. Economic Series*, 17(4), pp. 59–82, 2017. Available at: https://doi.org/10.26458/1746.
Neuman, W. Lawrence. (2013) *Social Research Methods: Qualitative and Quantitative Approaches.* 7th ed. Harlow, United Kingdom: Pearson Education Limited.
Oliveira, M.A. and Lopes, I. (2019) 'Evaluation and improvement of maintenance management performance using a maturity model', *International Journal of Productivity and Performance Management*, 69(3), pp. 559–581, 2019. Available at : https://doi.org/10.1108/IJPPM-07-2018-0247.
Saunders, M. *et al.* , '"Research Methods for Business Students" Chapter 4: Understanding research philosophy and approaches to theory development', in, pp. 128–171, 2019.
Singh, R.K. and Gurtu, A. (2022) 'Prioritizing success factors for implementing total productive maintenance (TPM)', *Journal of Quality in Maintenance Engineering*, 28(4), pp. 810–830. Available at: https://doi.org/10.1108/JQME-09-2020-0098.
Soltanali, H., Khojastehpour, M. and Kheybari, S. (2023) 'Evaluating the critical success factors for maintenance management in agro-industries using multi-criteria decision-making techniques', *Operations Management Research* [Preprint]. Available at: https://doi.org/10.1007/s12063-023-00348-1.
Transnet Freight Rail (2020) *Annual results.*

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