Proceedings of the 7th African International Conference on Industrial Engineering and Operations Management
Cape Town, South Africa, May 13-15, 2026

Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AF07.20260378
Published: May 13, 2026

Leveraging Digital Tools for Forecasting and Monitoring Railway Infrastructure Projects to Improve Project Delivery

K.F Chabalala, B.B.S Makhanya and J.H.C Pretorius
Postgraduate school of Engineering Management
University of Johannesburg
Johannesburg, South Africa
224208551@student.uj.ac.za, bmakhanya@uj.ac.za, jhcpretorius@uj.ac.za

Abstract

The South African railway sector continues to lag behind in digital maturity compared to other industries due to limiting operational efficiencies and competitiveness. This study assesses the digital tools currently being used in the railway sector and their effectiveness and barriers to digital adoption among railway professionals. A survey of 45 respondents, predominantly Engineering managers, revealed that, among the five digital tools assessed, the Internet of Things is the most familiar, followed by big data and analytics. In contrast, digital twins showed least familiarity. Respondents rated the tools as most effective for decision-making and stakeholder collaboration but less effective for cost reduction. The key barriers included governance issues (rigid hierarchy and bureaucracy) and resources and funding constraints (insufficient budget, inadequate IT infrastructure, and skills retention), which rated high severity. The study recommends prioritizing digital skills training programs, developing a clear digital strategy, and improving collaboration, while the respondents endorse greater use of big data & analytics and Artificial intelligence. The findings provide a practical insight into bridging gap in South African railways through phasing the interventions to ease the cost burden.

Keywords
Digital Transformation, Digital Tools, Barriers, Railways, Projects

1. Introduction
Digital transformation can best be described as the implementation of specialized or advanced technologies that optimize business operations and ultimately make them more efficient (Hizir, 2022). The transformation must go further than just the adoption of new technologies but be able to transform the entire organization. The organization must capitalize on the opportunities that are provided by the technologies to improve three main areas: customer experience, business models, and overall business processes (Benahmed & Hansal, 2022).There is a common misconception that digitization, which means replacing manual processes, will eventually lead to job losses, but in reality, digital transformation does not eliminate jobs but instead drives organizational change and creates new opportunities (Hizir, 2022).One of the many frequent barriers to successful digital transformation is the organizations lacking the necessary preparedness, which includes insufficient institutional capabilities, skillsets, and a detailed execution strategy (Kumar, et al., 2024). From the many successful interventions to transformation, these are the key success factors for effective implementation of digital transformation: a well-defined vision or strategy, building a capable team, adopting agile methodologies, fostering a culture of continuous improvement, and establishing flexible IT infrastructure (Kringelum, et al., 2025). There are great benefits that encompass a successful implementation of digital transformation, such as improved quality of products and services, enhanced organizational culture, competitive advantage, and increased market share (Isik, et al., 2024). There are several concerns when it relates to the adoption of digital technologies which spans over data security and potential misuse, limited affordability of broadband access due to high initial and ongoing maintenance costs (Xiao, et al., 2024). In addition to these concerns,

there are several impediments particularly in state-owned railways where there is poor prioritization of digital investments and reliance on taxpayer funding which often competes with national priorities (Sarp, et al., 2024). The railway industry has long served as the backbone of public transportation, playing a pivotal role in economic growth and social development across many countries (Kumar, et al., 2023). Over the years, the industry has gradually incorporated digital technologies such as smart detections (axle, skew loading and hot bearings), and driver display units that provide real-time train health information. These innovations have influenced service offerings, train speeds, and train lengths (Awodele, et al., 2024). Like other industries the railway sector is now shifting toward cognitive railways with capabilities such as self-diagnosis and optimization (Ai, et al., 2020). There is potential to incorporate the Artificial Intelligence (AI) into the railways, AI is defined as an advanced technology that mimics the performance of tasks typically requiring human intelligence (Lyu & Liu, 2021).Despite the progress made, the railway digitalization has progressed more slowly compared to the other industries such as healthcare, manufacturing, and financial services (Dong, et al., 2022). The Major challenges that worsen the digital efforts in the sector include aging infrastructure that makes integration difficult, high deployment costs for automation, cybersecurity risks (especially with smart e-ticketing), resistance to change, and limited technical expertise (Awodele, et al., 2024). Even in the midst of these challenges there are notable successes that have emerged in predictive maintenance through use of data analytics and IoT sensors, and in passenger services via smart e-ticketing systems that deliver convenience and personalized experiences as exemplified by Deutsche Bahn in Europe (Sarp, et al., 2024; Kumar, et al., 2023). Astonishingly the Industry 4.0 technologies remain comparatively immature in developing and emerging economies such as Nigeria (Awodele, et al., 2024). Meanwhile, smart e-ticketing and similar initiatives have enhanced passenger experiences in Europe and Asia. There are significant research gaps pertaining to the influence of the social and organizational barriers to digital initiatives in South African railways. There is no sufficient literature coverage to how the socio-economic contexts and policies influence the adoption of the technologies in emerging economies. Regardless, the AI application and adoption have been extensively studied across industries, but its application in railways is still relatively new and underdeveloped. Limited research documents the current state of digital transformation in South African railways or the digital tools being used to improve project delivery. This study addresses these gaps by investigating familiarity and use of digital tools within the South African railway sector and examining the barriers to the adoption of digital technologies in South African railway projects. The main objectives are to identify the challenges impeding the adoption of digital tools in South African railways and to assess the tools in use, together with their effectiveness. By exploring these issues, the research aims to offer actionable insights to overcome barriers and advance digital transformation in South African railways. It will also contribute to a broader understanding of digital transformation in developing-country contexts, generating lessons applicable to other nations seeking to modernize their railway infrastructure and transport systems.

1.1 Objectives
The purpose of this study is to assess which digital tools are currently being used in the South African Railway sector and their effectiveness. Secondly the study seeks to identify the barriers that hinder the adoption of the digital tools

2. Literature Review
Digital transformation has garnered significant attention over the years because it fundamentally reshapes business operations and societal structures (Zhelin & Yihan, 2024; Tang, 2021). It necessitates the integration of specialized technologies into the operations and strategies of the organization which ultimately enhances performance, reduces costs and maximizes revenue (Paul, et al., 2024). By so doing organizations are able adapt and compete in the digital landscape(Paul, et al., 2024; Verhoef, et al., 2021).This literature review examines digital transformation in the railway sector, focusing on barriers to adoption and digital tools for improving project delivery in South African railways.

2.1 Barriers
Organizations embarking on the digital transformation journey, encounter many barriers related to customer centricity, governance, innovation and resources.

The underpinning downside of organizations struggling with customer centricity is that absence of customer centricity misaligns their technological investments with actual customer needs. The ripple effect of this misalignment results in underperforming systems, poor conversion of data into actionable insights, skewed resource allocation favoring back-office enhancements, and weak evaluation of digital investments (Muhlungu, et al., 2019; Verhoef, et al., 2021; Fitzgerald, et al., 2014) . In contrast, an organization that has the strong customer centricity enhances their marketing innovativeness, enables personalized digital touchpoints, improves customer engagement, and increases return on digital investments (Majchrazak & Wagner, 2014). Governance entails the structures that govern how decision making is carried out in various organizations. Mechanistic structures which are categorized by rigid hierarchies often hinder transformation efforts because it minimizes the urgency needed, collaboration, and rapid adaptation (Hanelt, et al., 2021). Meanwhile the other structure are known as flexible organic structures which are opposite, since these promote knowledge sharing, optimal resource utilization, and adaptability (Agrawal, et al., 2020). Effective governance frameworks are essential for decision-making in digital initiatives.

Innovation which entails creating new or significantly improved products, services, processes, or marketing methods (Taylor, 2017). This requires a cultural mindset shift together with supportive changes in policies and structures (Kahn, 2018). Any organization that wants to remain competitive would require to be innovative in their offering. The lack of innovation acts as a barrier by slowing the business model remodeling which is necessary for successful digital transformation.

Resources and funding include tangible assets (IT infrastructure, equipment, financial and human capital) and intangible assets (knowledge, intellectual property) that makes business able to operate/ function and to have the competitive edge against competitors (Hitt, et al., 2016). Resources are valuable and often rare to source and retain. The digital initiatives are not as easy exercise since they require substantial capital investment and skilled talent, which create major hinderance for small and medium enterprises (SME). This is further exacerbated by liquidity constraints, difficulty accessing finance for risky projects, and shortages of technology-skilled personnel (Chen, et al., 2021; Cichosz, et al., 2020). Surprisingly large organizations also face barriers related to resources and funding, however theirs stem from long payback periods and unattractive ROI (Cichosz, et al., 2020). When resources are adequate, organizations can invest in the advanced technologies. The digital investments then translate into higher operational efficiency through automation, improved information exchange, and greater adaptability

2.2 Digital tools usage

The common digital tools currently being leveraged by the global railway community include amongst several key tools the Internet of Things (IoT), cloud computing, big data analytics, artificial intelligence (AI), and digital twins, even though some of these tools/applications remain in early stages of adoption (Sarp, et al., 2024; Steele & Roberts, 2020). Internet of things (IoT) are known as tools that connects sensors and devices for real-time data collection and control without human intervention. With such functionality these sensors can support infrastructure maintenance by allowing early fault detection, and autonomous train operations with GPS (Singh, et al., 2022; Deepa, et al., 2024). Cloud computing is known as internet-based platform that allows storage of data sets (Kour, et al., 2013). This digital tool provides on-demand, scalable data storage and processing on a pay-as-you-use model. The platform has the ability of facilitating integration of diverse subsystem data (Tan & Ai, 2011). This allows the tool to improve maintenance diagnostics using the stored data and fosters stakeholder collaboration through data exchange by different users.

Big data and analytics are the digital tool that expropriate large volumes of data (100 terabytes from 100 sources). This tool can handle complex, high-volume datasets with capabilities to detect patterns and predict system behavior such as train delays which ultimately enhances service quality and asset maintenance (Adithya, et al., 2015).

The Artificial intelligence digital tool, defined as intelligence mimic human behavior to perform certain functions. This digital tool is so advanced that it can reason, learn, and problem-solve in applications including wheel-flat detection and automated train scheduling (Yin, et al., 2020).

Lastly Digital twins are digital tools that can create virtual replicas of physical assets using real-time data for simulation, predictive maintenance, and monitoring across rolling stock, signals, and as well as infrastructure (De nato, et al., 2023)

2.3 Comparative insights from Developing countries

Comparable challenges are evident not only in south Africa but across other developing countries which reflects the broader patterns of digital adoption hinderance in emerging economies. In Nigeria, both low awareness and adoption of the industry 4.0 stems from the inadequate infrastructure, funding shortages from local and international investors, skills gaps and organizational resistance to change (Awodele, et al., 2024).

Similarly, Kenya despite its extensive networks, are unable to attract the necessary investment for technological developments that will transform their railway systems. The existing deteriorating railway system needs urgent modernization, but this hampered by limited financial support and lack of the technical know-how to aid in plan for these technological interventions (Wangai, et al., 2020).

In the SADC region, Mulongo et al (2021) highlights that the legacy systems suffer from very low levels of digitalization. These networks rely on severely outdated signaling infrastructure that requires manual operations which results in low freight volumes with frequent breakdowns and poor reliability.

In contrast, Brazil as an emerging economy demonstrates it is possible to successfully leverage base technologies as foundation for digital advancement. Brazil was able to integrate IoT, Big Data & analytics into the passenger systems using the mobile WIFI connectivity and are currently advancing towards predictive analytics (Franz, et al., 2024). India which has the fourth largest rail network in the world has made significant efforts to digitalize their railway systems by incorporating data driven maintenance health checks using IoT and advancing its scheduling passenger trains using data loggers, it achieved this while being significantly challenged by funding and similar governance issues (Rajput & Naresh, 2025).

These country comparison shows varying stages of the digital transformation which span from access barriers for most of the African countries to system integration barriers for Brazil and India. South Africa even though is well resourced compared to the regional countries; it faces structural issues that prevent it to move beyond the adoption stage.

This literature review shows that the digital tools are advancing allowing for intelligent condition monitoring and overall railway system. The many applications of the digital tools are explored in isolation rather than as an integrated system. The research gaps include limited integration of technologies and heavy focus on developed countries that are well resourced while neglecting the developing countries context such as South African railways. Customer centricity although is being explored however the current research is merely on the commercial perspectives with little insight into its application in railway operations. These gaps highlight the need for context-specific research on integrated digital strategies tailored to emerging economies and railways.

3. Methods

This study adopted a deductive approach to investigate the digital tools and the barriers in the railway industry. According to Saunders et al (2019), deductive approach begins with existing theory from literature and tests it through a carefully designed research strategy. It relies on logical inference and is typically associated with quantitative data to test the hypothesis.

A survey strategy was selected as the overall research methos because it provides a broad overview of the area of an interest and effectively elicit individual perspectives and experiences (Johannesson and Perjons,2021). The survey strategy was the most suitable based on the following considerations; feasibility due to the limited time and resources, survey allows efficient data collection in a cost-effective way, suitability: it offers appropriate framework for addressing the research questions pertaining to the barriers and the digital tool preferences and alignment with research objectives: the research strategy aligns well with the deductive nature while practical for those dispersed geographically and are hard to reach.

As such the internet-based survey through online platform was employed to reach a significant and geographically dispersed pool.

4. Data Collection

The Primary data were collected using a structured questionnaire as the main data collection instrument. Questionnaires were chosen because they are cost -effective, allow data to be collected in a short time and allow systematic analysis (Taherdoost,2021). The questionnaire combined both closed-ended and open-ended questions. Closed questions (including nominal, ordinal polytomous and continuous rating scales). The target population consisted of railway personnel directly involved in railway operational activities across major South African organizations, including Transnet, PRASA, Gautrain Management Agency, and Bombela Operating Company. Due to the unknown parameters of the population, its geographical dispersion, and difficulties in direct access, snowball sampling (a non-probability sampling technique) was used. Initial participants who met the inclusion criteria (railway industry experts) referred other eligible individuals until the target sample size (up to 50 participants) or data saturation was reached. This approach also helped maintain participant anonymity. Secondly ethical clearance was obtained by the authorizing institution committee to ensure that ethical standards are adhered to, such as informed consent and data confidentiality. Data collection was conducted via online questionnaires, ensuring primary data of high reliability was obtained directly from the target respondents.

5. Results and Discussion

This section analyses the survey data collected from 45 railway professionals. It examines their level of familiarity with digital tools, perceived effectiveness of these tools in operational areas, major barriers to digital transformation and proposed strategies for improvement. Inferences are drawn in the context of South African railway sector's ongoing digital transformation efforts.

5.1 Numerical Results

A total of 45 railway professionals participated in the survey. Table 1 presents the demographic characteristics. The sample was dominated by engineering managers (67%) with 5-10 years of experience (56%). This provides relevant insights from mid-level technical professionals who are directly involved in railway infrastructure projects.

Table 1. Demographic information

Items	**Frequency**	**Percent**	**Cumulative percent**
Years of experience			
Less than 5 Years	7	16%	16%
5-10 Years	25	56%	71%
11-15 Years	6	13%	84%
More than 15 years	7	16%	100%
Total	**45**	**100%**	
What is your current role or position?			
Project Manager	8	18%	18%
Engineering Manager	30	67%	84%
Infrastructure Manager	5	11%	96%
IT specialist	1	2%	98%
Operations Manager	0	0%	98%
Senior executive	1	2%	100%
Total	**45**	**100%**	

Familiarity with digital tools and perceived severity of barriers were measured using the 5-Point Likert scale (1=Not familiar/Not severe at all, 5= Extremely familiar/Extremely severe). The descriptive statistics used in this study include:

- **Mean *(M):*** The arithmetic average of responses, representing the central tendency of participants' perceptions.
- **Interquartile range (*IQR):*** A measure of dispersion that represents the spread of the middle 50% responses. A lower IQR indicates higher/ greater consensus among the respondents.
- **Relative Importance index (*RII):*** Calculated as $RII = \frac{\sum W}{(A \times N)}$, where w is the weight assigned by each respondent, A is the maximum possible weight (5), and N is the number of respondents (45 in this study). *RII* values range from 0 to 1, with higher values denoting greater familiarity or severity.

All scales demonstrated good to excellent internal consistency (Cronbach's alpha ranging from 0.81-.096).

Table 2 summarizes the descriptive statistics including mean scores, Interquartile range (IQR) and relative importance index (RII).

Table 2. Digital tools Familiarity

Item	Mean	IQR	RII	Interpretation
Internet of Things	3.64	1	0.73	Strong Agreement
Cloud Computing	3.16	1	0.63	Moderate agreement
Big data and analytics	3.56	1	0.71	Strong agreement
Artificial Intelligence	3.13	2	0.63	Moderate agreement
Digital twins	2.67	1	0.53	Disagreement

Note: RII > 0.70 generally indicates strong agreement

Internet of things (IoT) achieved the highest familiarity (M=3.64, RII= 0.73) followed closely by big data and analytics. Digital twin showed the lowest familiarity (M=2.67, RII=0.53). The low IQR values indicate good consensus among the respondents. The primary use of the digital tools was reported in project planning & scheduling and predictive/preventative maintenance. These results indicate a clear maturity gap; respondents are comfortable with foundational tools (IoT, big data & analytics) but lag significantly in advanced technologies such as digital twins

Table 3 ranks the severity of 20 barriers across the four categories (customer centricity, governance, innovation and resources &funding).

Table 3. Descriptive statistics and severity levels of barriers

Rank	Category	Item	Mean	IQR	RII	Interpretation
1	Resources & Funding	Insufficient budget for digital transformation initiatives	3.87	2	0.77	**High severity**
2	Resources & Funding	Difficulty retaining technology-skilled employees	3.76	2	0.75	**High severity**
3	Governance	Rigid hierarchical structures slow decision-making	3.73	2	0.75	**High severity**
4	Resources & Funding	Inadequate IT infrastructure to support new technologies	3.73	1	0.75	**High severity**
5	Innovation	Absence of innovation incentives or rewards	3.71	1	0.74	**High severity**
6	Resources & Funding	High upfront costs of digital technologies	3.62	2	0.72	**High severity**
7	Governance	Excessive bureaucratic processes	3.56	1	0.71	**High Severity**
8	Innovation	Slow adaptation to market/industry changes	3.56	1	0.71	**High severity**
9	Governance	Inadequate governance frameworks for digital projects	3.53	1	0.71	**High severity**
10	Resources & Funding	Limited access to external funding sources	3.51	1	0.70	**High severity**
11	Governance	Lack of senior management commitment to digital transformation	3.49	1	0.69	**Moderate severity**
12	Innovation	Reluctance to adopt new technologies	3.49	1	0.69	**Moderate severity**
13	Innovation	Lack of knowledge sharing across departments	3.42	1	0.68	**Moderate severity**
14	Innovation	Limited culture of experimentation and risk-taking	3.36	1	0.67	**Moderate severity**
15	Customer Centricity	Insufficient stakeholder engagement in digital initiatives	3.27	2	0.65	**Moderate severity**
16	Governance	Unclear roles and responsibilities for digital initiatives	3.24	1	0.65	**Moderate severity**
17	Governance	Lack of cross-functional collaboration	3.20	1	0.64	**Moderate severity**

Rank	Category	Item	Mean	IQR	RII	Interpretation
18	Customer Centricity	Lack of metrics to measure stakeholder satisfaction with digital services	3.18	1	0.63	**Moderate severity**
19	Resources & Funding	Lengthy return on investment (ROI) periods	3.11	1	0.62	**Moderate severity**
20	Customer Centricity	Poor integration between customer-facing and back-office systems	3.09	1	0.61	**Moderate severity**
21	Customer Centricity	Technologies deployed do not address actual operational needs	2.89	2	0.58	**Low Severity**
22	Customer Centricity	Lack of understanding of stakeholder needs (passengers, freight clients)	2.67	3	0.53	**Low severity**

The top barriers are predominantly from resources & funding and governance categories; all rated as high severity (RII≥0.72). Insufficient budget, difficulty retaining skilled talent, rigid hierarchical structures, and inadequate IT infrastructure emerged as the most critical challenges to adoption of digital technologies. In contrast the customer centricity related barriers were perceived as less severe.

Regarding the barriers results, structural and resource constraints, particularly on the funding and skilled talent, emerge as the dominant obstacles. These challenges are commonly faced by many organizations in developing areas where there are legacy systems and a limited budget that slows down the adoption of new technologies

5.2 Graphical Results

Figure 1 shows the distribution of familiarity levels with five digital tools. The internet of things (IoT) was the most familiar tool with 64% of the respondents reporting high familiarity in contrast, digital twins recorded the lowest, with 24% of the respondents showing high familiarity. The big data & analytics (51%) and Artificial intelligence (42%) fell in the middle ranges. While cloud computing (33%) showed moderate recognition.

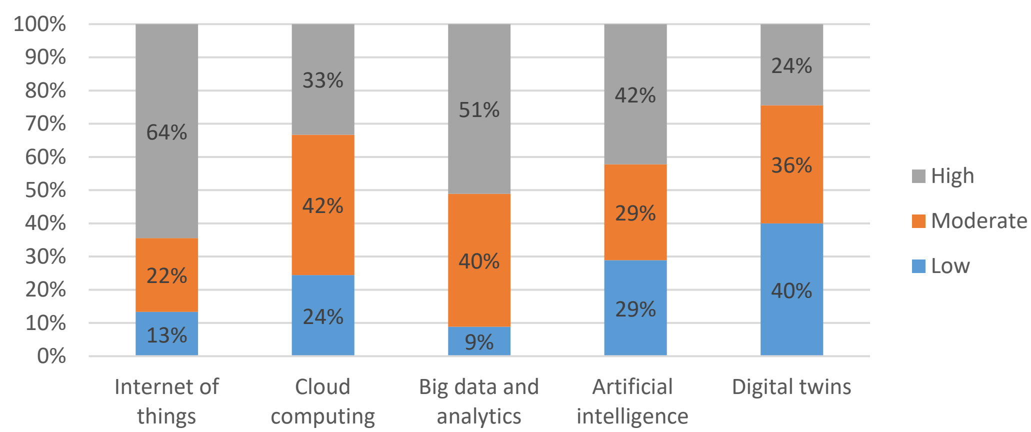

Figure 1. Digital tool familiarity

Figure 2 illustrates the perceived effectiveness of the digital tools across six operational areas. The respondents' rated the digital tools to be highly effective for supporting decision-making (62%) and facilitating stakeholder collaboration (60%). The cost reduction received the lowest score in terms of effectiveness (49%) which the respondents perceive the tools to be less effective in reducing operational costs.

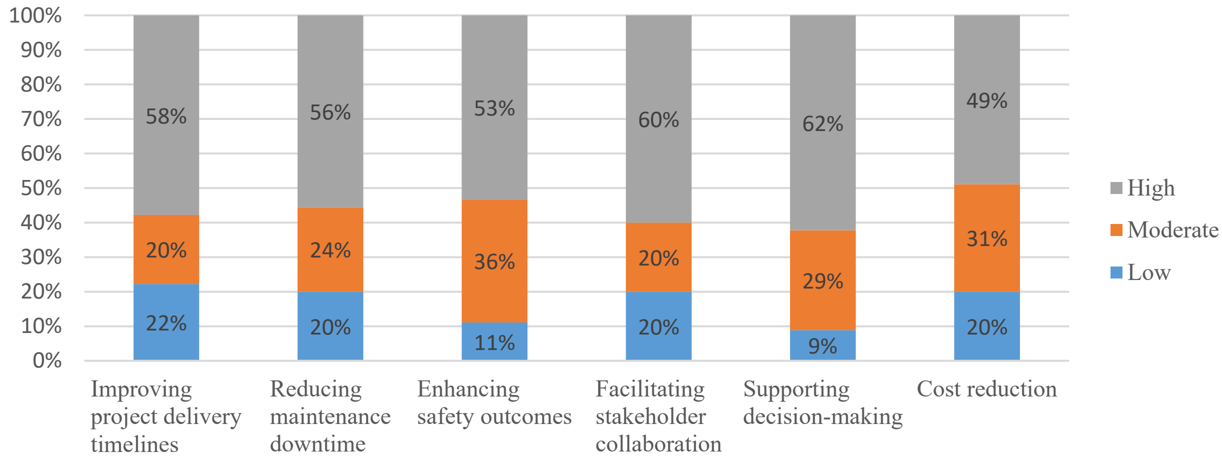

Figure 2. Effectiveness of digital tools

Figure 3- Figure 6 presents severity levels using a three-point scale (Critical, moderate, and minor) for barriers in Customer centricity, governance, Innovation, and resources & funding categories. In governance shown in figure 4, rigid hierarchical structures (60%) and excessive bureaucratic processes (56%) stood out as the critical barriers. In resources and funding shown in figure 6, Inadequate IT infrastructure (64%), high upfront costs (60%), difficulty retaining skilled talent (60%) were the most severe rated barriers. These graphical patterns reinforce that while digital tools show promise in operational decision-making and collaboration, significant governance rigidity and resource limitation are perceived as major hindrances. Low familiarity with digital twins could be due to funding challenges and shortages of skilled personnel, suggesting that the railway sector risks falling behind unless targeted interventions are implemented.

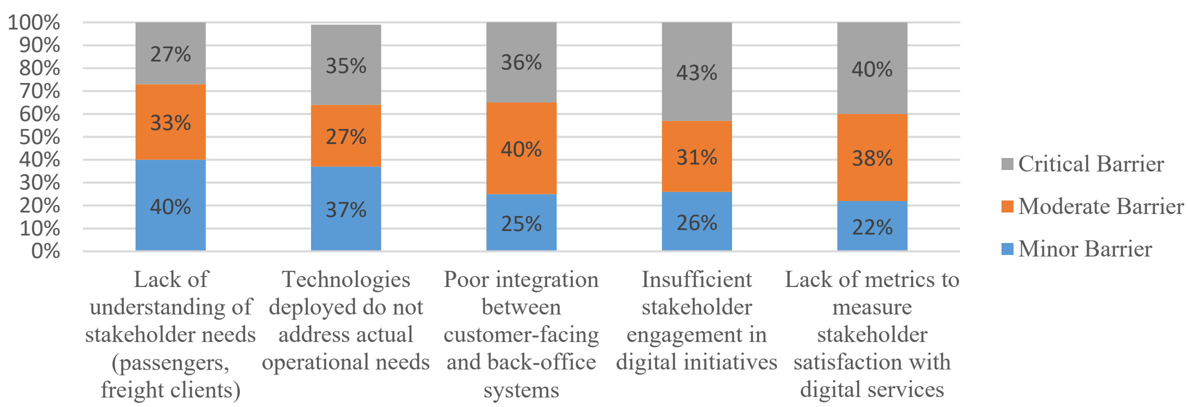

Figure 3.Customer centricity barrier

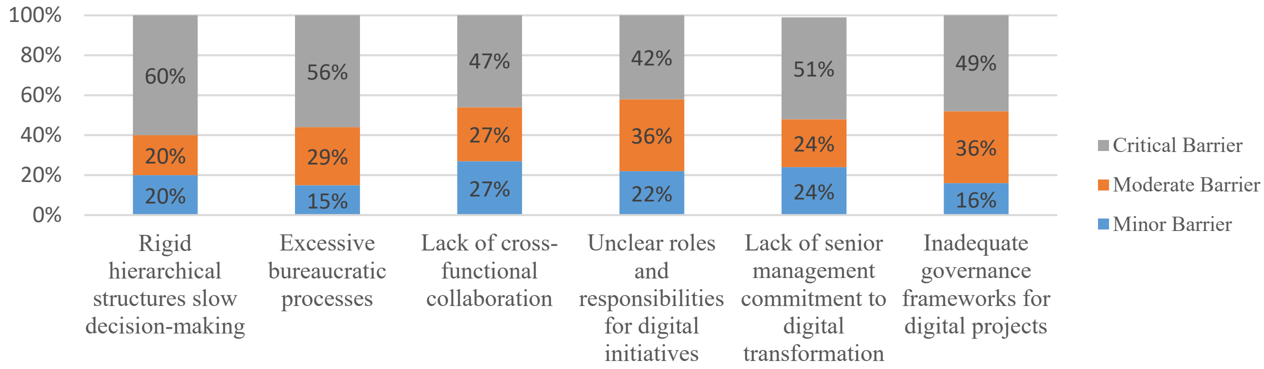

Figure 4. Governance barrier

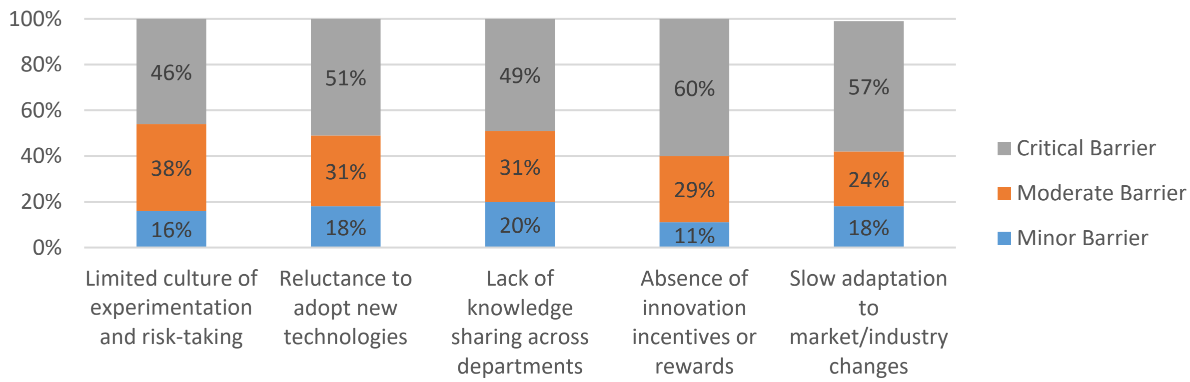

Figure 5. Innovation Barrier

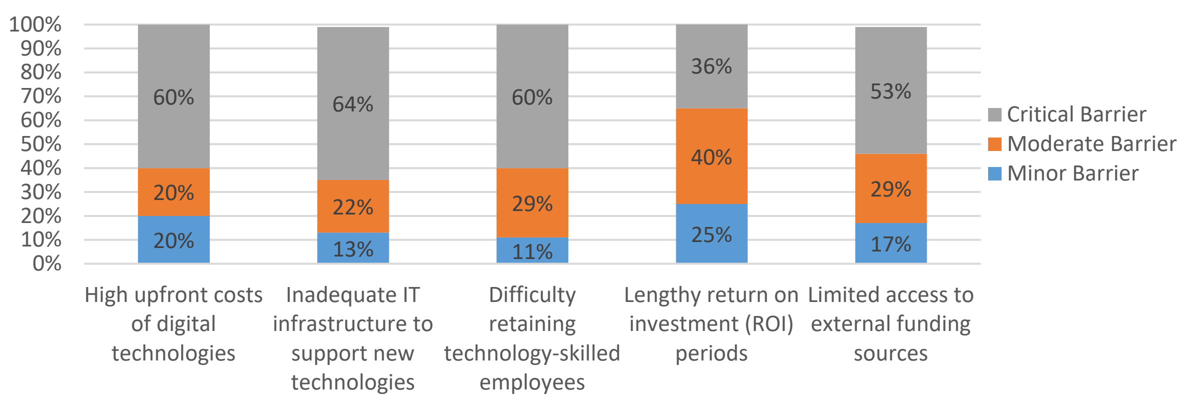

Figure 6. Resources and funding barrier

5.3 Proposed Improvements for Digital Transformation in the Railway Sector

In Table 4, Participants identified key initiatives to accelerate digital transformation in the railway sector.

Table 4. strategies for improving Digital transformation

Strategies	**Frequency**	**Percentages**
Development of Digital skills training programs	32	71%
Clear digital strategy	32	71%
Improved Collaboration	32	71%
Increased Government funding	31	69%
Public-private partnerships	30	67%

The top three strategies, each supported by 71% of the respondents, were development of digital skills training program, clear digital strategy and improved collaboration. These directly addresses the barriers identified in table 3.

Figure 7 shows the recommended digital technologies to improve the transformation of sector. Big data & analytics (82%) and by Artificial intelligence (73%) received strongest support while only 2% suggested digital twins. These proposals directly address the identified gaps: digital skills training and clear digital strategy (and/or roadmap) would help overcome low familiarity with advanced tools and governance barriers, while improved collaboration and funding vehicles/ mechanisms addresses the challenges related to resources and funding. Implementing these strategies will not only improve the sector but its digital transformation trajectory.

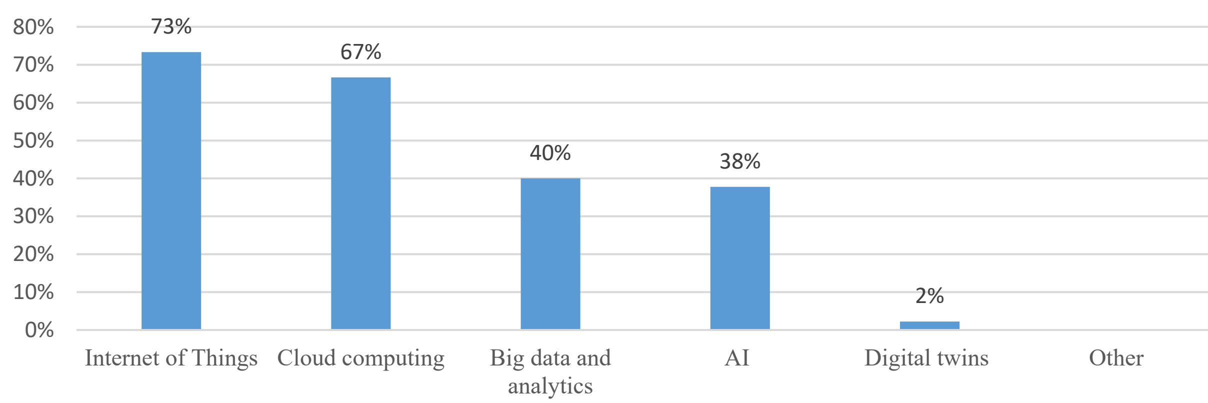

Figure 7. Recommended digital technologies

5.4 Data Validation

The reliability of the measurement scales (Likert scale) was assessed using Cronbach's alpha to ensure internal consistency of the Reponses. The analysis revealed the Cronbach's alpha values ranging from 0.81 to 0.96 across the digital tool's familiarity and the four barrier categories (governance, resources & funding, innovation, and customer centricity). These results indicate good to excellent reliability of the instrument. Prior to the data collection, the questionnaire was subject to expert review to establish the content validity. Secondly, during the data collection, the data was subject to preliminary screening to ensure that there were no missing values or outliers, ensuring overall data quality and usability.

6. Conclusion

This study examined two primary objectives in the context of the South African sector:

1. To identify the digital tools currently being used by the railway sector and their effectiveness
2. To investigate the key barriers hindering the adoption of these tools.

Both objectives have been successfully addressed through the survey of 45 professionals, of whom the majority were engineering managers with 5-10 years of experience. The finding reveals a clear maturity gap in the adoption of digital tools. While respondents demonstrated strong familiarity with foundational technologies such as Internet of Things (IoT) and big data and analytics, advanced tools like digital twins remain unknown and less implemented which is like what is experienced in Indian railways (Rajput & Naresh, 2025). The tools were perceived as most effective in supporting decision-making and facilitating stakeholder engagement, and very little was effective at reducing operational costs. The primary applications were reported in project planning & scheduling and in predictive/preventive maintenance. From the study results Governance-related barriers, including rigid hierarchical structures and excessive bureaucratic processes, together with resources and funding constraints, such as the insufficient budget, inadequate IT infrastructure, and difficulty retaining skilled personnel, emerged as the most severe hindrance. These results validate and extend the existing literature on digital transformation challenges in railway systems in developing countries (Awodele, et al., 2024; Wangai, et al., 2020). Structural and resource limitations are the sole reason the railway sector cannot progress beyond adopting only the foundational tools. The sector cannot advance beyond this scope unless proactive interventions are implemented. To address these gaps, participants recommend developing digital skills training programs to encourage retention and skills transfer within the sector. Developing a clear digital strategy is also key, as it outlines the roadmap for adopting various tools. Recommendations are to adopt a phased approach to integrate new technologies into existing infrastructure. Lastly, improving collaboration within the railway sector and alongside the private sector will accelerate the transformation efforts. The study provided practical evidence from frontline railway professionals, offering valuable insights that organizations can use to support policy and structural changes that will remove obstacles to the sector's digital transformation. Future research should include senior executives and assess long term impact of the proposed interventions.

References

Adithya, T., Galar, T. & Kumar, U., Railway Assets ; Potential domain for Big Analytics. *Proceedia Compute science ,* Volume 53, pp. 457-467.2015.

Agrawal, P., Narain, R. & Ullah, I., Analysis of Barrier,in Implementation of Digital Transformation of Supply Chain Interpretive structures modelling Approach. *Journal of modelling in Management,* 15(1), pp. 297-317. 2020.

Ai, B., Molisch, A., Rupp, M. & Dui, Z., 5G key technologies for smart railways. *Proceedings of the IEEE,* 108(6), pp. 856-893. 2020.

Banovic-Curguz, N. & Illisevic, D., *Customer centric culture and an enabler to Digital transformation.* Opatija, Croatia, IEEE. 2018.

Benahmed, S. & Hansal, A., The biggest digital transformation challenge for companies: An analysis framework. *Management and Information technology in the Digital era,* Volume 29, pp. 221-231. 2022.

Chen, C., Lin, Y., Chew & Pandia, H., Role of Government to enhance Digital Transformation in small service Business. *Journal in Sustainability,* 13(3), p. 1028. 2021.

Cichosz, M., Wallenburg, M. & Knemeyer, A., Digital transformation at Logistic service providers: Barriers, Success factors and Leading Practices. *International Journal of Logistics Management,* 31(2), pp. 209-238. 2020.

De nato, L. et al., Towards AI assisted Digital twins for Smart Railways. *Journal in Reliable Intelligent environment,* 9(3), pp. 303-317. 2023.

Deepa, N. et al., Internet of things enabled Rail Wheel Contact Temperature monitoring using fiber bragg Grating Sensors. *Journal of Optics,* pp. 1-8. 2024.

Dong, K., Romanov, I., McLellan, C. & Esen, A., Recent tect based Research and Application in Railways: A critical review and future trends. *Engineering Application of Artificial Intelligence,* 116(105435). 2022.

Fitzgerald, M., Knuchwitz, N., Bonnet, D. & Welch, M., Embracing Digital technology: A new Strategic Imperative. *MIT Sloan Management Review,* 55(2), pp. 1-112. 2014.

Gillian, S. & Cosford, P., Organisational Structures. In: C. Press, ed. *Leadership and Management for Doctors in training .* London: Taylor and Francis , pp. 26-31. 2021.

Gummerson, E., Customer centricity- Reality or Wild Goose Chase?. *European Business Review,* 20(4), pp. 315-330. 2008.

Hanelt, A., Bohnsuck, R., Marz, D. & Antures Marcante, C., A systemic review of the Literature on digital Insights on Implication for Strategy and Organisational Change. *Journal of Management studies ,* 58(5), pp. 1159-1197. 2021.

Hitt, A., Xu, K. & Carnes, M., Resource based theory in Operation Management Research. *Journal of Operations Management ,* 41(1), pp. 77-94. 2016.

Hizir, Z., Digital transformation : Jobcolypse or empowerment?. *Startegic HR review,* 21(1), pp. 6-9. 2022.

Imoleayo, A. et al., Awareness, adoptiom readiness and challenges of railway 4.0 technologies in a developing economy. *Heliyon,* 40(4). 2024.

Isik, L., Nilsson, C., Magnusson, J. & Koutsikouri, D., Benefits Realisation in digital transformation: The transitiion from policy tp practice in health care. *Transforming Governmeny: People; Process and policy,* 18(2), pp. 303-317. 2024.

Kahn, K. B.,. Understanding Innovation. *Journal of business horizon ,* 61(3), pp. 453-460. 2018
Kour, R., Karim, R. & Parida, A., 2013. *Cloud computing for maintenance performance improvement.* s.l., International conference on Industrial Engineering Management.
Kringelum, L. et al., Digital Transformation: Strategy comes first to lay the ground work. *Business Strategy ,* 46(1-2), pp. 3-10. 2025.
Kumar, A., Salmona, M., Berry, R. & Grummert, S., Digital Transformation preparedness: an explanatory study. *Digital Transformation snd society ,* 3(2), pp. 127-144. 2024.
Kumar, M., Goel, O. & Jain, S., Advancements in Digital Initiatives for enhancing passengers experience in Railways. *Darpan International Research Analysis,* 11(1), pp. 40-60. 2023.
Lyu, W. & Liu, J., Artificial intelligence and emerging digital technologies in the Energy Sector. *Applied Energy,* Volume 303. 2021.
Majchrazak, A. & Wagner, C., Enabling Customer Centricity using Wiki and the Wikis. *Journal of manament Information System,* 23(3), pp. 17-43. 2014.
Muhlungu, N., Chen, J. & Alkena, P., The underlying factors of a successful organisational Digital Transformation. *South African journal of Information,* 21(1), pp. 1-10. 2019.
Paul, J. et al., Digital Transformation: A multi-disciplinary perspective and future research agenda. *International Journal of Consumer studies ,* 48(2), p. 13015. 2024.
Pujari, S. & Saha, S., Barriers hindering Digital Transformation in SMEs. *In Drivers of SME Growth and Sustainability in Energy Markets ,* pp. 140-156. 2024.
Sahay, A., A Peeling Saunder's Research Onion. *In Research Gate,* 3(2), pp. 1-5. 2016.
Sarp, S., Kuzlu, M., Jovanic, V. & Polat, Z., Digitalisation of Railway transportation through AI powered services: Digital twins. *European Transport Research Review,* 16(58). 2024.
Shah, D. et al., Path to customer centricity. *Journal of Service Research ,* 9(2), pp. 113-124. 2006.
Singh, P. et al., Internet of things for sustainable Railway Transportation: Past, Present and Future. *Cleaner Logistics and Supply Chain,* Volume 4. 2022.
Steele, H. & Roberts, C., Towards a Ssustainable DIgital railway. *In Sustainable Railway, Engineering and Operations ,* Volume 8, pp. 239-263. 2020.
Tang, D., What is Digital Transformation?. *EPDACS,* 64(1), pp. 9-13. 2021.
Tan, X. & Ai, B.,. *Issues of Cloud computing in high speed Railways.* Habin, China, IEEE. 2011
Taylor, S. P., What is Innovation? A study of definitions, academic models and application of Innovation to exmaple of Social housing in England. *Journal of social sciences,* 5(11), pp. 128-146. 2017.
Verhoef, P. et al., Digital Transfromation: A multi-disciplinary reflection and Research agenda. *Business Research,* Volume 122, pp. 889-901. 2021.
Xiao, J. et al., Overcoming barriers and seizing opportunities in the innovative adoption of mext generation digital technolgies. *Innovation and Knowledge,* 9(4). 2024.
Yin, M., Li, K. & Cheng, X., A review on Artificial intelligence in high soeed Rail. *Journal in transportation Safety and Environment,* 2(4), pp. 247-259. 2020.
Zhelin, L. & Yihan, X., Digital transformation and the frontier of China's state governance. *Societal Science in China,* 45(2), pp. 70-91. 2024.

Biographies

Ms. Khanyisa F. Chabalala holds a BSc in civil engineering from the university of the Witwatersrand (Wits) and is currently pursuing a master's degree in engineering management at the Postgraduate engineering management, University of Johannesburg. Her research focuses on digital tool usage and barriers hindering technological adoption in the South African Railway Infrastructure Projects. Passionate about industry 4.0, she explores how these technologies can drive improved project delivery outcomes in the rail sector.

Prof Jan-Ham Pretorius obtained his BSc Hons (Electrotechnics) (1980), MIng (1982) and DIng (1997) degrees in Electrical and Electronic Engineering at the Rand Afrikaans University and an MSc (Laser Engineering and Pulse Power) at the University of St Andrews in Scotland (1989). He worked at the South African Atomic Energy Corporation as a Senior Consulting Engineer for 15 years. He also worked as the Technology Manager at the Satellite Applications Centre. He is currently a professor at the Postgraduate School of Engineering Management in the Faculty of Engineering and the Built Environment where he has worked since 1998. He has co-authored over 240 research papers and supervised 61 PhDs and over 270 Master's students. He is a registered professional engineer, professional

Measurement and Verification practitioner, senior member of the Institute of the IEEE, a fellow of the SAIEE and a fellow of the South African Academy of Engineering.

Dr Bheki B. Makhanya is a Senior Researcher at the Postgraduate School of Engineering Management, University of Johannesburg. He is also the Technical Fleet Manager at Transnet Freight Rail. Dr Makhanya holds a PhD in engineering management from the University of Johannesburg and has more than a decade of experience in asset management and reliability improvement in the railway industry. He has been a co-author of numerous peer-reviewed research papers since 2017 and has supervised over 40 master’s students in Engineering Management from the University of Johannesburg, South Africa. Dr Makhanya's research interests include cost of quality, total quality management, reliability improvement, and risk management.