Exploring some Manageable Factors Influencing the Availability of Train Authorisation Systems in South Africa

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Abstract

The performance of the railway industry significantly influences the performance and growth of a country's economy. Recent performance reports from both the freight and passenger rail industries indicate that there has been a steady decline in the performance of the South African railway industry. The railway industry's performance and capacity depend on various departments, including the Train Authorisation Systems or signalling department. The research focuses on investigating the factors that improve the availability of train authorisation systems (TAS) in South Africa. The literature emphasised the deterioration in the performance of the railway network in South Africa. Some of these performance issues can be attributed to the unavailability of the TAS equipment. The review also detailed the complex nature of the railway and TAS equipment and the specialised knowledge and skill required to maintain the systems. The empirical investigation concluded that the factors identified as contributors to the unavailability of the TAS are within the control of industry management. Then, practical and implementable recommendations were made to address the challenges identified. The results obtained through the execution of the empirical investigation confidently state that the railway industry does not contribute to the development and growth of the economy to the necessary and expected extent. In addition, it can also be concluded that the unavailability of the TAS equipment is contributing to this poor performance. However, there are practically implementable steps that management can take to address this unavailability of TAS.

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1. Introduction

1.1. Background

In South Africa, over 22,000 kilometres of rail infrastructure connect the country to the different ports (Phaladi *et al.*, 2019). In addition to the rail used for freight movement, the passenger rail owns over 2,200 kilometres of rail used for a combination of freight and passenger rail traffic (Department of Transport, 2021). The railway system has become a reliable mainline passenger service for urban and metropolitan passengers and a freight-transporting train service (Transnet, 2016). This unified organisation became the basis for the freight and passenger rail operators in South Africa today. The steady decline in performance is probably due to various factors, and management is continually developing new processes and procedures to improve performance. Improved performance benefits the entire economy (Myszczyszyn & Mickiewicz, 2020). Thus, ensuring that the initiatives being taken align with the actual failings is important. The failings of the rail network in South Africa have been well-documented in recent years. The overall performance has not been substantially improved, even though the Gibela partnership was launched in 2013. This study will focus on the performance of the signalling systems. PRASA recently launched its Rolling Stock Fleet Renewal Programme in partnership with Gibela to add more trains to the SA railway network. Gibela was formed in 2013, and the Gibela Rail Transport Consortium comprises French rail company Alstrom and South Africa's Ubumbano Rail. Gibela has an R51 billion contract with the SA government to manufacture 600 commuter trains for PRASA (Gibela. 2024), which, according to the signed 2015 contract, was due for delivery in 2025. However, the latest date for completion is now in 2029.

1.2. Problem statement

Reports from freight and passenger rail industries have shown a steady secular decline in performance (Passenger Rail Agency of South Africa, 2020; Transnet Freight Rail, 2021). The freight and logistic market in South Africa contributed $1364 billion to the South African economy in 2023, equating to 9.3% of the Gross Domestic Product (GDP) (Mordor Intelligence, 2023). This shows the significance of a performing freight and logistic market in South Africa to which the railway industry should contribute significantly. Several challenges impact the reliability of the rail network in South Africa. In South Africa, security challenges to the railway network relate to cable theft, vandalism, and track theft. One of these problems alone is a severe challenge to the railway network. However, in South Africa, all these problems are happening simultaneously (Freight Forwarding, 2023). In the 2020 financial year, the rail freight industry recorded a total loss of R8,4 billion, with various reasons provided, from constrained demand to derailments (Transnet Freight Rail, 2021). Most of the reasons provided speak directly to the TAS (Train Authorization Systems) and how the systems have impacted the decreased tonnages transported. In considering this, a core challenge identified is the unavailability of the TAS, which is critical in ensuring that a world-class, on-schedule railway network is achieved. Without suitable TAS, the rail network's capacity will be severely underutilised, resulting in fewer trains. The TAS also provides additional safety measures to ensure the safe movement of trains and prevent possible conflicting movements between trains. The factors that could affect the unavailability of the TAS are not widely acknowledged. The unavailability of the TAS is not specific to the freight or passenger rail services or a region or corridor, but the challenges may vary depending on the location and requirements of the maintenance depot.

1.3. Research objective

In line with the problem statement above, this study's primary objective is to investigate manageable aspects of improving the availability of Train Authorisation Systems in South Africa.

2. Literature Review of the South African Railway System

Railways are a climate-smart and efficient way to move freight and people. It promotes economic growth while cutting greenhouse gas emissions. They are a clean and compact way to move most passengers and millions of tons of goods across countries and continents. However, according to the World Bank (2024), it constitutes a shrinking share of transport in many developing countries like South Africa due to lousy service levels, poor integration with other forms of transport, lack of reliability, and lack of maintenance and investment.

2.1. The importance of freight and passenger transportation

As the most cost-effective means of transport over long distances, rail significantly reduces transport costs, increases the safety and reliability of transport services, and consequently stimulates regional trade and economic growth (Sequeria, 2024). The railway industry in South Africa consists of two types of service: freight and passenger. PRASA operates the Metrorail service division (which operates in urban areas) and the Shosholoza Meyl service division (which operates long-distance rail service between cities and regions) (National Government of South Africa, 2022). The freight rail service consists of all freight nationally transported via rail. The railway network plays a significant role in the economic growth of a country, and several studies and investigations have been done in this regard (Myszczyszyn & Mickiewicz, 2020). The socio-economic impacts of a functioning national railway system provide a considerable boost to the economy in the area and improve the standard of living.

Train Authorisation Systems (TAS) form part of the railway infrastructure and authorise trains between two specific areas (stations or sections). Railway signalling (BE), or railroad signalling (AE), is a system used to control the movement of railway traffic. Trains move on fixed rails, making them uniquely susceptible to collision. There are two main types of TAS in South Africa, namely Track Warrant and Colour Light signalling. Track Warrant involves little to no trackside equipment and depends on stable radio communication between the train driver and Train Control Officer (TCO).

This working method limits the number of trains to 12 per direction per day. Colour Light signalling, on the other hand, uses various trackside elements, such as points, signals, and track vacancy detection systems. No limit is specified to how many trains a colour light section can accommodate per day, but it depends on the layout and signalling design.

The TAS or signalling department is only one of six departments used by infrastructure depots. The other departments are Electrical, Permanent Way, Telecommunications, Technical Support, and Support. These are the standard infrastructure departments in all railways worldwide, but other disciplines, such as rolling stock, are not considered infrastructure departments (Greenland, 2019).

2.2. The South African rail network

In South Africa, over 22,000 kilometres of rail infrastructure connect the country to the different ports (Phaladi *et al*., 2019). In addition to the rail used for freight movement, the passenger rail owns over 2 200 kilometres of rail used for a combination of freight and passenger rail traffic (Transport, 2021). The South African Railway has evolved significantly since the first railway company was initially formed back in 1853, with the formation of the Cape Town Railway & Dock Company. However, it was not until 1858 that the first railway line was launched when an agreement between the Cape Town Railway & Dock Company and the Government of the Cape of Good Hope was signed (Rail, 2010). The first state railway system was established in South Africa in 1877, when the Cape Railway system, procured in 1872, and the Natal Railway system, procured in 1877, became the official property of the South African Government. There was then a push to link these two state-owned railway systems to the diamond deposits in Kimberley and the gold deposits in the then-Transvaal Republic (Transnet, 2022). This was followed by a unification and development plan completed in 1910 when the railway system was merged with the harbour group to form the South African Railways and Harbours Administration (SAR&H). A little over 20 years after this unification, the railway system became a reliable mainline passenger, urban and metropolitan, and freight transporting train service (Transnet, 2022). This unified organisation became the basis for the freight and passenger rail operators in South Africa today.

The issue underplayed thus far is international benchmarking, which shows South Africa's rail network is too large. Internationally, there are approximately 1 million km of rail routes, of which 2% are in the South African economy. South Africa realises that the railway is only about 0.4% of the world's GDP (World Bank 2022), and it is too big in comparison - it is estimated that it should be about 1%. The international case study shows that South Africa's network size - route kilometres - has effectively remained unchanged. More specifically, less than 10% of South Africa's route kilometres have been lifted, resulting in a heavy burden of fixed costs.

2.3 Performance of the South African Railway Industry

Table 1 summarises the rail and road transportation industry's annual performances concerning freight and passenger services (Stats SA, 2013 - 2022).

Table 1: Rail vs Road Volumes (Stats SA, 2013 - 2022)

Year	Rail		Road	
	Freight Payloads (000 tons)	Passenger Journeys (000)	Freight Payloads (000 tons)	Passenger Journeys (000)
2013	213 584	559 427	520 793	308 788
2014	223 568	544 082	565 265	302 476
2015	222 229	490 285	550 372	297 668
2016	219 744	412 683	561 593	286 772
2017	229 843	318 918	683 831	320 442
2018	217 401	253 413	753 110	309 185
2019	215 740	174 599	696 972	293 606
2020	191 847	29 628	614 945	202 944
2021	178 795	21 762	688 846	208 288
2022	154 679	19 118	839 218	244 487

Table 1 shows how rail freight payloads steadily increased from 2013 until 2017 and then drastically declined. At the same time, road freight payloads have steadily increased, except for a brief decline attributed to COVID-19. This is graphically represented in Figure 1 below.

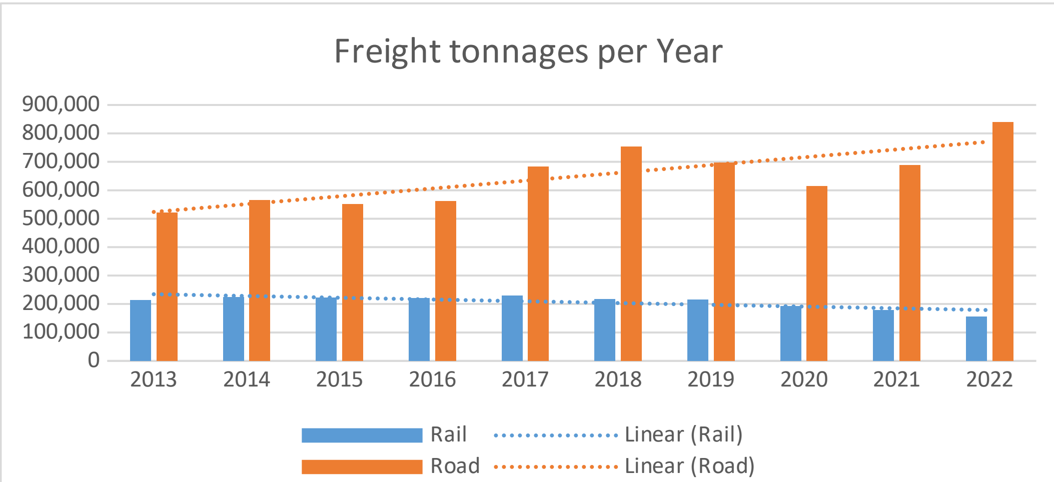

Figure 1: Freight Tonnages per Year (Stats SA, 2013 - 2022)

The trendlines in Figure 1 show that the freight tonnages moved by road have increased over time, while the freight tonnages moved by rail has decreased. These changes occurred when the freight transportation annual tonnages were the highest that they have been for ten years. The market share of the rail and road industries, when considering freight transportation, is indicated in Figure 2.

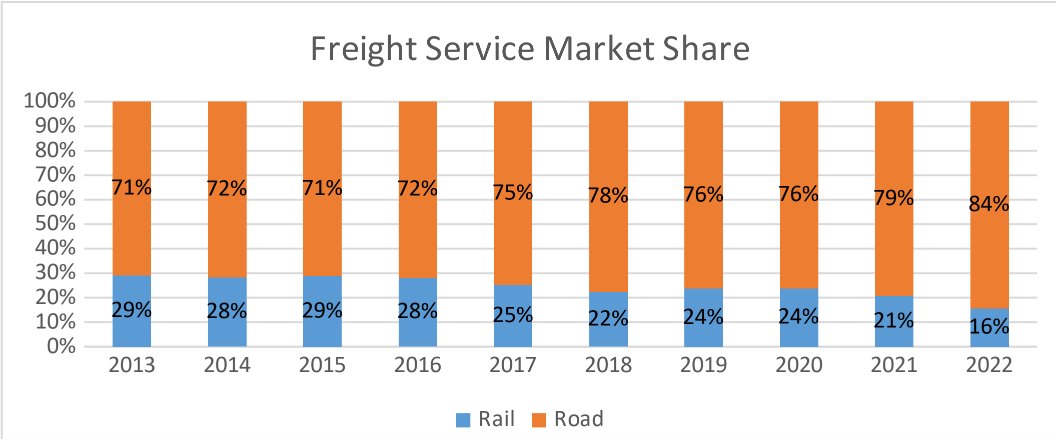

Figure 2: Freight Market Share (Stats SA, 2013 - 2022)

According to the above figure, the market share for rail freight is being lost to the road freight industry. From these data, it follows that the performance of the rail freight industry is steadily declining. A similar analysis is done regarding the passenger transportation industry. The trendlines in the relevant data show that passenger journeys via road have increased, while passenger journeys via rail have decreased. Like the freight industry, these changes have also occurred when the number of passenger journeys per year is the highest that they have been in the previous ten years. Thus, the market share for rail passenger service is being lost to road passenger service mainly due to the steady decline of the rail industry. This continuous increase in the road-over-rail market share started in the 1980s when the road freight industry was deregulated and has continued even more since 2000 when private freight-carrying vehicles were allowed access to port terminals. This shift in the market share is due to rail freight taking longer to complete the end-to-end journey (Havenga *et al.*, 2021).

Like the challenges faced in the freight industry, the passenger rail reported that for the 2019 and 2020 financial years*, the TAS was the largest contributing factor to train delays in the industry, contributing a staggering 45.7% of all train delays* (Havenga *et al.*, 2021, Passenger Rail Agency of South Africa, 2020). This resulted in decreased passenger trips, trains operated, on-time trains, and the line capacity (scheduled trains) are illustrated in Figure 3 below.

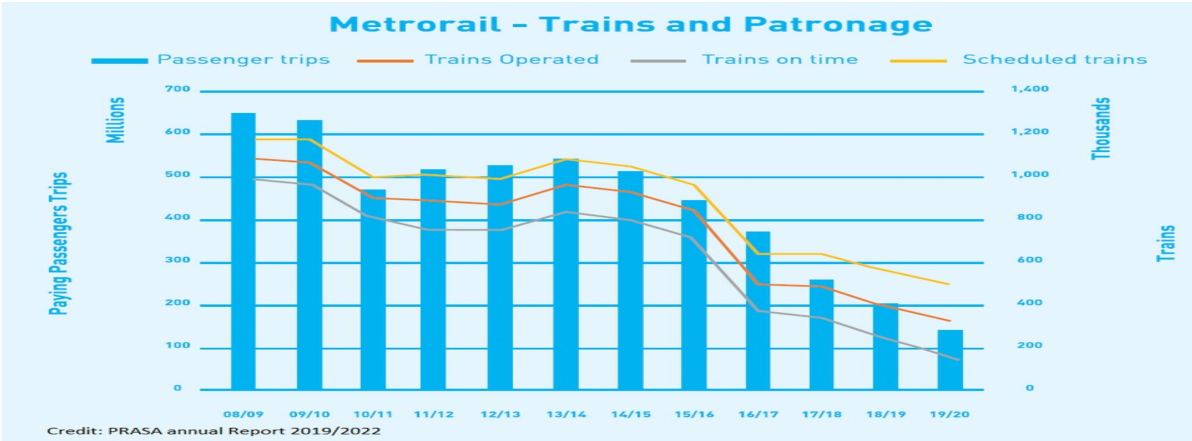

Figure 3: PRASA Trains and Trips (Passenger Rail Agency of South Africa, 2020)

These statistics indicate the challenges faced by the TAS and the impact these systems have on the country's economic growth (Mukwena, 2018; Ramuhulu & Chiranga, 2018). The government acknowledges that inadequate network maintenance funding impacts operational performance (Transnet, 2024). Rail (freight and passenger) and port capacity declines in SA remain a severe barrier to domestic and regional economic trade. The Government’s plans to spend R900 billion by 2027 on rail infrastructure have been beset by regulatory, organisational and operational challenges (ITA, 2024). Commodity exports have consistently dropped in the last decade due to rail inefficiencies. The railway SOE’s intentions of addressing rail industry failures have made little progress in streamlining the freight and passenger network of the economy. Internal inefficiencies have made competing against road freight almost impossible (ITA, 2024).

2.4 Factors influencing the capacity of the rail network

Deteriorating asset reliability and availability levels result in delays, cancelled train slots, volume loss and eventual permanent capacity loss (Transnet, 2024). Failure rates of the asset base are increasing, and in the context of this research focus, most TASs *are obsolete (some are more than 60 years old)*. Several factors can affect the capacity of a section, network, or corridor. However, not all these factors have an equal effect on the maximum capacity of a section and only a few should be considered key success factors in ensuring the maximum capacity is reached. Thus, there needs to be a clear understanding between what is considered *a major maximum capacity influencer and what is simply a capacity influencer*.

2.4.1 Factors Influencing Maximum Capacity

The most popular formula used to calculate the capacity of a section is a formula known as Scott’s formula (Calculator Academy Team, 2022). This formula and the different components in the formula are described as follows:

$$C = \frac{1440}{(T+t)} \times E$$

C – The theoretical capacity of the section
T – The time taken for the slowest train to enter and exit the section
t – The time the TCO takes to communicate with the train driver.
E – The efficiency factor of the section (%)
1400 – The total number of minutes in a day

As observed from the formula, three factors affect the capacity of the section. The two times represented in the formula are considered the factors that affect the maximum capacity of the section, while the efficiency factor includes all other factors that will affect the general capacity of the section. The two-time factors are considered to be the influence of maximum capacity because even if the railway section's efficiency is at 100%, if these two-time factors are not adequate, then the desired operational capacity cannot be obtained (Calculator Academy Team, 2022). *When considering the factors affecting the maximum capacity of a section, they are both heavily reliant on the signalling system installed.* The two factors are divided into travel time and operating time. Consequently, one of the critical factors affecting the maximum capacity of a section is the type of signalling system used, including the layout and installation of the system.

2.4.2 Additional Capacity Influences

In addition to the critical factors that affect the maximum capacity of a railway network, several other factors affect and influence the operational capacity of the rail network in South Africa. The above maximum capacity can only be achieved if these additional factors align with the maximum capacity requirements (Connor, 2012; Khadem-Sameni *et al.*, 2010; Ljubaj *et al.*, 2020). These additional factors can be technical, operational, and commercial and will not be discussed for the scope of the research paper.

Five disciplines are usually associated with railway infrastructure: Permanent Way (Perway), Electrical, Technical support, Telecommunications, and Signalling. Although all disciplines are dependent on each other and critical for the efficient operation of the railway, the Perway, Electrical, and Signalling disciplines are considered to have the biggest influence on the capacity of the network, although they are still dependent on the availability and performance of the other disciplines (Connor, 2012).

Perway: The Perway Department is vital to the railway industry's capacity, efficiency, and profitability. An important consideration for Perway's influence is the close relationship that the Perway and signalling departments have with each other. The signalling department relies on the Perway department to maintain critical elements to ensure that the signalling system is available and reliable (Mukwena *et al.*, 2019). The most significant influence is that some track vacancy detection systems use the rail as a medium to communicate, and if the Perway components needed for this communication, such as the block joints, are not maintained, then the signalling system will be unavailable. Thus, the Perway has a significant effect on the efficiency of the railway network and is vital in ensuring that the maximum capacity of the section is achieved (Mukwena *et al.*, 2019).

Electrical: The Electrical department also affects the availability and reliability of signalling systems. Technical requirements require electrical maintenance activities to affect the performance of the signalling system, but the most significant factor is that the electrical department supplies all signalling equipment with the power needed to operate (Rail UK, 2020).

Summary of Capacity Influences: The investigation above into the capacity of influencers is complex. This is because maximum capacity determines the maximum number of trains that can pass through a section, thus determining actual train capacity, while factors also determine the maximum volume that can be transported. A graphical summary of the above encapsulates this.

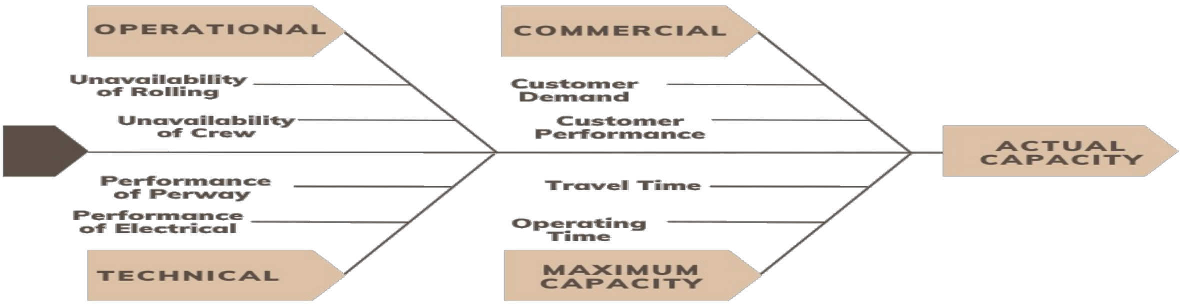

Figure 4: Factors influencing capacity (Source: Own Compilation)

Capacity utilisation is also a function of railway efficiencies that is conceptually difficult in terms of a single description. Operators will define it in terms of access to and cost of infrastructure. Users are looking at issues like availability, reliability or speed (ITF, 2019). The national regulator will look at technical and allocative efficiency metrics and require different data to evaluate both. The easiest approach is to derive key performance indicators from the available data to draft a balanced scorecard. This scorecard should have the following aspects: system scope, asset utilisation, human resources, operational performance, financial performance and customer-centric indicators. This is the best practice in European Countries like France (ITF, 2019). The Netherlands benchmark indicated that moving to a performance-based contract (like maintenance) is a best practice and decreases maintenance costs.

This investigation shows that all disciplines and capacity influences need to be operating in unison to achieve maximum capacity. With all this considered, the biggest influences on the maximum number of trains that can pass through a section are:

- The time it takes for the slowest train to enter and exit the section
- The time it takes for the TCO to communicate with the train driver.
- The efficiency factor of the section

These factors rely on the signalling systems and methodologies deployed, which will be discussed in the following section.

2.5 Signalling in South Africa

Railways Africa (2024) emphasises that interlocking train control systems and track vacancy detection are essential for efficient rail operations. Highly available signalling control systems assist in making railway services even safer and more cost-effective. To understand the current condition of the infrastructure in South Africa, it is important to understand where the technologies and philosophies used have come from and how they were developed. This section aims to provide a background to the implementation of signalling systems in the railway industry that have been developed over time with the advancements in technology and the capacity requirements of operators.

2.5.1 A brief history of railway signalling in South Africa

The first traces of the history of railways date back to 700 BC (Lewis, 2001) when ancient civilisations utilised various ways to transport goods and products. These runways then paved the way for the development and use of rail travel using hand-propelled rail vehicles. However, these developments in hand-propelled rail vehicles only led to further developments, with the construction of the first steam locomotive railway system in the 1800s. These initial developments of the steam and locomotive systems then led to the advancements in railway and locomotive technologies with the development of diesel and electric locomotives. Electrical, diesel and steam locomotives are still in use (Carvalhaes *et al.*, 2017; Malia, 2008). However, the railway system is not without its limitations, and it was imminently clear that to effectively and efficiently increase the railway network's capacity and ensure the safe operations and movements of trains, there was a need to design, develop and install a method to control trains. This requirement was met by the development of different train authorisation methodologies and technologies, called signalling systems or Train Authorisation Systems (HRD Integrated Services, 2022; Lingaitis & Sinkevičius, 2014; Merriam-Webster, 2023; Aloui, 2022; Dick *et al*., 2019).

There have been and continue constant developments in signalling systems and technologies. These developments primarily depend on technological advancements and developments available at that time, and they have significantly changed over the years. The first known method of train control was hand signals or hand signalling. With technological developments, these hand signals were upgraded to include a stopwatch. The stopwatch recorded when a train should enter and exit a specific section. The technology and philosophies developed even more over time, including operators using whistles, flags, lamps, and even bells (Palumbo, 2013).

The different signal systems, technologies and philosophies used, developed and implemented over the years, specifically on single-line working sections (Cambridge, 2023), were tokens, the telegraph system, semaphore signalling, radio train order, interlockings – with the development of the electronic interlocking system in SA. Although the electronic interlocking system has been developed and deployed for several years in other countries, the capital investment of the system has delayed the roll-out of the system in South Africa.

The two terms, *fail-safe* and *vital*, form the basis of all signalling systems and thus are extremely important to understand to grasp the signalling technologies and train control methodologies fully. It is important to be knowledgeable about the influence that each technology may have on the system and capacity of the network. Thus, the different technologies installed and used on the network are described and listed below. The relevance of passenger rail and high-capacity freight railways in SA use colour light signalling, using some form of interlocking (Huang, 2020). Light signalling is necessary to mitigate the high speeds trains can drive at, and the rail signals indicate that you may need to slow down or stop at the next signal or continue at full speed, which maintains safety levels and, with the right time, train running.

Table 2: Colour Light Signal Technologies (Source: Own Compilation)

Technology Name	Technology Description
Points machines	Points machines are employed to reposition railway junctions, or turnouts, to enable trains to cross. The speed at which a train can travel over a turnout increases as the turnout's length increases, necessitating more sophisticated points machines.
Signals	The signal serves as the primary method of communication between the Train Control Officer (TCO) and the train driver. The aspect shown on the signal provides information not only for the immediate section following the signal but can also convey information for sections beyond the subsequent signal. This dual function enhances the line's capacity and the overall safety of the network.
Track Vacancy Detection	The track vacancy detection system identifies a train's presence on the railway network. This data is then fed into the interlocking system, which uses it to prevent conflicting movements and ensure safe rail operations.
Fail-Safe Data Transfer	The fail-safe data transfer system is employed for station-to-station communication. Its inherent fail-safe characteristic guarantees that if a received message cannot be verified, the system will fail to a safe state.
Interlocking	Interlocking is the most important technology in the signalling system. Its primary role is to guarantee the absence of conflicting movements and align all actions with established signalling principles. The previously mentioned systems play a crucial role in the interlocking system's inputs and outputs, serving either to provide data for vital functions or to verify the accurate execution of these vital functions.

The above technologies and systems are the base of all colour light signalling systems in South Africa and are vital in increasing the network's capacity. The latest technological developments are electronic interlocking and in-cab signalling. The Infrastructure Manager (IM) acknowledges in a draft Network Statement (Transnet, 2024) that most of the TAS in SA are very old and, as such, are becoming obsolete and that the failure rates of the asset base are increasing. Consequently, this is the impact of inadequate network maintenance funding. Various benefits could flow from an improved network by meeting the commercial needs of the underserved mining, manufacturing and agricultural sectors. Banquart and Koning (2017) stated that the spread of investment funding is affected by demand and, in terms of cost-benefit analysis, by changes occurring in users' surplus. It can ultimately culminate in a higher Keynesian multiplier and positive economic spillovers. It is estimated that R10bn funding in infrastructure could generate a commensurate return from just road maintenance cost savings of R8,09 bn and reduced carbon emissions of R1,62 bn (Transnet, 2024). Transnet (2024) proposed in a draft document the Global Best Practice Allowed Revenue Methodology, which will facilitate the provision of the desired network availability and reliability levels. This will also enhance financial stability. In connection with global benchmarks, the European Union speaks of allowances that need to be made for its member states to set prices high enough to cover the fixed costs of infrastructure and admits that the financing gap created by marginal cost access pricing is usually partly covered by state subsidisation.

3. Research Methodology

3.1 Research design

The study followed a quantitative research approach through an online survey. Because the factors contributing to the TAS's unavailability may be known, it is possible to measure these factors from the study accurately. Considering the information that will be made available, the access to knowledgeable employees, and the exploratory nature of this study, a mono-method quantitative study is considered the best methodological approach.

3.2 Target population and sampling

The target population is the specific group of individuals, in this case, that are available to participate in the research investigation (Bryman, 2014). The target population was all staff employed in the freight rail operating division nationwide. Over 20 TAS maintenance depots (Central Offices and Technology Management) exist throughout SA. These are the locations where the study population was approached. The study will follow a non-probability sampling technique with all respondents selected based on a non-random criterion – knowing about the TAS system (Acharya *et al*., 2013). Although the study will consist of inferential statistics, the interpretations of this study will be done using effect sizes. For this specific study, no all-inclusive sample frame is available, which limits the choices available. Considering this and the sample population's estimated size, the study size should be between 50-60 respondents. The aim is to achieve a sample size of at least one or two members of staff with relevant knowledge per depot, and this size provides a balance between statistical validity and practical feasibility.

3.3 Data collection

The questionnaire was designed and developed to identify specific elements affecting the availability of the TAS and establish if these elements were shared across the country or specific to different maintenance depots/provinces/corridors. To achieve this, the questionnaire was divided into five sections, each focusing on the elements affecting the performance of the railway industry and, more specifically, the availability of the TAS in South Africa.

3.4 Data Analysis

Data analysis has been done in collaboration with the North-West University Statistical Consultation Services. The study used exploratory factor analysis to confirm its validity. The factor analysis identified variables related to the availability of TAS equipment and related infrastructure that could be grouped to form a single factor (Darlington, 2010). In addition to the factor analysis, the study also used the MSA technique (Hill, 2011), which provides a numerical value representing the intercorrelation between the different variables (Hill, 2011). The following guidelines were used to determine whether the factor analysis was appropriate. MSA Interpretation Guidelines: ≥ 0.80 (meritorious), 0.70 (middling), 0.60 (mediocre), 0.50 (miserable) ≤ 0.50 (unacceptable). This paper used Cohen's effect sizes to determine if there were meaningful relationships between the variables. As a result of the study using non-random sampling, the effect sizes indicated the practical significance of the specific research outcome. The guidelines used to interpret the effect sizes (determine the practical significance) according to the *'d' values* were: ≤ |0.2| (small), |0.5| (medium), and ≥ |0.8| large effects (Cohen, 1988).

3.5 Validity and reliability

The validity of a measuring instrument is the accuracy by which it measures the factors it was designed to measure (Bryman, 2014). However, this is not easy to measure and calculate, as it depends on the respondents' attitude, mindset, and honesty. *Thus, the validity of this study was focused on ensuring that the questions asked were clear and concise, ensuring that the respondents were answering questions they understood*. The questionnaire also focused on questions that were based on facts and experiences. Therefore, the results were less reliant on how the respondent was feeling now of answering. The validity of the measuring instrument was then calculated by conducting a factor analysis described below. The reliability of a study indicates the consistency of the measuring instrument in obtaining the same results if the test is conducted under similar conditions. The reliability of the study was determined using the value of the Cronbach alpha coefficient (Ravinder & Saraswathi, 2020). The Cronbach alpha values were calculated, and values greater than 0.6 indicated that the factor was reliable.

3.6 Research ethics

The research was ethically cleared (NWU-0057523-A4) by the relevant Faculty Ethical Committee (FEMSREC). It must be noted that all respondents who accepted the informed consent form and completed the questionnaire are part of the study population. As such, the study complies with the Protection of Personal Information Act (No. 4 of 2013) (POPIA) (SA, 2013).

4 Results and Findings

4.1 Profiling the Respondents

The demographic information was gathered to ensure that the respondents met all inclusion criteria and no exclusion criteria. A breakdown of the demographical information received is described as follows:

The *age groups* in the questionnaire were separated into the four generational brackets currently in the workforce. From the responses received, 7% of respondents formed part of the Gen Z generation, 77.2% formed part of the millennial generation, 7% formed part of the Gen X generation, and 8.8% formed part of the Boomer generation. From the responses received, it can be noted that most respondents, 77%, fell within the millennial generation bracket. This, however, is a 15-year period; thus, the number of years of experience was used to gain additional insights.

The *years of experience* were more evenly spread, with 5.3% having less than three years of experience, 14% having between three and five years of experience, 29.8% having between six and ten years of experience, 35.1% having between 11 and 20 years of experience and 15.8% having over 20 years of experience. The results show a good variation between the years of experience and respondents, with most respondents (64.9%) having between six and twenty years of experience.

Some 98% of respondents indicated that they gained experience in the freight rail industry, 2% indicated it was gained in the passenger rail industry, and 0% indicated that it was gained in a different/other industry. The interconnectivity between the passenger and freight rail industries in South Africa, including shared networks and infrastructure, indicates that all experience was gained in the railway industry.

The question on *where experience was gained* was to ensure that the experience was gained in the areas identified as the target population. Although multiple options were provided, these options were analysed and summarised into two main groups: maintenance and support. The maintenance group included the operations and infrastructure maintenance respondents (representing 57.9% of the respondents). The support group included all other departments. These departments are not directly responsible for train movements or maintenance but supply critical support to the maintenance group. This group contributed 42.1% of the responses.

4.2 The Current Condition of the Railway Infrastructure?

It is noted (Transnet, 2024) that the mention of deteriorating levels of asset reliability and availability is the consequence of the lack of network restoration and sustaining capex-level requirements. Network funding demand is in dire straits in addition to R51bn restoration requirements (Transnet, 2024). Most TASs are at end-of-life and must be replaced. As such, it is advisable to consider new technology within the digitisation narrative.

This section was divided into two parts. The first part consisted of eight questions (7-14), that made use of a 4-point Likert scale. The final question in Section (15) used a multiple-choice question, where respondents were required to indicate a single factor that had the most significant influence on railway performance. *Due to the different types of questions asked and the different measurement scales used, the two divisions of section C were analysed separately. An important note for the 4-point Likert scale is that the middle point of the scale is 2.5* - used to determine the extent to which respondents weighted their responses to the specific question. The data was initially analysed using frequency analysis. This was done per question to identify how many respondents selected that extent for the same question. The result of this analysis is shown below.

Table 3: Frequency Analysis (Source: Own Compilation)

No.	Frequency									
	1		2		3		4			
	Count	%	Count	%	Count	%	Count	%	Mean	St. dev.
Q7	3	5.3%	25	43.9%	20	35.1%	9	15.8%	2.65	0.8
Q8	19	33.3%	23	40.4%	8	14.0%	7	12.3%	2.07	1
Q9	4	7.3%	17	30.9%	29	52.7%	5	9.1%	2.63	0.75
Q10	0	0.0%	11	19.3%	12	21.1%	34	59.6%	3.4	0.81
Q11	0	0.0%	5	8.8%	14	24.6%	38	66.7%	3.6	0.66
Q12	1	1.8%	3	5.3%	10	17.5%	43	75.4%	3.65	0.67
Q13	2	3.6%	9	16.1%	16	28.6%	29	51.8%	3.3	0.86
Q14	0	0.0%	6	10.5%	17	29.8%	34	59.6%	3.4	0.69

In addition to the frequency analysis, a mean analysis was performed to determine the average extent to which respondents have selected per question. The first three questions (Q7-9), focused on determining the respondent's opinion on how the railway industry is performing and how it is supporting economic growth. Interestingly, when the mean is considered, respondents felt that the freight rail industry operated better and supported growth and development in the country more than the passenger rail industry. Questions 10-14, aimed at identifying factors affecting the performance and capacity of the network, the responses indicate that all factors contribute to the perceived poor performance of the railway industry. However, *the factor identified as having the most significant effect was the unavailability of key signalling infrastructure* (Q12).

Question 15 was analysed separately from the first part of the section. Respondents were asked what factor had the most significant influence on the railway industry's poor performance, and the results are shown below.

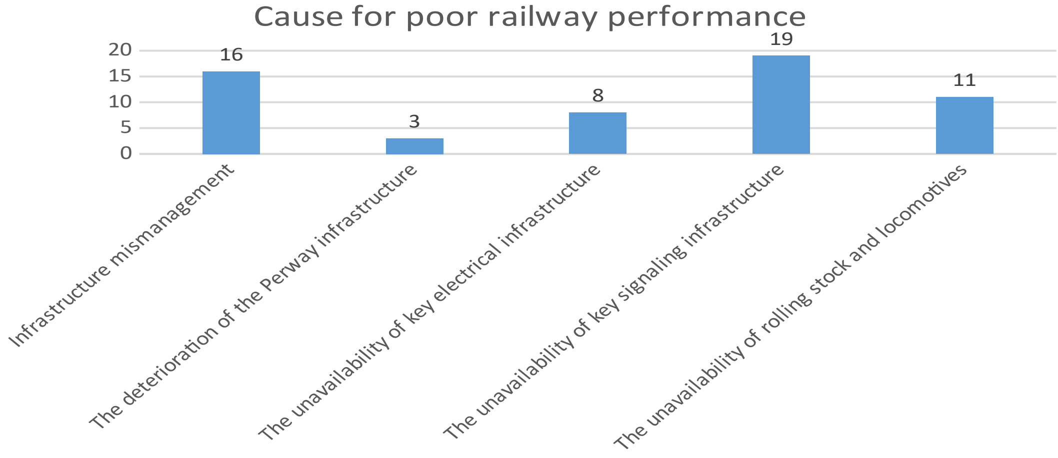

Figure 5: Number One Contributor to the Performance Challenges of the Railway Industry (Source: Own Compilation)

The respondents identified the unavailability of key signalling infrastructure as the primary contributor to the poor performance of the railway industry. These results indicate that the respondents identified that the freight and passenger rail railway industry is not supporting, to a large or moderate extent, the growth and development of the country. The respondents also identified the inaccessibility of key signalling infrastructure as the primary contributor to this.

Validity: The study's validity was determined using a factor analysis. It is important to note that a factor analysis was done separately on sections C and D, as the required outcomes were different. Two factors were identified for section C of the questionnaire. A summary of the factors identified from the analysis is described in Table 4 below.

Table 4: Factor Analysis Results (Source: Own Compilation)

Factor Number	Factor Label	Questions Applicable	N	MSA	Cumulative Variance	Cronbach α
C1	Performance of the railway industry	Q7, Q8 and Q9	55	0.768	Between 0.411 and 0.775	0.707
C2	Contribution to performance challenges	Q10, Q11, Q12, Q13 and Q14	55			0.780

From the results above, the calculated MSA value is greater than 0.7, thus within the middling rating, and indicates that validity is assured. The Cronbach alpha coefficients calculated are above 0.7, which indicates that all factors identified are reliable.

Effect Sizes: Two different effect sizes were used. The first effect size analysis investigated the respondents' years of experience. Respondents with less than ten years of experience (labelled E1) and respondents with more than ten years of experience (labelled E2) were grouped. The second effect size analysis investigated the location of respondents. Respondents from coastal provinces, KwaZulu Natal, Eastern Cape, Western Cape, and Northern Cape, and respondents from inland provinces, Gauteng, North-West, Limpopo, Free State, and Mpumalanga, were grouped. The coastal provinces were labelled L1, and the inland provinces were labelled L2. The results obtained are shown in Table 5.

Table 5: Descriptive statistics and effect sizes (Source: Own Compilation)

Subtest	Group	N	Mean	SD	d-value
C1-Performance of the railway industry	E1	28	3.51	0.56	0.1
	E2	29	3.47	0.52	
	L1	25	2.43	0.93	<0.1
	L2	32	2.39	0.93	
C-2 Contribution to performance challenges	E1	28	2.51	0.78	0.2
	E2	29	2.33	0.60	
	L1	25	3.48	0.74	<0.1
	L2	32	3.47	0.79	

The results in Table 5 show that the d-values are equal to or less than 0.2 - indicating limited practical significance to any difference in responses between more and less experienced respondents or based on the respondent's location.

4.3 Analysis of Factors Identified

The investigation also considered the means of the factors identified during the factor analysis. Factor analysis aims to simplify a broad concept by considering more granular, contextual information to identify underlying factors that explain the pattern of correlations within a set of observed variables. Table 6 summarises the factors and the mean of each factor.

Table 6: Mean Analysis of Factors - Section C

Factor Number	Factor Label	Questions Applicable	N	Mean
C1	Performance of the railway industry	Q7, Q8 and Q9	55	2.421
C2	Contribution to performance challenges	Q10, Q11, Q12, Q13 and Q14	55	3.487

From the means, the respondents perceived the railway industry's performance below average (2.421). However, they also indicated that capacity-influencing factors largely contribute to performance challenges. This indicates a *misalignment* between perceived performance challenges and the factors affecting performance.

4.4 Performance of Signalling Systems

Section D aims to gather information on the current condition and performance of the TAS equipment. This was done to identify what contributes to its inaccessibility and to determine if measures can be taken to improve its performance and, subsequently, the performance of the railway industry.

5 Analysis of Results

Section D consists of two parts – the first consisted of nine questions (Q16-24) that used a 4-point Likert scale. The final question (Q25) required the respondents to indicate a single factor significantly influencing TAS performance. The result of this analysis is shown in Table 7.

Table 7: Frequency Analysis - Section D (Source: Own Compilation)

Question Number	Frequency									
	1		2		3		4			
	Count	%	Count	%	Count	%	Count	%	Mean	SD
Q16	0	0.0%	7	12.3%	19	33.3%	31	54.4%	3.47	0.66
Q17	14	24.6%	22	38.6%	10	17.5%	11	19.3%	2.29	1.05
Q18	20	35.1%	17	29.8%	8	14.0%	12	21.1%	2.16	1.13
Q19	7	12.3%	24	42.1%	16	28.1%	10	17.5%	2.49	0.92
Q20	33	58.9%	8	14.3%	5	8.9%	10	17.9%	1.84	1.18
Q21	5	8.8%	21	36.8%	24	42.1%	7	12.3%	2.56	0.83
Q22	2	3.5%	21	36.8%	28	49.1%	6	10.5%	2.67	0.72
Q23	11	19.6%	24	42.9%	14	25.0%	7	12.5%	2.33	0.92
Q24	15	26.3%	18	31.6%	16	28.1%	8	14.0%	2.29	1.03

A mean analysis was performed to determine the average extent to which respondents have selected per question. Question 16 specifically investigates the respondents' opinions on how the unavailability of TAS equipment contributes to the performance challenges within the railway industry. The mean and frequency analysis emphasise that the unavailability of TAS equipment is contributing to the performance challenges within the railway industry to a large extent. Therefore, Questions 17-24 aimed to identify to what extent sufficient support exists to improve and maintain the availability of TAS equipment. With the information above, the factors can be prioritised according to the responses. This prioritisation can be seen in the table below - note that the lower the mean, the higher the prioritisation, and the worse the current support for that element.

Table 8: Prioritisation of Responses (Source: Own Compilation)

Prioritisation	Question Number	Question Description	Mean
1	Question 20	Sufficient security provisions	1.84
2	Question 18	Sufficient equipment spares are provided	2.16
3	Question 17	Sufficient budgetary provisions	2.29

4	Question 24	Sufficient employee retention	2.29
5	Question 23	No obsolete technologies installed	2.33
6	Question 19	Sufficient skills and competencies	2.49
7	Question 21	Sufficient personnel	2.56
8	Question 22	Correct and suitable technologies	2.67

Six elements from this analysis fall below the midpoint of 2.5. However, the focus will be on the three lowest scores. The respondents have identified the lowest extent to which there are sufficient provisions currently made as the security provisions, second are spare provisions, and third are budget provisions and employee retention. These *highlight four areas* that can be focused on to improve the availability of the TAS equipment.

The second part of section D (Q25) was analysed separately from the first part of the section. This section specifically asked the respondents what the focus should be on improving the availability of the TAS in South Africa, and the results are shown below.

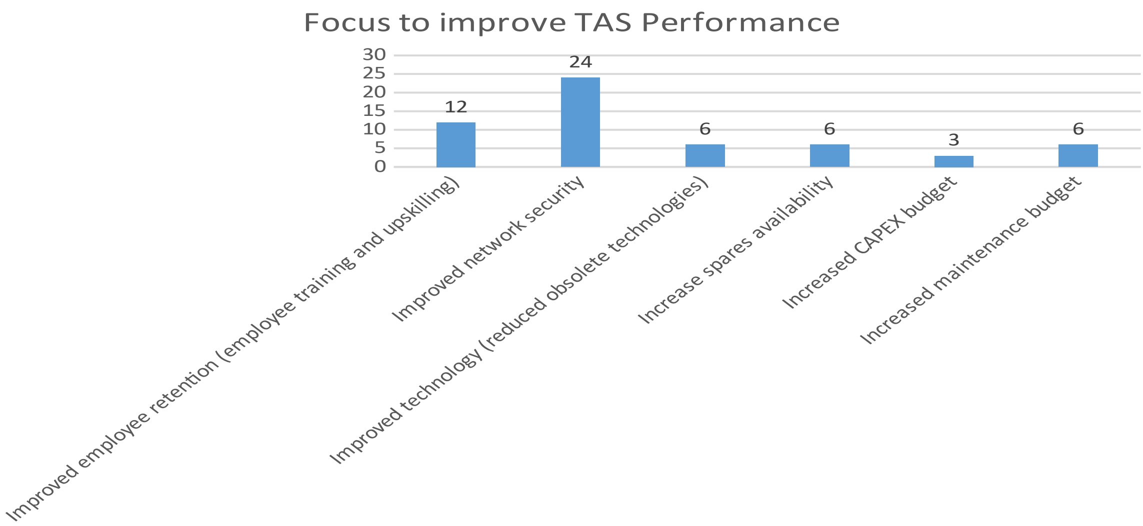

Figure 5: Focus to Improve the Availability of the TAS in South Africa

From the above, improved network security has been identified as the highest priority, with improved employee retention as the second focus area (representing 63.16% of the responses).

Validity: The study's validity was determined using a factor analysis. As mentioned above, it is important to note that a factor analysis was performed separately in sections C and D, as the required outcomes were different. Two factors were identified for section D of the questionnaire. The table below summarises the factors identified, applicable questions, and results of the analysis.

Table 9: Section D - Factor Analysis Results (Source: Own Compilation)

Factor Number	Factor Label	Questions Applicable	N	MSA	Cumulative Variance	Cronbach α

D1	Performance of the TAS equipment	Q16	55	0.827	Between 0.458 and 0.762	N/A
D2	Factors affecting the availability of TAS	Q17, Q18, Q19, Q20, Q21, Q22, Q23 and Q24	55			0.8618

From the above results, the MSA value calculated exceeds 0.8, thus a meritorious rating, indicating that the validity is guaranteed. The reliability of the study was determined by calculating the Cronbach alpha coefficient. The coefficient was calculated separately for each factor. Factor D1 consists of only one question; as such, it is not possible to calculate the Cronbach alpha. The Cronbach alpha coefficient calculated for factor D2 is above 0.8 and indicates a reliable factor.

Effect Sizes: Section D also conducted two different effect size analyses. The first effect size analysis investigated the number of years of experience of respondents with less than ten years of experience (E1) and respondents with more than ten years of experience (E2). The second effect size analysis investigated the location of respondents. Respondents based in coastal provinces (L1), KwaZulu Natal, Eastern Cape, Western Cape, and Northern Cape, were grouped, and respondents from inland provinces (L2), Gauteng, North-West, Limpopo, Free State, and Mpumalanga, were grouped. The results of the effect sizes are shown in Table 10.

Table 10: Descriptive statistics and effect sizes - section D (Source: Own Compilation)

Subtest	Group	N	Mean	SD	d-value
Performance of the TAS equipment	E1	28	3.61	0.57	0.5^{Δ}
	E2	29	3.24	0.79	
	L1	25	3.24	0.76	0.5^{Δ}
	L2	32	3.56	0.61	
Contribution to performance challenges	E1	28	2.30	0.81	0.1
	E2	29	2.39	0.57	
	L1	25	2.38	1.07	0.1
	L2	32	2.30	0.97	

Table 10 shows that the d-values for the contribution to the TAS performance challenges are less than 0.2. This indicates limited practical significance to any difference in responses between more and less experienced respondents or based on the respondent's location. However, the performance of the TAS equipment shows a medium effect size, as the d-value is equal to 0.5. This shows that there is a medium practical significance. This is due to the more experienced respondents observing that the performance of TAS equipment affects the performance of the railway industry to a lesser extent (3.24) than the respondents with less experience (3.61). Furthermore, respondents based in coastal provinces observed that the performance of TAS equipment affects the performance of the railway industry to a lesser extent (3.24) than those based in inland provinces (3.56).

5.1 Analysis of Factors Identified

The investigation also considered the means of the factors identified during the factor analysis. The factor analysis aims to describe multiple variables into a few factors, providing insight into the general responses regarding the factor. Table 11 summarises the factors and the means of each factor.

Table 11: Mean Analysis of Factors - Section D (Source: Own Compilation)

Factor Number	Factor Label	Questions Applicable	N	Mean
D1	Performance of the TAS equipment	Q16	55	3.421
D2	Factors affecting the availability of TAS	Q17, Q18, Q19, Q20, Q21, Q22, Q23 and Q24	55	2.345

From the means in the table above, the respondents perceived the unavailability of key signalling infrastructure to contribute to the railway industry's poor performance to a large extent (3.421). The mean of factor two indicates that, to a small extent, is the perception that sufficient provisions are being made to support the availability of the TAS equipment. This indicates a misalignment between the factors affecting the performance of the railway industry and the provisions being made to reduce challenges and improve railway performance.

5.2 Open-ended final comments by the Respondents

The questionnaire concluded with three open-ended questions. These were included to gain additional insight from respondents and determine if any factors were not considered that the respondents wanted to mention or include in the study.

- The first question aims to identify *the biggest challenge facing the Railway Industry in South Africa currently,* and the most important aspects identified were
    - Under-investment in railway projects and maintenance
    - Incorrectly implemented and maintained procurement processes
    - Incorrect appointments in critical positions

It is important to note that, of the 47 responses received to this question, 31 respondents (66%) referred to theft and vandalism as the biggest challenge facing the railway industry in SA.

- The second question aims to identify the *largest factor contributing to the unavailability of the TAS* in South Africa.
    - Inventory management and allocation

- Knowledge/Skills transfer
- Maintenance backlogs

Of the 47 responses received to this question, 29 respondents (62%) referred to the theft and vandalism of line-side TAS equipment as the biggest challenge in SA.

- The final question aims to identify the *most important factor to ensure the availability and sustainability* of the Train Authorisation systems in South Africa.
    - An improved and performance-driven culture
    - Clear and communicated financial investment plan
    - Relevant and suitable technology upgrades and roll-out plans

A total of 35 (of 48 responses) respondents (73%) referred to improving security. This included the deployment of strategic security plans, the installation of more robust technologies, and the deployment of security technologies.

6 Managerial Implications

First, due to the complexities regarding the measurement of railway efficiency, it is highly recommended that broader management derive a balanced scorecard for the industry. It is also recommended that simple indicators for aggregate analysis of rail performance be used, with econometric models to capture the complexity of rail performance and to invest more into data-centric decision-making and indicators relating to service quality. A revisited security implementation plan - the lack of security provision was seen as the most significant contributor to the unavailability of the signalling systems. Thus, any recommendations must focus on different strategies management can use to improve the security provisions. In this regard, improved technology research and development is required. This is because the technologies that are currently deployed use high-valued material. This high scrap value makes the material and the subsequent technology vulnerable to theft. Due to the socio-economic crisis in South Africa, an improved security monitoring system is needed. Although there may be unique aspects within the railway industry, industries experiencing similar challenges may already have solutions and technologies available to improve security monitoring. More visible security services are needed - response teams and guards are the best defence against crime. Other leading factors contributing to the unavailability of the signalling systems were the lack of sufficient and focused budget allocation and spare provisions. The high turnover rate of employees is also a significant factor contributing to the unavailability of signalling systems. Improved Skill Retention is recommended with clear succession plans in place that are regularly updated.

South Africa rail needs to invest capital in network rehabilitation and collaborate more with relevant private sector entities to reverse the decline in network quality and lost capacity caused by historic underinvestment. International benchmarking indicated that going forward, performance-based contractual arrangements are a best practice that is recommended for decreasing maintenance costs.

The study's biggest limitation was possibly the limited available and applicable academic literature on the subject. In addition, the manuals and details of the systems and technologies used within the railway industry were developed when the technology was developed originally. This led to outdated or illegible manuals and situations where the information was unavailable.

7 Conclusions, Limitations and Future Research

Several findings were made regarding the performance of the railway industry and the factors affecting capacity performance. The railway has more opportunities for supporting sectors like mining, agriculture, and people mobility, but the density potential is low and will require significant subsidisation. The business case of a loss of market share with the railway industry has lost a substantial portion of the passenger and freight market to the road transportation industry. In this instance, the factors affecting operational capacity require that all departments, disciplines, and capacity influences operate in unison to achieve maximum capacity. Some compensations can be made, but the full potential of the railway service cannot be achieved unless these capacity influences are aligned. It can be deduced that the biggest influences on the maximum number of trains that can pass through a section, and thus the biggest influences on capacity, are the time it takes for the slowest train to enter and exit a section and for the TCO to communicate with the train driver plus the efficiency factor of the section. These factors are reliant on the signalling systems deployed. Thus, the signalling systems play a critical role in the rail network's capacity and are a vital factor affecting the performance of the railway industry. Unfortunately, the gap between network revenues, maintenance, and rehabilitation expenditures requires interim funding solutions. The current state of the network (including the TAS) will not be conducive to the expected increase in business volume. Line quality has deteriorated to such an extent that in the last five years, an estimated 65mt lost volumes were experienced. The continued reduction of planned Capex will have unintended consequences of escalating safety risks, failures, network unavailability and poor reliability. The knock-on effect will seriously impact the envisaged rail reform with reduced rail volumes – electricity supply in SA is a noteworthy case in this regard.

From the factor analysis, the main findings from the empirical investigation are divided into two sections: The first aspect relates to the performance of the railway industry that is not contributing to the growth and development of the country to the extent that it should be. The respondents identified that there is not one specific area at fault, but there are several contributing factors that need to be addressed, albeit the unavailability of key signalling infrastructure was identified as the biggest contributor to the performance challenges in the railway industry. The second aspect was the performance of TAS equipment - that, as such, is largely contributing to the performance challenges of the SA railway industry. Several factors were identified as contributors to the performance challenges of the TAS equipment - the most significant contributors were the lack of security provisions, the lack of spare provisions, the lack of budgetary provisions, and poor employee retention.

It can be concluded that the unavailability of the TAS equipment is a vital contributing factor to the overall poor performance of the SA railway industry. South Africa has the most extensive rail infrastructure on the continent. Therefore, the vision of the South African railway industry playing a key role in a transcontinental transport logistics corridor must be secondary to the identified challenges with the TAS system in the domestic economy. An implemented strategy is much more prioritised to transform this critical part of the SA economy from landlocked to land-linked. However, looking at the future of the narrative of a digital railway system in connection with signalling can be promising and exciting. To top it all, the predominant consideration that can be derived from these factors identified in the study is that most of these issues are manageable. This indicates that effective management practices and tipping point leadership are required. As such, the notion of network economics that railways are shared assets that provide economic value by enabling geographic access can become a reality!

8. Recommendations for Future Research

A more focused study (for example, on a specific corridor) can enable more specific recommendations. The study focused on operational staff who work with and manage the system daily. To provide a more holistic representation of the perceived challenges and mitigating actions required, senior management and the railway industry's governance must express their views on the current systems and their challenges.

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