Technological catch-up and railway innovation at Transnet in South Africa

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ABSTRACT

This research aims to explore technological catch-up and railway innovation in the South African railway industry. It seeks to highlight the importance of innovation and technological catch-up in significantly improving operational performance and maintaining a competitive advantage for South African rail operators. The research design of this study involves a single, embedded case study that examines the effects of railway technological innovation and the process of technological catch-up in the railway industry, specifically within the global south. Transnet is utilised as the primary focus for exploration and analysis. The research findings show that Transnet has made considerable effort to keep up with prevailing railway technological innovation and the organisation currently resides in the duplicative imitation stage and is struggling to move beyond this stage. This is due to several factors: a lack of effective learning and technological capability building, a shortage of financial and vital resources, and unfavourable government policies. The recently gazetted National Rail Policy in South Africa presents an opportunity for the government to support the railway industry in its technological catch-up efforts and promote innovation to maintain its competitive advantage. In this respect, further recommendations for Transnet are made in this research report. The technological catch-up process is a complex and continuous process that may take decades and is not guaranteed. However, it is much more likely to be successful if an intentional, systematic, yet dynamic process is undertaken. Thus, there is hope for the South African railway sector.

KEYWORDS

Technology Catch-up, Innovation, Railway Industry, Transnet.

DECLARATION

I, ITUMELENG MTEBELE, declare that this dissertation is my own unaided work except as indicated in the references and acknowledgments. It is submitted in partial fulfilment of the requirements for the degree of Master of Management in the field of Innovation Studies at the Wits Business School in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other University.

Signature: ……..

On this 03 day of NOVEMBER 20 23

I MTEBELE

Name

DEDICATION

I would like to dedicate my hard work to my loving family, firstly my kind-hearted husband Banele Mtebele and my two beautiful daughters Lwandle Mtebele and Lathitha Mtebele. Throughout this challenging academic pursuit, they have been my pillars of strength, unwavering in their support, and a constant source of inspiration.

To my lovely grandmother (Masiteng Mothopeng) whom I suck all the wisdom and knowledge, your unwavering belief in my abilities and your endless encouragement has been instrumental in my success. Your patience and sacrifices during this journey are deeply appreciated. Thank you for standing by me and reminding me that ‘nothing is impossible’. I also dedicate this work to my mother Lorraine Mothopeng and Uncle Sonny Mothopeng, who have since been my buddies and cheerleader throughout.

Lwandle and Lathitha, your vibrant spirits, infectious laughter, and boundless love have brought joy to my life every single day. Your understanding and patience during moments when I needed to dedicate time to my research are truly remarkable. I am grateful for your presence, which motivated me to push harder, and may this paper be a constant reminder to you to always be fearless in chasing your dreams and goals.

To my family as a whole, thank you for the support and understanding. Your strong belief in my dreams and your constant reassurance have been my driving force. This achievement would not have been possible without your love, sacrifice, and belief in me. May this dedication serve as a small token of my immense gratitude for everything you have done for me.

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LIST OF ABBREVIATIONS & ACRONYMS

CSIR	Council for Scientific and Industrial Research
DST	Department of Science and Technology
DTI	Department of Trade and Industry
ECP	Electronically Controlled Pneumatic Brakes
LCF	Late Comer Firm
LCMS	Locomotive Condition Monitoring System
MDS	Market Demand Strategy
OEM	Original equipment manufacturer
ODM	Original brand manufacturer
OBM	Original design manufacturer
OD	Operating Division
OTF	On-the-Fly
PPFA	Preferential Procurement Policy Framework Act
R&D	Research and development
R&D-D	Research and Development and Demonstration
RDP	Radio Distribution Power
SA	South Africa
SOC	State Owned Company
TAL	TransAfrica Locomotive
TFR	Transnet Freight Rail
TLP	Technology Localisation Programme
TE	Transnet Engineering
UBRD	Ultrasonic Broken Rail Detector

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1. CHAPTER 1: INTRODUCTION

Rail transportation plays a significant role in South Africa's economy. It is widely recognised as the preferred global method of transportation due to its energy efficiency, lower greenhouse gas emissions, and cost-effectiveness when it comes to transporting large amounts of freight over long distances. Currently, South Africa possesses the eleventh largest rail network worldwide, consisting of around 20,911 route kilometers and 31,000 track kilometers (South Africa Rail Factsheet, 2020). However, is it the most efficient mode of transportation? Technological innovations have been found to have a positive impact on railway transportation, improving efficiency and safety amongst others (Ohlhaber, 2022). This study aimed to investigate the technological developments in the South African railway industry to understand the technological catch-up phenomenon. This chapter gives more details about the study by outlining the research purpose, problem statement, context, and significance of the study.

1.1. PURPOSE OF THE STUDY

According to the Department of Trade and Industry, between 2008 and 2018, overall rail transport income increased by more than 9% annually, outperforming their competitor’s income growth in the transport sector (Fact Sheet Rail, 2020). Consequently, there is a substantiated market demand for rail services in various crucial commodities. However, in the past decade, the utilisation of rail for freight and passenger transportation has experienced a steady and significant decline. This can be attributed to the limitations imposed on rail capacity due to inadequate network infrastructure and a substantial increase in security incidents that adversely impact both the rail network and rolling stock assets. (TFR Investor Relations, 2021).

To remain competitive in the fast-paced global transportation industry, technology, and innovation have been found to be key enablers in achieving this goal (Ohlhaber, 2022). One of the biggest bottlenecks is acknowledged as being technological innovation, particularly in middle and low-income countries (Lee, 2005). Thus, for rapid economic growth, technological catch-up is required. As mentioned by Lee (2005), the concept of catching up extends beyond developing countries striving to narrow the gap with more advanced nations. It encompasses the ability to quickly enter new market,

enhance productivity, achieve manufacturing excellence through advanced engineering, and helps to seize the opportunity for "first-to-market". Is the South African railway industry keeping pace with the latest technological advancements to help maintain its competitive advantage? This is of particular interest for this study.

The technology catch-up phenomenon which spans from way back to the 80s has led to substantial literature, that explores how technology affects the process of catching up at sectoral and other levels as examined by Kashani et al., (2022). However, the challenges faced by the South African railway industry in the catch-up process are not known. Thus, the purpose of this study is to investigate technological catch-up and railway innovation in the South African railway industry using Transnet as a case study.

1.2. CONTEXT OF THE STUDY

Transnet is a state-owned entity that owns and operates the largest rail network on the African continent. Transnet Freight Rail (TFR) is a division of Transnet which is responsible for transportation of heavy goods in Southern Africa. TFR's extensive rail infrastructure accounts for approximately 80% of the total rail infrastructure across the African continent (Fact Sheet Rail, 2020). As the global demand for transportation rapidly increases, greater reliance on rail is seen to be of utmost importance for achieving energy efficiency, reduced environmental impact, and economic growth (The Future of Rail – Analysis, 2019). Thus, there is a dire need for innovative solutions to keep the railway system as the most efficient mode of transportation. This study focused on two of the most crucial business units of Transnet SOC Ltd which are Transnet Freight Rail and Transnet Engineering. This is because TFR is the largest operating division of Transnet responsible for providing rail transportation of the commodities and Transnet Engineering is a key enabler and support to TFR to make sure the rail business runs smoothly (Transnet Investor Relations, 2021). Moreover, both divisions, rely heavily on technology and innovations to maximise their productivity amongst others.

Transnet Freight Rail is the largest operating division (OD) of Transnet and a significant role player in South Africa’s transportation sector (TFR Investor Relations, 2021). Over the years TFR has been looking for ways to increase productivity efficiency and cutting operational costs. Acquisition of foreign technological

innovations has been at the forefront of these measures to increase efficient operations (Creamer Media, 2019). There is no clear indication of a strategy to invest in technological capability, research and development and demonstration (R&D-D) and no clear path of technological catch-up path to be taken. Currently, TFR is reliant on the adoption of foreign technology to improve its operations, and this can be good or bad. This is because, as seen with the recent debacle with China's CCRC contract, Transnet's business performance declined drastically due to the legal disputes that have blocked Transnet's access to key parts and components from the OEM which resulted in about 53 Class 20E locomotives, and 67 Class 21E locomotives idling and out of service (Shezi, 2022; Creamer Media, 2022). This shortage of locomotives results in poor performance, hence technological catch-up becomes critical in this case, because had TFR reached the ODM or ideally OBM stage of its technological development, then operations would have not been adversely affected, because they would have managed to develop and manufacture their own components and spare parts to keep the trains running (Lee, 2005).

Transnet Engineering (TE) is another Transnet division responsible for manufacturing, upgrading, repairs, and overall maintaining TFR's rolling stock amongst others. Over time, TE has developed a diverse set of essential skills in researching, designing, testing, assembling, and maintaining railway rolling stock. TE has established itself as the leading manufacturer of wagons in Africa. With ownership and operation of roughly 143 depots and six primary factories, Transnet Engineering is strategically positioned to serve its main clients. TE envisions becoming a globally recognised OEM for rolling stock and logistics equipment, as well as being the preferred partner for maintenance, repairs, and overhauls of rail throughout Africa. Furthermore, TE aims to establish centers of excellence dedicated to fostering technical and engineering skills development across the continent. All this in efforts to grow the South African economy (Transnet Engineering, 2020). In order to assist Transnet in pursuing its goal of lowering the cost of conducting business in SA, TE plays a vital role as a cornerstone for TFR, supporting its efforts in attaining operational efficiency and increasing productivity.

Aligned with TE's aspiration to become a Africa's original equipment manufacturer (OEM) of choice, TE has achieved significant milestones in researching, designing,

producing, and testing a specialised locomotive known as the TransAfrica Locomotive (TAL) (Transnet Engineering, 2020). The success of the TAL locomotive indicates that Transnet Engineering aims to follow the OEM, ODM, and then OBM stages of technological development. This is because the TAL locomotive was mainly an assembly production using both imported and locally outsourced parts, which, as observed by Lee et al (2001)., and Wu et al (1991) is a common path followed by most latecomer firms (Lee, 2005).

Like many latecomer firms, TE faces difficulty in acquiring design capability (Lee, 2005). Hence, TE is focused on cultivating and reinforcing collaborations with other original equipment manufacturers (OEMs) to enhance its current skills, capabilities, and expertise in order to offer more valuable products and solutions. Additionally, the division is dedicated to bolstering its research and development (R&D) initiatives to ensure it possesses state-of-the-art technologies and capabilities, enabling the delivery of exceptional products and services on a global scale (Transnet Engineering, 2020).

1.3. FORERUNNERS AND LATECOMERS IN THE RAILWAY INDUSTRY

According to the World Economic Forum (2019), the top five countries that have the most efficient (efficient in the sense that they have the highest quality of railroad infrastructure) railway industry are Japan, Hong Kong, Switzerland, South Korea, and Singapore (Statista.com, 2019). No African country is part of the forerunners yet. According to Statista.com records for the world's largest (by length) rail network around the world in 2019, South Africa is part of the top 10 ranked countries (see appendix A), which therefore means there is potential, in the future, to compete against the global market leaders shown in Figure 1 below:

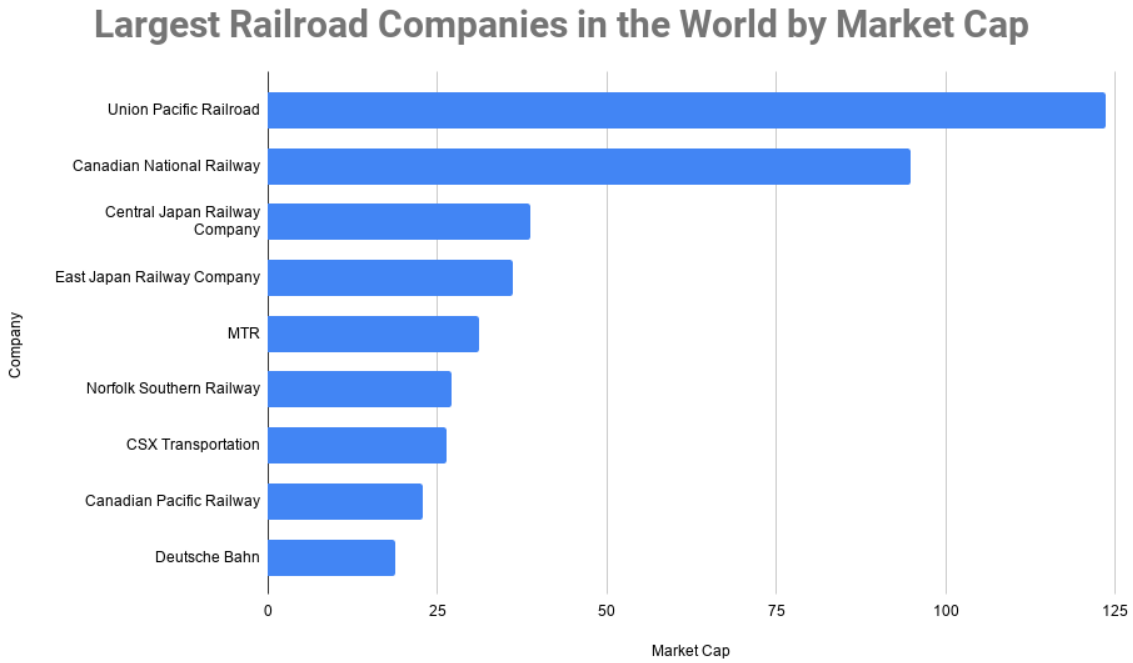


Figure 1: Largest Railroad Companies in the world by Market Cap by 2022.

[Source https://blog.bizvibe.com/blog/largest-railroad-companies]

Railways are increasingly recognised as one of the major drivers of regional trade within Africa and as a more effective way to transport large numbers of people between key cities. Hence, there is a rise in African national, state, and local governments starting to support rail and even competing on the quality and speed of their networks due to its wider benefits on industrialisation (Transport, Urban Development and ICT Department, 2015). Advanced technological development backed by a developed economy is at the forefront of the success stories for the global leading firms in the railway industry (Huang et al., 2021). China's high-speed train industry is noted as the fastest and very rare development in the economic history of China and thus, many scholars have proposed different explanations for this success (Huang et al, 2021; (Jones, Past, present and future: The evolution of China's incredible high-speed rail network, 2022). Most of the research (for example research done by Wu et al, 2009; Petti et al, 2019 and others) points to China's effective process of building its knowledge base through technology acquisition and transfer, strategic learning, and the government's full support throughout the capability-building and technological innovation process as analysed by Huang et al. (2021). To date, China remains the

leader in the high-speed railway industry, expanding and advancing railway technology even further. This industry is an example of successful catch up (Jones, 2022). Many lessons can be learned from China's railway industry case because this country was also classified as a developing country and on inception, their rail operations were also reliant on foreign technology acquisition, relatively behind compared to leaders in the railway sector globally, and yet they have managed to successfully catch up (Huang et al., 2021).

1.4. RESEARCH PROBLEM STATEMENT

In 2012, Transnet introduced its Market Demand Strategy (MDS) with the goal of increasing South Africa's rail capacity to handle an increase in freight volumes for the projected future demand. Through the successful implementation of Transnet's MDS, the projected revenue increase was from R46bn to R128bn by 2019 (Batwell, 2012). According to Transnet's officially announced annual results, an increase of 1.6% in revenue was recorded for the year 2019, and since 2020 the company has been facing a lot of challenges which resulted in a drastic revenue decline. In the annual financial records for 2021, the revenue was R67,3 billion which was a 10.5% decline, and this was due to a 13.7% decrease in transported tonnages which were impacted by backlog maintenance, aging infrastructure, COVID-19 pandemic effect on the South African economy, adverse weather conditions, as well as an increase in derailments and criminal activities affecting the rail infrastructure (Transnet Investor Relations, 2021). As a result, Transnet experienced a substantial decline in its market share, with road freight emerging as a preferred alternative due to its perceived safety, reliability, and cost competitiveness due to lower oil prices. (Fact Sheet Rail, 2020). The operational challenges contributed immensely, amongst other things, to the decline of revenue for Transnet, and this is mainly because the operational performance still heavily relies on old technology and working processes, as well as the loss of critical skills in the organisation. Therefore, an optimal strategic turnaround programme and significant transformation are required to reform the rail business to maintain the global competitive edge and subsequently grow the economy (Meulen, 2011).

The subject of technological catch-up has regained prominence due to the potential consequences faced by countries that fail to obtain and effectively utilise new advanced technologies. Such countries may face a gradual exclusion from the global

economy, as the rapid influence of novel technologies significantly impacts the trajectory of global trade (Clark and Juma, 2002). Several scholars agree that technological catch-up is possible, even from developing countries, and that the most important part of the process of catching up is the speed at which the follower can engage in technological imitation and move beyond just imitation to mastering imported technology (Clark and Juma, 2002; Lee, 2005; Xiaobo Wu, 2009). The secondary innovation model has been found to be a common model of catch-up for latecomer firms, particularly in the Chinese context (Chen et al., 2011; Huang et al., 2021). Could this model work for latecomer firms in the Global South contexts? This is an empirical question that can be addressed.

Lee (2015) and many other authors have found that leapfrogging as a type of catch-up ("stage-skipping and "path-creation) is a common catch-up pattern followed by latecomer firms (Clark and Juma, 2002; Lee, 2005; Marleba and Lee, 2021). This is contrary to the traditional literature which concluded that latecomers typically attempted to bridge the technology gap by assimilating and adapting outdated technologies from forerunners (Lee and Kyoo-Ho, 2006; Malerba and Lee, 2021). In addition, the Malerba and Lee (2021) new and different view also found that technological cycle time, the knowledge base, and access to knowledge amongst other factors have a major impact on the progress of catch-up for developing countries (Clark and Juma, 2002; Lee and Kyoo-Ho, 2006; Lee, 2005; Maleki et al., 2019; Petti et al., 2019). However, it is not clear why technological catch-up is difficult and rare in the context of the South African railway. Thus, this study aims to address this gap. Closer to home, Drine's (2012) found that North African nations encounter substantial challenges in their ability to obtain and adopt new technologies. Factors such as weak governance and knowledge deficiencies hinder their ability to achieve successful technological development. These challenges may help explain the rarity of catch-up phenomena in those regions (Drine, 2012).

The literature indicates that learning and technological capability building supported by effective national and sectoral innovation systems are key to successful catchup, but it is not specific on the 'how' (Malerba et al., 2021). As alluded to by Malerba and Lee (2021) catch-up is an "evolutionary process" that is "not deterministic" because it occurs in unpredictable and dynamic contexts, and depends on both external events

and endogenous systems that generate and respond to change. The level of technological development of latecomer firms in the railway industry in the Global South remains unclear, and it is of particular interest for this study to investigate which stage Transnet has reached in order to identify the catch-up process and its challenges for futher upgrading.

1.5. RESEARCH QUESTIONS

The study, therefore, seeks to explore the following:

1.5.1. What is the current state of technological development at Transnet's railway operations?

1.5.2. What are the factors influencing the technological catch-up process and innovation in the South African railway industry?

1.5.3. What are the pathways to strengthen technology catch-up process in the railway industry in SA?

1.6. SIGNIFICANCE OF THE STUDY

The study aims to highlight the need to focus on using technological innovation to improve operational performance. It also has the potential to highlight the obstacles that affect the technology catch-up process and technology capability building in the South African railway sector, which are useful for the railway operators and government. The identification of these obstacles will help with the development of key features required for a national innovation system that cultivates innovation in South Africa and beyond. Moreover, it opens room for policy amendments which will support the enhancement of capabilities and learning.

Since the catch-up process is an uneven process across different levels (sector, region, and national levels) and cannot be planned or determined, this study is significant in contributing to the literature about the factors influencing the technological catch-up process in the South African railway sector. Moreover, the technological catch-up phenomenon has been extensively studied in the Global North, which faces completely different grand societal challenges compared to the Global South and may possibly influence the catch-up process. Because catching up is an unceasing and uncertain process this study plays an important role in bringing insight into the literature on the challenges of this process in the African context.

1.7. DELIMITATIONS OF THE STUDY

This study focuses on the South African railway sector using Transnet as a case study. It does not in any way intend to investigate the national innovation system, catch up at a national level, and intrinsic technical details about the advanced technologies in railway sector. The precise nature of the losses incurred as a result of the more aggressive introduction of advanced technology and innovation in the railway industry during the past two decades is outside the scope of this study. Moreover, this study does not imply that poor performance at Transnet is due to a lack of technological advancement and does not focus on competition between Transnet and forerunners in developed countries. It only aims to highlight the importance of technological catch-up in improving operations and possibly introducing new innovative products. It is to be noted that the case study, Transnet, is a freight railway company, thus this exploratory study may not necessarily apply to passenger rail operators.

The goal of this study is not to examine the knowledge base, variety, and complexity of learning as alluded to by Lee (2005) and Maleki et al.,(2019) as well as the rail business market conditions.

1.8. ASSUMPTIONS

The study assumes that participants are aware of the impact of technology in the railway sector and are aware of the latest railway-specific technologies and innovations currently in use locally and/or internationally. In addition, it also assumed that a reasonable number of respondents would be available for semi-structured interviews for the study to be successful. Moreover, the participants are assumed to be open and honest about the information they convey, with limited bias, considering that they are employees of Transnet.

1.9. DEFINITION OF KEY TERMS

1.9.1. Innovation:

According to the Oslo Manual - Organisation for Economic Co-operation and Development (2021) Innovation is defined as: “Innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations” (Gault, 2016; Salisu, 2019).

1.9.2. Technological Capability:

Technological capability is “the firm’s ability to design and develop a new process, or product and upgrade knowledge and skills required to acquire, assimilate, utilise, adapt, change, and create technology” (Wu et al., 1991; Clark and Juma, 2002). Moreover, technological capability encompasses a "wide range of practical and theoretical knowledge, procedures, experience, methods, and physical equipment” that enables firms to develop operational competencies (Salisu, 2019).

1.9.3. Technology Catch-up

“A process by which a latecomer country increases its innovation capacity vis-`a-vis the technological leaders” (Ebrahim Souzanchi Kashani et al., 2022). The most important aspect of catching up is the speed and stages the country goes through to master certain technologies (Clark and Juma, 2002; Lee 2005; Fagerberg, 2012).

1.9.4. Developing Country

A developing country refers to a nation that exhibits relatively low levels of economic development and industrialisation, as well as high levels of poverty, inequality, and social vulnerability (Nielsen, 2011).

1.9.5. Late Comer Firm

As Mathews (2002) extensively explains that a latecomer firm can be defined by four conditions. Firstly, the firm enters an industry later than others, not as a deliberate choice but due to historical circumstances. Secondly, it initially lacks resources such as technology and market access. Thirdly, its strategic intent is primarily focused on catching up to competitors. Lastly, the LCF possesses certain preliminary competitive advantages, such as low costs, which it can leverage to establish a spot in its chosen industry.

1.10. OUTLINE AND STRUCTURE OF THE REPORT

Chapter 1: Introduction

In the initial chapter, the research study is introduced, encompassing the research background, the study's importance, and its limitations. Furthermore, it presents the statement of the research problem, the study's objectives, and the research question that serve as the study's framework. Finally, the chapter defines the primary research assumptions and provides definitions for key terms utilised throughout the report.

Chapter 2: Literature Review

In the second chapter, an extensive literature review is conducted to establish the theoretical foundations of this research. It covers a comprehensive examination of existing literature, including studies conducted by other researchers, that address the broader scope of technological catch-up phenomena and innovation. Four relevant theoretical frame works are also analyses and used to develop the study’s conceptual framework. Furthermore, a thorough analysis of the literature pertaining to the case study is conducted to determine the level of technological development at Transnet, which is crucial for subsequent analysis.

Chapter 3: Research Methodology

In the third chapter, the research strategy and design are outlined, elucidating the techniques and procedures employed to address the research objective and answer the research questions. Furthermore, the rationale behind adopting a case study research methodology approach within a pragmatic paradigm is provided to ensure the effective execution of the research study. This chapter serves to establish a clear framework for conducting the research, highlighting the methodology's suitability and alignment with the study's goals and objectives.

Chapter 4: Presentation of Findings

The fourth chapter presents the summary of the data collected (results) from the semi-structured interviews held with the participants at Transnet Engineering and Transnet Freight Rail as well as any other additional archival records reviewed.

Chapter 5: Analysis of Findings and Discussion

In the fifth chapter, the relevant literature is synthesised with the research findings to address the specific research questions of the study. The chapter delves into a comprehensive discussion of the research outputs, thoroughly examining the significance and implications of the findings from the researcher's perspective. By combining the existing literature with the empirical results, this chapter provides a cohesive and insightful analysis that sheds light on the meaning and interpretations of the findings in the context of the study.

Chapter 6: Conclusions and Recommendations

The final chapter provides a synopsis of the research report. Specifically, outlining the key conclusions and recommendations to close the gaps in technological catch-up and innovation in literature, particularly in the African context. Potential opportunities for future research are also identified.

1.11. CONCLUSION

This study examines the technological development in the SA railway sector with an emphasis on problems relating to the concept of technological catch-up. This is to identify barriers and opportunities for catching up, as well as emphasising the importance of using cutting-edge technologies to deliver new products and improve business performance rather than competing with those developed in industrialised countries.

The secondary innovation model provides a favourable starting point for latecomer firms to shift from mere imitation to internal, endogenous innovation within a reasonable timeframe and cost (Wu et al., 2009). As such, it is necessary to learn more about the risks and challenges faced by the latecomer firms in the catch-up process, especially in the African context. This study aims to contribute to the literature by investigating how the catch-up process looks like in the railway industry in a developing country by critically analysing the process undertaken and its challenges.

2. CHAPTER 2: LITERATURE REVIEW

The pertinent literature for this study is reviewed in this chapter. Critical literature reviews are an important step in this research process, especially because there have been minimal studies done on the railway sector in developing countries in the context of this research. Thus, reviewing the existing literature provides valuable insights into the research topic by encompassing the extensive work carried out by other researchers thus far. Moreover, it helps in identifying potential opportunities for future research and showing areas where knowledge gaps exist.

2.1. INTRODUCTION

It is important to understand the challenges in the railway system in the African context before discussing any possible solutions to improve its operations. This is because as much as the railway networks were established in the Sub-Saharan region practically simultaneously as the rest of the world, it has at least three significant problems according to Boros et al. (2020), which are: Rail transportation primarily serves the port networks and historical colonisation interests; employing distinct approaches such as narrower rail gauges compared to the global standard; and It has not been well maintained or developed for quite a long time. Consequently, the Sub-Saharan railway network is mostly in a very poor condition (rail infrastructure and rolling stock in the obsolete state using outdated technology), there is a lack of financial support, lack of knowledge in operating and developing the railway system, and most importantly, no clear (or limited) information on the railway ecosystem and its impact to the grand societal challenges and economic development. The latter can be attributed to the lack of the National Rail Policy for many years (Boros et al., 2020; National Rail Policy - Green Paper, 2015). These challenges and historic events are very important to consider before one can delve into understanding the catch-up phenomena for developing countries (especially Africa).

The National Rail Policy was approved and released in March 2022 in South Africa (White Paper on the National Rail Policy , 2022). The absence of a cohesive National Rail Policy for over a century resulted in a lack of clear national direction to lead the growth of the rail industry, and to align, and rejuvenate it over time in accordance with the trajectory of rail's global development (National Rail Policy - Green Paper, 2015).

As a result, repositioning South African railways in market spaces that could serve as the foundation of its logistics and mobility systems and bring about transformative changes in the sector proved to be challenging (National Rail Policy - Green Paper, 2015). Now that the National Rail Policy has been gazetted, a considerable effort should go into implementation to address the challenges faced in the railway industry. As mentioned in the National Rail Policy, “Innovative thinking is required to address these issues” (White Paper on the National Rail Policy , 2022). In addition, as part of the new policy’s objectives, it aims to strengthen its investment to upgrade rail technologies to enable the South African railway sector to compete (locally and globally) effectively and sustainably. All things considered, technological catch-up, to enable the South African railway industry to be a technological leader relative to its competitors was near impossible in the past decade due to lack of focus and investment aimed at catching up. However, technological catch-up with a focus on increasing technological capabilities, and significantly improving business performance remains possible, and this study aims to explore that.

The “catch-up” literature has over the years revealed that the catching-up process is completely different between developed and developing countries. At a macro level, technological catch-up is related to the following variables: human capital investment, investments in the acquisition and transfer of new technology, formulation of economic reform goals, and how a country establishes relevant institutions to implement policies that support catch-up (Clark and Juma, 2002; Lee, 2005; Malerba and Lee, 2021). In developing countries, all of the above-mentioned variables still face immense challenges, and it’s mostly due to historical events. For example, Africa was designed to be a commodity-based economy rather than a knowledge-based economy to satisfy the colonisers’ needs, and thus lacked the drive to promote technological development (Clark and Juma, 2002; Drine, 2012;Soumonni and Muchie, 2023). Hence, for a developing country, it is difficult to proceed from the stages of imitation to the stage of innovation and eventually be at the forefront. However, as difficult as it is, it is also important to focus on technology catch-up and innovation because as alluded to by many experts and scholars, technology and innovation are key drivers to improving economic performance (Science, Technology, and Innovation in the New Economy, 2000; Drine, 2012).

According to the Japan International Cooperation Agency (JICA) Report (2012), their study has found that South Africa's state of rail technological innovation is far behind relative to their competitors globally in the freight rail business. The study has identified the following factors as a hindrance to the modernisation of the railway sector in South Africa: lack of human resource development to upskill and elevate the technical knowledge level of workers; lack of absorptive capacity to transfer advanced technologies which are mostly owned by foreign countries; no investment in developing local supporting industries (i.e. railway components manufacturers etc.) forcing the reliance on importing spare parts from overseas; low investment in upgrading the rail infrastructure to increase production capacity; and poor strategic intent focusing on future developments of the business and how to remain competitive globally (JICA (Japan International Cooperation Agency), 2012).

Starting in 2005, Transnet Freight Rail embarked on a strategic turnaround programme to stabilise, re-engineer and position the business for growth. This involved the acquisition of a new generation of locomotives and adapting to the inevitable technological changes from mechanical to electronics which have revolutionised the railway sector. Moreover, the strategy aimed to bring Transnet Freight Rail closer to becoming among the top five world-class railway operators (The "Technology" of People, 2015). The acquisition and deployment of foreign technologies came with challenges as legacy systems and assets had to be amalgamated with the new and modern technology. The revitalisation did not only bring technical challenges but also had implications on how employees operate, think, and behave (amongst others), which required the organisation to learn rapidly. Transnet Freight Rail put substantial effort into training employees in collaboration with the OEMs, School of Rail, and School of Engineering in the modernisation plan (The "Technology" of People, 2015). Details of the nature of learning are not very clear and even though plans to adapt to the advancement of technologies have been established, the plans to move beyond just technology acquisition are not known.

Moreover, the MDS strategy puts human capital development and localisation at the core of its strategy, but it is not clear what its intentions are when it comes to

developing the technological capabilities and competences in the organisation (TFR Investor Relations, 2021; Transnet Market Demand Strategy, 2012; The “Technology” of People, 2015). However, there is still hope and more potential for catching up. As alluded to by Mathews (2002), the condition of firms in developing countries, like certain areas in Asia-Pacific, Sub-Saharan Africa, Central America, or Central Asia, may not be entirely bleak. In fact, their chances could improve rather than deteriorate at a time when inter-company relationships are global, as long as they develop strategies that consider their limitations as latecomers and the potential benefits (Mathews, 2002).

2.2. WHAT IS INNOVATION? WHY IS IT IMPORTANT FOR RAIL TRANSPORTATION?

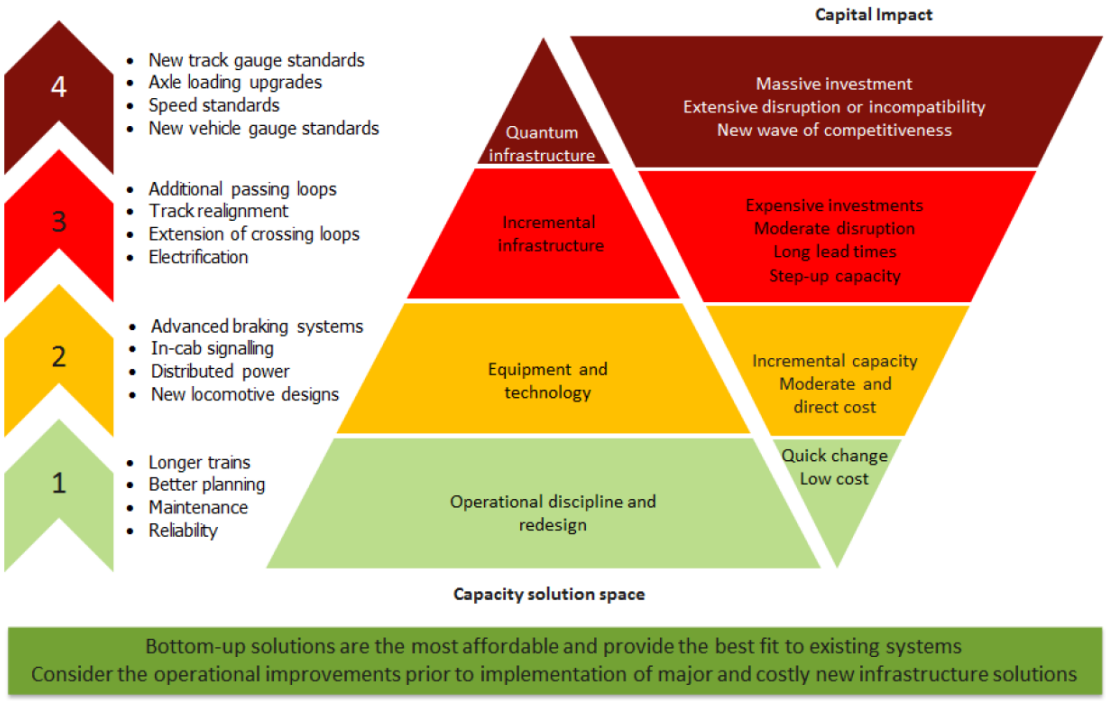
According to the Oslo manual, innovation is the “implementation of a new or significantly changed product or process” that adds value (Organisation for Economic Co-operation and Development, 2005).The manual further emphasises the importance of the term ‘implementation’ as a typical innovative trait (Gault, 2016). As a broader concept, there are multiple studies and literature on innovation. However, my interest is in contextualising innovation in Africa, because, unlike developed countries, Africa is characterised as a latecomer economy relative to other regions in the world and this comes with its challenges. Hence, when you consider the latter, Egbetokun et al., (2016) suggest that innovation be broadly defined to “include the processes of adoption and possibly modification of products and technologies which were developed elsewhere” (Egbetokun et al., 2016). Broadly speaking, innovations are regarded to be fundamental for stimulating beneficial long-term economic development. Moreover, innovation capability has been increasingly recognised as the key solution for rapid and sustainable economic growth (Science, Technology and Innovation in the New Economy, 2000). At a firm level, innovation helps to foster company growth, gives a business a competitive advantage, allows for adaptability to overcome unforeseen challenges such as the COVID-19 pandemic, and increases productivity to mention a few (Science, Technology and Innovation in the New Economy, 2000; Egbetokun et al., 2016). Hence, innovation is something worth considering and incorporating in all aspects of the business to sustain it and maintain its competitive advantage.

There are three degrees of innovation: Radical, Incremental, and Breakthrough Innovation (Mitchell and Goffin, 2017). In the railway sector, the introduction of electric and diesel-powered locomotives in the early 1990s is an example of a radical innovation that transformed the railway sector by replacing steam-powered locomotives. The modern high-speed trains are a breakthrough innovation because of its unique features that have since provided benefits to customers, which generates growth for the industry, and lastly, in-cab train signalling system is an example of an incremental innovation that was an improvement to the existing train service (Lacôte, 2001). Transnet rail operations have since incorporated mostly foreign acquired technological innovations, taking advantage of the rapid advancement of technology, to achieve safety milestones, increase volumes, and strive to maintain their competitive edge. Table 1 below, highlights a few of the major technological innovations that the Transnet rail business has since deployed, relative to advanced technological innovations from global leaders that have since helped shape the railway industry overall. The deployment of these technological innovations has had a huge impact on Transnet's business. Hence in 2019, Transnet made a breakthrough for the heavy haul railway industry by operating the world's second longest (7302m long), which is slightly shorter than the first longest freight train in the world Australia's BHP Iron Ore (7352m) (Briginshaw, 2019; Poel, n.d.) This world-renowned achievement was made possible by the utilisation of radio-distributed power technology amongst other things (Transnet Investor Relations, 2021). Technology is at the core of Transnet's Long-Term Development Plan framework, as shown in Figure 2 below. Through the implementation of the Transnet 4.0 strategy, Transnet leadership aims to accelerate company growth to reach the MDS strategy targets (Transnet Market Demand Strategy, 2012). Thus, innovation and technological catch-up phenomena become vital in helping Transnet achieve its strategic goals.

Table 1: Railway Industry Technological Innovations[1]

Category	**South Africa (Transnet)**	**Global Leaders**
Rolling Stock (Railway Technology,2015; (Van Der Meulen, n.d.))	• Electric and diesel-powered trains • Radio Distributed Power (RDP) • Electronically Controlled Pneumatic Braking (ECPB) and Wired Distributed Power (WDP) • Onboard energy management system • Regenerative Braking	• Hydrogen-powered trains (Germany) • Optimised hybrid power trains, using an board rechargeable energy storage system (RESS) (UK) • Wagon Double stacking containers (US Australia)
Signalling and Telecommunications (Burns Engineering, 2021; Alstom, n.d.; In2tec[i], 2019)	• Colour light signalling • Centralised Traffic Control	• Communication-Based Train Control – In cab signalling (Europe) • Digital Rail Interlocking (Germany) • Autonomous Freight Train (U.K)
Condition Assessment Systems (Staden et al, 2019; In2tec, 2019; Gräbe, 2021; Legobe et. Al, 2020)	• Ultrasonic Broken Rail Detector • Integrated Train Condition Monitoring System • Vehicle Identification Systems • Wheel Temperature Monitoring System • Onboard computer (OBC) • Onboard Locomotive condition monitoring system (LCMS) • Locomotive Identification System	• IoT-enabled advanced analytics (China) • Big Data and Analytics for maintenance • Optical Metrology • Automatic Train Protection

[1] There currently is a wide range of technological innovations in the railway industry locally and globally. However, for the context of this research I have selected a few major innovations to illustrate Transnet's technology progress and how far they still need to go to make a technology catch-up with global leaders in the railway industry.



Source[https://www.transnet.net/BusinessWithUs/LTPF%202017/LTPF%20Chapter%203%20Rail%20Development%20Plan.pdf]

Figure 2: Transnet's Capacity Creation Logic

The rail technology used by Transnet is mainly from foreign companies like CCRC Corporation, GE Transportation, Siemens, etc. that are global leading manufacturers in rail (Batwell, 2012; South Africa Rail Factsheet, 2020).In support of the government's localisation policy, Transnet procures rail components from local manufacturers and aims to develop new suppliers to locally manufacture components in the rail industry (Transnet Market Demand Strategy, 2012). In addition, TFR and TE have been striving to build technological capability and increase competence by acquiring the relevant skills and fostering technical training (TFR Investor Relations, 2021; Transnet Engineering, 2020). The railway technological innovations that have since been adopted in the South African railway industry have positively impacted the industry and have the potential to do more to position the industry to effectively aid the national economic reform.

Several studies have found that most businesses in developing countries face various challenges such as lack of knowledge (creation, transfer, adoption, adaptation, and diffusion), lack of financial and vital resources, poor infrastructural base, poor quality of the business environment, and lack of adequate government policies affect their

innovation (Wangwe, 2003; Aubert, 2004; Oyelaran-Oyeyinka 2014; Daksa, 2018). As much as these challenges may be applicable to the railway industry, there is limited comprehensive, empirical evidence on factors influencing innovation in the railway industry, especially in Southern Africa. Moreover, little is known about the opportunities such as a rich cultural heritage and a wealth of natural resources that are unique to Africa which can be harnessed to drive innovation.

2.3. TECHNOLOGICAL CATCH UP

Rosiello et. Al (2021) defined technological catch-up as “a process by which a latecomer country increases its innovation capacity vis-`a-vis the technological leaders”. It is generally understood to mean the rapid accumulation of technological capacity to levels that enable a country to compete with other technologically advanced countries or become a leader in that field (Clark and Juma ,2002). However, Clark and Juma (2002) explain that “Technological catch-up may also involve the use of advanced technologies to deliver new products and services that do not necessarily compete with those developed in the industrialised countries”. The latter definition is important for this study because the focus is not only on being a global leader in railway technological innovations (yet). However, the major focus is on catching up for the purposes of revamping the currently ailing freight rail business in South Africa.

The "catch-up” argument (dating as far back as 1962), which has been advanced by several economists including Gerschenkron, Gomulka, Abramowitz, Maddison among others, focuses on the opportunities for imitation. According to this argument, nations that are behind the technological advancements of the world can experience faster growth by copying technologies that have already been developed in more advanced economies, and pursuing the same path of development (Clark and Juma, 2002; Fagerberg, 2012; Gholizadeh et al.,2022). However, little is said about how catching up was done, especially for developing countries that already have underlying challenges. Oqubay and Tesfachew (2019) also found very little research focused on examining the firms and countries in the early stages of technological development and industrialisation, which encompass virtually all African countries.

The majority of the early literature, which is of particular interest to this study, has focused on explaining developing countries efforts to catching up (Lee, 2005). The perspective presented in this literature highlights the progress made by countries in

Asia, such as Japan, Korea, and Taiwan to explain the catch-up process. Through critical analyses of these cases, Malerba and Nelson (2011), and Lee and Malerba (2017) found that latecomers' attempts to catch up do not always include 'cloning', but rather the creation of alternative approaches that differ from the strategies employed by the frontrunners. Simply mimicking the technologies developed by forerunners may not lead to sustainable growth in the long term, as these technologies may not be well-suited to the local context or may become obsolete quickly. Hence, there has been a growing consensus that the technological catch-up process is a dynamic and very complex process due to the continuous change and uncertainty it constantly faces (Malerba and Lee, 2021; Lee, 2005;Clark and Juma, 2002). The process also has its unique challenges depending on the circumstances.

Kim (1997) identified the stages of technological development to be divided into the "duplicative imitation, creative imitation, and innovation stages" which he extensively explains using Korea's economic development. Lee (2005) adapts from Kim (1997) and describes these stages as OEM, ODM, and OBM which are common at a manufacturing firm level. On a high level, these stages describe whether a firm is just assembling final goods, using imported parts, making parts, or has reached a level of designing the products themselves (Lee, 2005). In addition to the three identified technological development stages, Lee, and Lim (2001) have discovered different patterns for technological catching up and they are as follows:

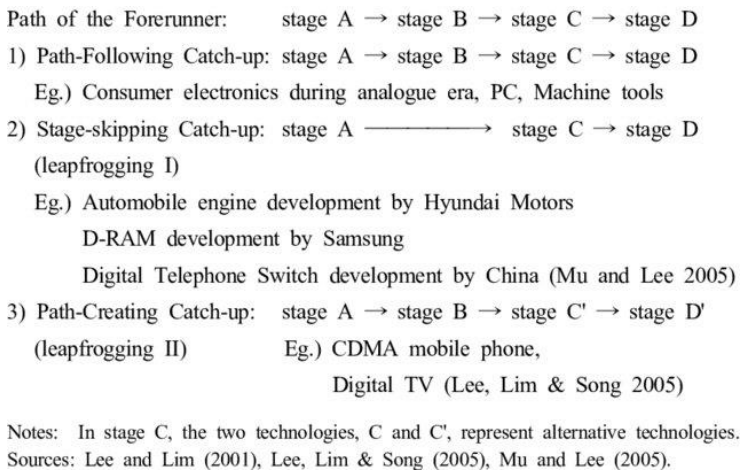

Path of the Forerunner: stage A → stage B → stage C → stage D
1) Path-Following Catch-up: stage A → stage B → stage C → stage D
Eg.) Consumer electronics during analogue era, PC, Machine tools
2) Stage-skipping Catch-up: stage A ——————→ stage C → stage D
(leapfrogging I)
Eg.) Automobile engine development by Hyundai Motors
D-RAM development by Samsung
Digital Telephone Switch development by China (Mu and Lee 2005)
3) Path-Creating Catch-up: stage A → stage B → stage C' → stage D'
(leapfrogging II) Eg.) CDMA mobile phone,
Digital TV (Lee, Lim & Song 2005)
Notes: In stage C, the two technologies, C and C', represent alternative technologies.
Sources: Lee and Lim (2001), Lee, Lim & Song (2005), Mu and Lee (2005).

Figure 3: Three patterns of Catch-up considering that there exists a technological trajectory consisting of several stages.

Source : https ://www.researchgate.net/publication/228668443_Making_a_Technological_Catch-up_Barriers_and_opportunities/figures?lo=1.

Figure 3, according to Lee (2005) shows that in Stage A, latecomers gain operational skills by running the foreign-imported plant with the assistance of foreign producers. This stage involves “duplicative imitation” and following the path set by leading companies. In this initial stage, important sources of technological learning and capability development are foreign technology and expertise. Therefore, it is critical to form partnerships with reliable technological partners who share the same goal of knowledge transfer (Tesfachew and Oqubay, 2019). In Stage B, latecomers acquire process technology as they establish factories and assembly lines based on designs provided by pioneering firms. Although there is a potential for “stage-skipping” catching up, this stage primarily involves duplicative imitation and following the path set by others. During Stage C, latecomers become capable of imitating existing products often with the aid of specialised R&D firms and human resources from abroad. Since the latecomers’ designs often differ and even enhance those developed by leading companies, this phase can be viewed as a process of “creative imitation” that presents additional possibilities for catching up by skipping stages. In the final Stage D, latecomers can create new products through real innovation, resulting in “path-creating or path-leading” catching-up (Kim, 1997a ; Lee, 2005;). Lee’s (2005) catch-up patterns are similar to Wu et al.,(2009)’s secondary innovation model which emphasises the relationships and interconnections between foreign developed technologies and locally developed technologies, and the local market environment. Moreover, both scholars point out that foreign technology acquisition is the starting point toward catching up, nevertheless, without sufficient active assimilation and absorption , the latecomer firm would likely get caught in a cycle of ‘import- fall behind’, and then ‘import again’ (Lee K., 2005; Wu et al., 2009). Wu et al (2009)., labelled the stages as ‘duplicative imitation’, ‘creative imitation’, ‘exploitative imitation’, and ‘explorative imitation’. The authors stipulate that the first stage which is duplicative imitation entails merely basic assimilation which involves mastering the technology to the point of imitating and adapting it, and you progress up the different stages up to the explorative imitation final stage where a firm would invent a novel technology and introduce it to the market (Wu et al., 2009).

Clark and Juma (2002), Lee (2005) as well as many other authors have found that the stages take time and the speed of catch-up progress has been uneven because some

latecomers may catch up rapidly while others are lagging, and this is attributed on the difficulty of industrial learning which entails getting the product design capability beyond just the production technology. This is the reason why Clark and Juma (2002) argue that the first point of entry to technological catching up is the “accumulation of basic technological competence in society”, by investing in human capital. The authors further explain that the latter is particularly important for developing countries to aid their capacity building, or else the countries will struggle with their technological development (Clark and Juma, 2002) and thus won’t move to the next stage of the catch-up process without the requisite technical competence. Indeed, learning and capacity building is of utmost importance for latecomer firms and countries. However, in the African context, Oqubay and Tesfachew (2019) argue that effective application of industrial policy, consistent and active engagement by the government are required to enable capacity building for catching up. Policymaking aiming at promoting intensive technological learning and openness to experimentation is a key driver for successful catch-up (Drine, 2012; Oqubay and Tesfachew, 2019).

Catching up may come with challenges and opportunities. As a result, numerous research projects have concentrated on challenges and chances for latecomer countries and firms to catch up technologically. These studies’ fundamental finding is that the firm’s inability to catch up is caused by a lack of advanced knowledge and innovation; poor institutional conditions; poor government support; lack of innovation systems; lack of physical, human, managerial and R&D capital resources (including finance), and lack of supporting strategic intent, amongst other factors (Lee and Lim, 2001; Lee, 2005; Lee and Temesgen; 2009; Malerba and Nelson, 2011; Drine, 2012; Malerba and Lee, 2021; Rosiello et al, 2021). The factors that impede or hinder the catch-up process of a latecomer firm are multifaceted and vary from country to country as well as across different sectors. The complexities involved make it challenging to pinpoint universal obstacles, as each context presents unique circumstances that affect the catch-up process. Hence, this research wants to, as a contribution to the literature, use a qualitative approach to determine these factors, in an effort to develop a conceptual framework that can guide the increase in technological innovation in the South African railway industry.

Technological catch-up is not a one-dimensional approach and as much as it has benefits, there may be negative consequences. Some scholars argue that the pursuit of catch-up can lead to a neglect of indigenous innovation and the development of local technological capabilities, especially in the African context where some innovations that originated in Africa are not recognised globally. This neglect can result in a dependence on foreign technology and a lack of competitiveness in global markets (Baloyi et al., 2017). In South Africa, which is still widely recognised as a country with significant economic inequality and a dual economy with the highest GINI coefficient in the world, the process of catching up may result in an unequal distribution of benefits. This is because a significant portion of the citizens may not have access to new technologies or may not see any economic gains from technological progress (Kruss, 2020; Soumonni and Muchie, 2023). Hence, Soumonni and Muchie (2023) propose what they call “inclusive catch-up” which focuses on improving human development outcomes more quickly than they have been improved in the past, in order to reduce the gap between the desired outcomes and a specific reference society, goal, or time frame. In this way, the grand societal challenges would be reduced at a faster rate than in the past, and consequently, technological developments would benefit and empower all South African citizens. In conclusion, while the concept of technological catch-up has been a promising way for countries and regions to close the gap with more advanced economies, it is important to consider the potential drawbacks and limitations of this approach. The technological catch-up approach cannot be a ‘one size fits all’. As much as it is important to learn from forerunners, it is critical to ensure that the approach is suitable for the unique scenario and always promotes sustainable and inclusive economic growth.

2.4. SUMMARY

The South African railway system’s strength is its largest, well-connected rail network and the several innovations which have been implemented in recent years to improve the system (e.g. dual-powered electric trains, ECPB, WDP, RDP, and colour light signalling systems). However, South Africa’s state of rail technology and innovations are far behind its global competitors in the freight rail business. The hindrances to modernising the railway sector include a lack of human resource development, absorptive capacity to transfer advanced technologies, investment in developing local supporting industries, upgrading rail infrastructure, and poor strategic intent. In

addition, the lack of a National Rail Policy for over a century in South Africa has led to a lack of clear national direction and a difficult position for the country to revitalise and align its rail industry with global development. With the new National Rail Policy approved in March 2022, there is an opportunity to strengthen investment in upgrading rail technologies to enable the sector to compete effectively and sustainably. Understanding the current state of technological development in Transnet, including the strengths, weaknesses and underlying challenges overall faced by the railway sector is important to study the technological catch-up phenomena. Limited comprehensive empirical evidence exists on factors influencing innovation in the railway industry, especially in Southern Africa, and little is known about the opportunities unique to Africa that can be harnessed to drive innovation and consequently lead to a successful catch-up.

The technological catch-up process involves imitating and adapting the technologies already developed in advanced economies. However, several studies have shown that successful catch-up may also involve the creation of alternative approaches that differ from the strategies employed by frontrunners. It is apparent from the peer-reviewed literature that the technological catch-up process is a dynamic and complex process. It cannot be precisely planned due to uncertainty and continuous changes. The approach and steps taken by one firm may not necessarily be applicable to the other. Thus, catching up requires dynamic capabilities, that aid the ability to learn from and master change with sufficient support from all role players. According to the literature review, developing countries, including those in Africa, face various challenges that weaken their technological catch-up process (and innovation activities) such as lack of knowledge, financial and vital resources, poor infrastructure, poor quality of the business environment, and unfavourable government policies. These have been found to be the common challenges also faced by Transnet.

2.5. THEORETICAL FRAMEWORK(S)

This research is guided by four key theoretical frameworks that will be explored in this section in order to better understand the complex dynamics of technological catch-up and innovation, particularly in the context of developing countries. The following theoretical frameworks: "Secondary Innovation," "Sectoral Systems Framework," "Evolutionary Perspective on Economic Catch-up," and "Endogenous Growth Theory"

provide unique perspective on the complex interplay of factors that drive technological catch up and innovation in developing countries. Beyond their theoretical direction, these frameworks serve as critical tools for comprehending and analysing the opportunities and challenges that come with developing countries' technological development.

After thorough exploration of the four frameworks, two specific theoretical frameworks, namely the Sectoral System (SS) framework and Secondary Innovation (SI), emerge as central to this research, particularly in the case study of Transnet. These two frameworks were chosen to construct the research's conceptual framework due to their capacity to provide a deeper and more nuanced understanding of the intricate dynamics involved in the process of technological catch-up.

2.5.1. Secondary Innovation

The term "secondary innovation" describes the process of using pre-existing technology or knowledge to produce new goods or services. This kind of innovation focuses on discovering new methods to use already-existing knowledge or technology rather than developing new knowledge or technology from scratch (Wu et al., 2009). Secondary innovation is crucial for developing countries because it enables them to catch up to economies that are more developed without having to spend a lot of money on creating new technologies or knowledge from the start. Developing countries can create new goods and services to satisfy their market demands and to compete with well-established goods produced by more developed countries by utilising available technologies and knowledge. According to Wu et al. (2009), latecomer firms which heavily rely on imported technology like Transnet may catch up by first mastering the operation technology by importing technical expertise, necessary equipment, and production manuals amongst others. By doing this, the firm would be, in what the authors refer to as "Basic Assimilation," the early phases where the main goal is to simply master a specific technology through imitation and some degree of adaptation. The end of basic assimilation may come with the mastery of imported foreign technologies and hence the firm may be classified to be in the "duplicative imitation" stage of catch-up (Wu et al., 2009; Lee, 2005). The duplicative imitation is followed by "creative imitation" and lastly "innovation" stages. According to Wu et al.,(2009) 'structural understanding', 'functional understanding', and 'conceptual understanding

is required to move up the stages, respectively. The latter stages involve substantial liasons and exchanges at various levels between the foreign technologies acquired, the local technological environment, and the home market environment with the intention of reducing reliance on foreign technology. (Wu et al., 2009).

Latecomer firms can use secondary innovation as a useful steppingstone to help them make the critical transition from simply copying others to developing their own in a cost- and time-efficient way. However, there are some challenges associated with secondary innovation. Firstly, there might not be as much access to the required technologies or expertise, which might constrict secondary innovation's potential. Developing countries may also lack the political will, infrastructure, or financial resources needed to fully implement secondary innovations, such as reliable electricity or financial access (Drine, 2012; Wu et al., 2009: Lee,2005: Clark and Juma, 2002). Furthermore, since secondary innovation frequently builds on already-existing technologies or knowledge that may be protected by patents, there may be issues with intellectual property rights. Due to this, developing nations that want to participate in secondary innovation may face entrance barriers (Wu et al., 2009; Lee, 2005).

Fagerberg (2012) argues that catch-up is "far from the easy, smooth process" and he puts an emphasis on the need for strong "social capability" which means being able to mobilise the necessary resources required for catch-up. More relevant to the African continent, Drine (2012) uses a metafrontier approach study, which has found that North African countries' capacity to obtain and adopt advanced technology is extremely constrained because of poor governance, political instability, knowledge deficiencies, poor financial development, and low institution quality. Emphasis is put on the need to improve governance and institutions for the region's catch-up process because the authors prove through their empirical methodology that the inadequate standard of governance in the regions is the cause of incompetence. Ethiopian Airlines' success story can attest to the importance of good governance because as alluded to by Oqubay and Tesfachew (2019) catching up in Ethiopia's aviation industry would have been impractical without the state's steadfast dedication and consistent support. Overall factors that adversely affect a latecomer firm's catch-up process are complex and differ from one country to another and across sectors. Hence, good

governance and institutions are required for secondary innovation to effectively accelerate development in underdeveloped countries.

2.5.2. Sectoral Systems Framework

The sectoral system framework presented by Lee and Malerba (2017) is an analytical framework that aims to understand the dynamics of technological and industrial change within specific sectors of the economy. The framework highlights the interdependencies between different actors and institutions within a particular sector, including businesses, governmental organisations, research institutions, suppliers, consumers, and other stakeholders (Franco, 2017).

Sectoral systems of knowledge and abilities, sectoral systems of production, and sectoral systems of innovation make up the framework for sectoral systems. The creation, diffusion, and adoption of advanced technologies and innovations within a sector are all handled by a group of organisations, actors, and networks collectively referred to as the sectoral system of innovation. This includes organisations that conduct research, academic institutions, business associations, and government organisations responsible for financing and overseeing R&D activities (Lee and Malerba, 2017; Malerba, 2005). The group of firms, consumers, suppliers, clients, and other actors engaged in the creation, distribution, and marketing of products and services within a sector is referred to as the sectoral system of production. This encompasses both long-standing businesses and new entrants, as well as the various middlemen and service providers who assist them. The group of organisations, actors, and networks involved in the procurement, application of knowledge and skills and diffusion within a sector are referred to as the sectoral system of knowledge and skills. This includes educational and training institutions, trade schools, and other businesses engaged in the development of human capital, as well as groups like professional associations and other networks that promote the sharing of information and skills within the sector (Malerba, 2005).

The sectoral systems framework is useful for analysing the drivers and barriers to technological catch-up within specific sectors, as well as the opportunities and challenges for policy intervention to support technological catch-up (Malerba, 2005; Malerba and Lee, 2017; Malerba and Lee, 2021). By identifying the key actors and institutions involved in each sectoral system, the framework provides a systematic way

of analysing the complex interdependencies and feedback loops that shape the trajectory of technological catching-up over time. It can also help policymakers identify policy levers and intervention points for promoting innovation, competitiveness, and sustainability within specific sectors. Overall, the sectoral systems framework offers a valuable analytical tool for understanding the dynamics of technological catching up in specific sectors, and for developing evidence-based policies to support economic development and growth (Malerba, 2005).

2.5.3. Evolutionary perspective on economic catch-up

Malerba and Lee (2021) propose an evolutionary perspective framework on economic catch-up. This framework is based on well-established explanations of catching up and extensive studies in the academic literature which bring forth comprehensive, evolutionary explanations of the catch-up phenomenon. Firstly, the authors argue that starting the catch-up process by copying the leaders may be successful initially, but real success in catching up cannot be attained in the long run by merely replicating existing goods or technologies. Instead, success comes from developing unique products or technologies that differ from those of the leaders, or by pioneering new paths that are different from those of the leading countries or companies (Malerba and Lee, 2021). This conclusion is based on the findings that Malerba and Lee (2021) made when examining the historical experiences of catch-up by latecomer countries such as Japan, and China, where they identified the common features of their catch-up strategies. The authors suggest that the three important components of an evolutionary view of catch-up are “learning and capability development”, institutions, and “innovation systems”, and that catching-up is a process that needs to be studied over the long term (Malerba and Lee, 2021). The environment in which firms operate, including the innovation systems in place, plays a critical role in shaping their learning and capability building efforts. Hence, this perspective sees catch-up as a dynamic, continuous process that cannot be precisely planned due to its unpredictable nature and ongoing evolution. Evolutionary economists support this notion because they strongly believe that the nature of firms evolves over time (Nelson et al., 2018). This is mainly because there are new kinds of industries and new varieties of markets emerging every day, which require changing government policies and changing laws to enable effective economic activity. Moreover, Nelson et al., (2018) contend that when it comes to technological progress in one sector, technological catching up is

likely to differ significantly from what goes on in other sectors. This is because there are national differences broadly, and disparities of about specific industries. Thus, Nelson et al., (2018) propose that technological advancement should be understood as an evolutionary process.

Malerba and Lee (2021) argue that catching up is influenced by external events ('windows of opportunities') and the unique behaviours of different actors with varying perspectives and backgrounds. As a result, latecomer countries and firms respond in different ways (such as following a path, skipping stages, or leapfrogging), even when faced with similar technological or market conditions (Malerba and Lee, 2021). Moreover, this "evolutionary" perspective on catch-up suggests that public policy can play a significant role in addressing not only market failures but also capability and innovation system failures in the catch-up process. The authors conclude that policies may focus on correcting learning and capability failures through education and training, technology diffusion, and collaboration among key actors. Moreover, policies can also address failures in the innovation system by fostering the development of knowledge infrastructures, establishing financial investments, and promoting coordination among various actors and institutions. To effectively support the dynamic evolutionary process of catch-up, policies must be agile and evolve over time in response to the various stages of the process (Nelson et al., 2018; Malerba and Lee, 2021). Moreover, this perspective It emphasises the need for a holistic approach that involves both domestic and international factors to foster sustainable and inclusive growth.

2.5.4. Endogenous Growth Theory

Endogenous growth theory suggests that economic growth can be generated internally by a country or firm through investments in human capital, research and development, and technological innovation (Aghion et al., 1998; Romer, 1990). Unlike traditional neoclassical growth theory, which assumes that technological progress is exogenous and external to the economy, endogenous growth theory argues that technological progress can be generated endogenously through the creation of new ideas and innovations that are generated within the economy. As alluded to by Romer (1990), government policies, including investment in R&D and intellectual property laws, helped foster endogenous innovation and sustainable economic growth. This,

implying that catching up is rather a result of investments in research and development, education, and other physical and human capital factors with robust policy interventions that promote innovation (Thach, 2021).

The notion of ‘increasing returns to scale’ is a key principle in the endogenous growth theory. This means that as more and more resources are invested in a particular area, the productivity of those resources increases. In the economy or firm as a whole, for instance, the degree of knowledge rises as more investment is done in education, research, and development, leading to further innovations and long-term economic growth (Aghion et al., 1998; Romer, 1990). This key principle offers a more realistic and comprehensive explanation of the drivers of long-term sustainable economic growth. Moreover, this theory acknowledges the pivotal role governments play in promoting economic growth by investing in education, infrastructure, and R&D (Fine, 2000; Thach, 2021). Endogenous growth theory has, however, come under some critique in the literature. The theory seems to postulate that knowledge and technology are public commodities that are easily accessible to all economic actors is one of its main criticisms. In reality, information and technology might be considered private goods protected by intellectual property rights and trade secrets, which could restrict how widely they are used (Fine, 2000). Moreover, as alluded to by Drine (2012) the global south is still struggling with political instability, and poor governance which drastically implements effective policy implementation, and this has not been considered in the practical application of the theory.

2.6. CONCEPTUAL FRAMEWORK

The sectoral system (SS) framework and secondary innovation (SI) theoretical frameworks discussed in section 2.5 guide the development of the conceptual framework of this study. These two frameworks are chosen out of the four abovementioned frameworks because they provide a more comprehensive and nuanced understanding of the technological catch-up dynamics at play. The sectoral systems framework and secondary innovation take into consideration the unique traits of each sector, such as its technological developments, institutional context, and network of key players. This is useful because it enables one to pinpoint the precise challenges and opportunities that are distinctive to the South African railway sector. The developed conceptual framework diagrammatically represented in Figure 4 below

is based on a thorough understanding of the organisation's current situation from pertinent literature review and is grounded in a realistic assessment of the factors that contribute to successful technological development adapted from the literature review.

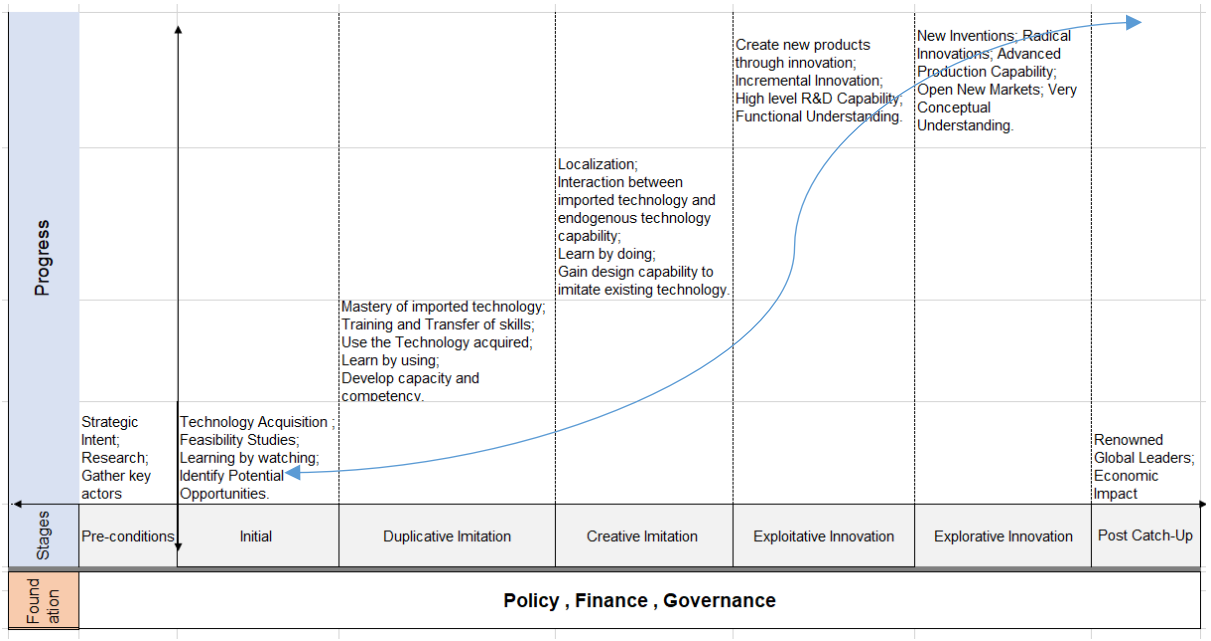


Figure 4: Technological Catch-Up Conceptual Framework adapted from Wu and Xu, 1991; Wu et al., 2009; Malerba and Lee, 2021

In Figure 4, the horizontal x-axis is a categorisation of the different stages of catch-up as and the vertical y-axis shows the progress of technological development as you go through each stage. Right below the x-axis are the core contextual factors for successful catchup. These core factors are policy, finance, and governance, the bedrock required to foster catch-up. Without these three, catch-up is likely to fail or be stagnant at some stage, especially in the Global South (Fagerberg, 2012; Drine, 2012). It is the view of this paper that the technological catch-up process is a dynamic, complex, and continuous process which is not deterministic and requires an extensive exploration of the scenario itself before solutions that worked in other cases can be considered. Hence, the blue, double arrow, non-linear line depicts the process to be continuous and may take any shape or form depending on the circumstances. Moreover, the stages are not separate from one another and might be linked by feedback. It is also possible for stages to overlap (Wu and Xu, 1991).

This conceptual framework will be used in this study to discover the stage at which TFR and TE are in the catch-up process. This will help identify the barriers, and opportunities and support the study's objective to highlight the role of technological innovations in improving the rail business and the need to catch up for maintaining the competitive advantage. Knowledge of this information will also help evaluate and classify at which stage is Transnet overall, as well as the challenges they face. This will not only be a useful contribution to literature but also help to identify the gaps in the South African railway industry's technological development and provide recommendations.

2.7. STATEMENT OF PROPOSITIONS

Based on the relevant literature review, it is clear that South Africa's railway system has lagged behind those of other developed nations. One of the primary factors contributing to this disparity is the insufficient investment in the railway infrastructure. (White Paper on the National Rail Policy , 2022). This lack of investment has resulted in a deterioration of the rail lines and equipment, making it difficult for the system to keep pace with advances in technology. There is potential however to forge ahead, especially with the recent introduction of the National Rail Policy promising to focus on developing the railway system which was neglected for many years. Transnet has over the years put forward technological development as part of its strategic intent, but it still faces many challenges (Transnet Engineering, 2020). My exploratory propositions are therefore as follows:

Research Question: What is the current state of technological development at Transnet's railway operations?

- Transnet (both TFR and TE) is currently at the initial catch-up state moving at a very slow pace (JICA (Japan International Cooperation Agency), 2012; The "Technology" of People, 2015; Boros et al, 2020).

Research Question: What are the factors influencing the technological catch-up process and innovation in the South African railway industry?

- The slow progress in catching up, technologically is due to the lack of robust learning and technological capability building with support from an effective rail innovation system (Wong, 1999; Drine, 2012; Egbetokuna et al., 2016).

- Transnet is also stuck at foreign technology acquisition and there are minimal, to no effective strategies available to enable technology transfer. Thus, making the business fully dependent on foreign technology (Transnet, CRRC E-Loco say 'in-principle agreement' reached to resolve legal disputes, 2015; Ayanda Shezi, Transnet's Spokesperson, 2022; Creamer).
- There is a lack of intervention policy and government support to foster innovation and technology development (Presidential Infrastructure Coordinating Commission, 2012; National Rail Policy – Green Paper, 2015).

Research Question: What are the pathways to strengthen technology catch-up process in the railway industry in SA?

- In order to attain desired results, technological catch-up cannot be taken for granted and needs to be continuously fostered. Thus, new interventions are required to enable an effective catch-up process, and it must include (but not limited to) the following: Transnet should consider investing in building technological capability with a strong focus on various knowledge development activities. To enable this, an effective sectoral system should be present, and Transnet as a state-owned company has the powers to greatly influence this through the support of policy and active intervention from key actors (Clark and Juma, 2002; Malerba, 2002; National Rail Policy – Green Paper, 2015).

3. CHAPTER 3: RESEARCH STRATEGY AND METHODOLOGY

3.1. INTRODUCTION

A paradigm based on pragmatism was adopted to achieve the aims of this research. This approach is chosen because it helps explain the phenomenon of technology catch-up by considering many viewpoints, concepts in the South African context (Sekaran and Bougie, 2016). A pragmatic approach is more suitable for this type of study because it is open to a combination of methods that can shed light on the actual and practical behaviour of the phenomena in the railway industry. The catch-up phenomenon has been studied extensively in different contexts over the years. However, it does not mean there is one best answer to catch up, depending on the circumstances, the process is changed and adapted as and when required. Hence, a pragmatic qualitative approach is chosen because it allows for flexibility in data collection, analysis methods and acknowledges that there may be multiple perspectives on a phenomenon and seeks to get an in-depth understanding of all perspectives considering the context (Gregson and Bettis, 2002).

3.2. RESEARCH STRATEGY AND DESIGN:

Case study research that utilises an explanatory research design methodology was used to explore the technology catch-up phenomena. This single, embedded case study used Transnet and its two division Transnet Freight Rail and Transnet Engineering division to extensively study the technological development and thus understand the catch-up phenomena. These two divisions are selected because they are the two key divisions that are responsible for the deployment of advanced technologies in operations and maintenance to keep the railway business running. Transnet Freight Rail as the main rail operator is responsible for choosing the technologies to be used in railway operations and Transnet Engineering is responsible for choosing technologies to maintain rolling stock for an efficient and effective railway business (Transnet.net, 2021). Therefore, studying these two divisions helped explore the technological catch-up process over the past 10 years. Observing and investigating the technological developments from the past 10 years will give more insight because the R300 billion investment for the Market Demand strategy was launched in 2012 (Batwell, 2012). Therefore, due to the developments and upgrades done to align with the MDS strategy, it is safe to conclude that the study is feasible.

Semi-structured interviews were the main source of collecting data from participants in this study. Interviews were conducted, face-to-face or online, the choice depends on the participant's availability and comfortability. Participants were requested via email to participate in the study. Those who agreed were requested to sign a consent form before the interview process began. The semi-structured interview method is considered because it provides an opportunity for an in-depth, flexible exchange between the researcher and the respondent. The semi-structured approach is suitable for this study because it takes a pragmatic approach that seeks to find many different ways of interpreting the technology catch-up phenomena by investigating what happens in reality (Sekaran and Bougie, 2016). In addition, archival data and all other relevant documents relating to the technology used in Transnet were collected to enrich the analysis of the study. The investigation was a generic qualitative approach that was guided by the study's research questions (Gregson and Bettis, 2002). This approach allows a naturalistic, in-depth understanding of the technological catch-up phenomenon from multiple perspectives while understanding the practical implications of the process in the context of the case study. It prioritises comprehension instead of clarification or simply comparing Transnet with the global railway industry frontrunners (Golafshani, 2003).

3.3. SELECTION OF PARTICIPANTS

Transnet employees from the two divisions of interest form part of the participants who were interviewed. The case site was in the TFR Johannesburg offices and TE Pretoria offices as these are the divisions' main offices. The personnel selected ranged from technicians, engineers, and management who are directly involved in the design, development, and maintenance of technologies used in Transnet. Experts and retired ex-Transnet employees who are currently not working for Transnet, but fully informed of railway technologies were sought and consulted where possible. This was necessary because Transnet has since declared that they had a huge loss of critical skills, thus valuable information was sourced from the people who have since left the organisation. The documents to be studied were requested from Transnet Academy, officially released communications from the company and/or through references done by participants during the interview process. The plan was to get a minimum of 20 participants interviewed. Preferably 10 from TE and 10 from TFR so that the two divisions may be equally and fairly represented. However, a total of 18 participants

were interviewed due to time constraints. This was deemed to be a sufficient number, especially given that a satisfactory level of saturation was achieved, such that few additional insights would have been gained by interviewing more people.

3.4. RESEARCH METHODOLOGY

The qualitative methodology was used because the research is of an exploratory nature, seeking to understand the technology catch-up phenomena in the context of the railway industry in South Africa. Content and framework analysis are methods used for this study. Given the complex and dynamic nature of this research context, content analysis was used to comprehensively investigate the current state of rail technology and identify hindrances to catching up which may be unique to South Africa, such as, the absence of a cohesive National Rail Policy, compared to other developing countries. Framework analysis was crucial in structuring and categorising the multifaceted data, organising key themes, and enabling methodical comparisons to address the intricate challenges and opportunities in the South African rail sector. Moreover, this research is based on a pragmatic paradigm, thus, it is open to interpreting and finding out important aspects of content which might not necessarily be aligned with the existing frameworks in academia, although they may have similarities and/or differences to the worldwide technology catch-up phenomena. This type of analysis aims to find descriptive or exploratory conclusions in a structured and easy way to understand (Gregson and Bettis, 2002). This is mainly because of the complex and dynamic nature of technological catch-up phenomena and innovations necessitates a flexible and adaptable framework, as there is no ‘one-size-fits-all’ solution to catching up (Gay et al., 2006; Franco et al., 2017).

3.4.1. Data Collection and instrument

Semi-structured interviews were conducted either online or face-to-face and they were all audio recorded. The face-to-face interviews were recorded and later transcribed. Online interviews were transcribed during the meeting with the help of Ms. Teams platform and later interpreted for purposes of analysis.

The researcher planned to conduct interview sessions that are short and to the point, with an average duration of 20 minutes. The research instrument is found in Appendix B. The interpretation of the data collected through interviews was an iterative process, involving the re-reading of transcripts until the meaning of the answers is clear and

categorised according to the themes of the study. The researcher aimed to avoid introducing bias in the interview sessions by being always conscious conscientious of them also being Transnet employees. To achieve this, the researcher stuck to the interview questions and limited follow-up questions for the purpose of elaboration only. The researcher consulted with the supervisor when interpreting the data to ensure objectivity.

In cases where face-to-face or online interviews are not possible, the researcher sent pre-selected questions via email and/or used the Ms Teams chat function to communicate with the interviewees. The researcher followed Transnet's procedures to request archival data by submitting a request through the Transnet Academy and referenced all relevant documents where required.

3.5. LIMITATIONS OF THE STUDY

Although the study's topic may be applicable in various situations (i.e., PRASA, GAUTRAIN, and other transportation modes) this study focuses on Transnet, TFR, and TE. Thus, careful consideration and further research should be done for other contexts.

The researcher, being a Transnet employee, acknowledges the importance of maintaining objectivity throughout the process of conducting interviews and interpreting collected data to avoid bias. The data collection and analysis were guided by the conceptual frameworks aligned with the study. By following this approach, the researcher minimised the risk of any potential bias in the study.

3.6. ETHICAL CONSIDERATIONS

The researcher committed to maintaining a high level of rigour, integrity, sensitivity, and confidentiality of information throughout the research process. The researcher strictly adhered to the ethical standards set out by the Wits Business School code of ethics. This includes ensuring that all information was handled with the utmost confidentiality and sensitivity. The researcher recognises the importance of upholding ethical standards to ensure that the research is conducted in a professional and responsible manner and has taken all necessary steps to comply with the ethical guidelines set out by the WBS.

Permission to conduct interviews and do the study was done as stipulated in the Transnet academic research guidelines. Therefore, no interviews, analysis of documents, or archival records was done until approval was granted by the organisation's Chief of people (Madihlaba, 2022). The identities of the participants were not shared, and the data analysis did not in any way reveal the participant's identities. The data collected is for academic research purposes only.

3.7. RELIABILITY AND VALIDITY

3.7.1. Reliability

The data collection procedures are consistent throughout the study. The semi-structured interviews were conducted using MS. Teams platforms or in person, however, the questions asked were the same for all participants. All interviews were digitally recorded, and handwritten notes were used as a measure for recording where necessary. In addition, where possible, the findings were presented to participants to ensure that their perspectives have been accurately represented. Follow-up questions and clarifications during the interview process were used to ensure that the different perspectives are accurately presented. This helps to ensure the reliability and accuracy of the data and to maintain consistency so that the data can be easily analysed (Golafshani, 2003).

3.7.2. Validity

The researcher ensured that the findings of the study accurately reflect the participants' views and experiences by being transparent about their role and perspective on the progress of technology development at Transnet. This includes acknowledging any potential biases that may arise from the researcher's observations. To minimise the impact of these biases on the study, participants were asked for clarification where necessary to ensure that the researcher's interpretation accurately reflects their views and experiences. In addition, the researcher's supervisor is well versed in the catch-up phenomena, thus has moderated the collected data to ensure that the data is genuine and not influenced by the researcher's personal views. This approach helped to ensure that the study's findings are credible and that the findings are reliable and trustworthy (Golafshani, 2003).

3.8. SUMMARY

This chapter outlines the research strategy and methodology to explore the technology catch-up phenomenon in the South African railway industry. The study adopts a pragmatism paradigm, using a case study approach that utilises an exploratory research design methodology. The Transnet Freight Rail and Transnet Engineering divisions are the case study subjects due to their responsibility for the deployment of advanced technologies in operations and maintenance. Semi-structured interviews were the main source of data collection with a total of 20 participants, along with archival data and relevant documents. The research employs a generic qualitative approach guided by the research questions, content, and framework analysis methods. The aim of the research methodology is to achieve a comprehensive understanding of the technological catch-up phenomena from multiple perspectives while prioritising comprehension over clarification and comparison with global railway industry frontrunners. The researcher strove for high validity and reliability using the techniques listed above. Due to the complexity of the catch-up phenomena, it is important to note that the findings of this research may not necessarily be applicable to other contexts.

4. CHAPTER 4: PRESENTATION OF FINDINGS

4.1. OVERVIEW

This chapter presents the findings of the research study on technological catch-up and railway innovation in South Africa's railway industry using Transnet as a case study. A comprehensive overview of the information gathered, analysed, and interpreted during the investigation is detailed in this chapter. The focus was on highlighting the key findings that give a clear understanding of the current state of technological developments, to help identify the stage at which Transnet is, and why.

4.2. BRIEF INTRODUCTION

Before delving into the findings, it's crucial to remember that this research is qualitative and adopts a pragmatist paradigm, using Transnet (TFR and TE) as a case study to address this meaningful, complex real-world challenge of technological catch-up. An exploratory research design methodology is utilised because technological catchup in the railway industry, is a relatively unexplored challenge, especially in the African context (Gay, 2006). Thus, this design methodology enables a more comprehensive comprehension of the research issue at hand and provides useful insights into the body of knowledge on the dynamics faced by the railway industry in the global south.

The presentation of findings is structured to address the research questions and objectives outlined in Chapter 1 and it is guided by the developed conceptual framework in Chapter 2. Hence, the answers to the interview questions were used to identify the stages in the developed conceptual framework at which TE and TFR can be located.

4.3. BACKGROUND PROFILE OF RESPONDENTS AND PROCESS FOLLOWED

A total of eight participants from Transnet Engineering and 10 participants from Transnet freight rail were interviewed as shown in table 2 below. All TFR participants are from the Technology Management department. This department is responsible for providing innovative engineering solutions for TFR to achieve its targets, whilst ensuring safe and reliable operations. Therefore, the selected TFR participants are all somewhat involved in the deployment of technology to help TFR operate efficiently. The TE participants are responsible for the manufacturing, maintenance, repairing, testing, and upgrading of the technology deployed by TFR on the rolling stock. Thus,

all selected TE participants are responsible for making sure that the technologies used, are ensuring smooth operations of trains. Both TE and TFR participants were Transnet employees during the time when the interviews were conducted. They have all been employed by the organisation for more than four years and have been involved with various technologies during their tenure in their respective Transnet divisions. Moreover, all participants have formal tertiary education from accredited academic institutions, and some have undergone functional training more than once in their respective roles.

As a Transnet employee myself, it was important to be cognisant of the data collection method used as it has the potential to introduce measurement error, as alluded to by Podsakoff et al. (2003). Thus, participants' permission was requested in advance to conduct the interview via email, which clearly stated the purpose of the interview and had details of how their anonymity and confidentiality will be assured. The latter was important to motivate participants to offer accurate and unbiased information since they are aware that their comments can not be traced to them personally. In addition, a good rapport was built with the participants before the interview, to help create a relaxed atmosphere and lessen the social desirability bias (Philip Podsakoff, 2003). The interview questions were approved by my supervisor before the interview process commenced.

Table 2: List of Internal to Transnet Interview Participants

Transnet Internal Participants						
	Division	**Role**			**Division**	**Role**
Participant 1	TE	Chief Engineer		Participant 1	TFR	Chief Engineer
Participant 2	TE	Principal Engineer		Participant 2	TFR	Principal Engineer
Participant 3	TE	Principal Engineer		Participant 3	TFR	Senior Engineer
Participant 4	TE	Engineer		Participant 4	TFR	Senior Engineer
Participant 5	TE	Engineer		Participant 5	TFR	Specialist
Participant 6	TE	Engineer		Participant 6	TFR	Specialist
Participant 7	TE	Principal Engineer		Participant 7	TFR	Engineer
Participant 8	TE	Principal Engineer		Participant 8	TFR	Engineer
				Participant 9	TFR	Engineering Technician
				Participant 10	TFR	Engineering Technician

To strengthen the validity and dependability of my conclusions, two additional participants who are external to Transnet and additional data sources were included to the interview data (see Table 3 below). Additional data sources included relevant documentation, archive data, and observations to supplement the interview data and mitigate any potential biases brought on by self-reporting (Podsakoff et al., 2003; Golafshani, 2003). Each interview session took approximately 40 minutes. A total of nine participants were interviewed face-to-face, one participant requested to respond in writing, while the remainder of the interviews (10) were conducted via Microsoft Teams. Interviews were recorded using personal handwritten notes or MS Teams transcription , and a cellphone for the online and offline sessions,respectively. Consent forms were signed by all participants.

Table 3: List of external to Transnet Interview Participants

External Participants		
EXTERNAL/RETIRED		**Role**
Participant 1	RETIRED	Principal Engineer
Participant 2	RESIGNED	Principal Engineer

4.4. PRESENTATION OF FINDINGS

4.4.1. Understanding the Participant's involvement in railway innovations and Technology

It is important that the selected participants are aware of and have been involved in railway technologies in their careers. Thus, the first section of the interview was dedicated to understanding the participants' roles and responsibilities relating to railway technology, to what extent they are involved, and understanding their view of the role of railway innovation in running the Transnet business. The responses are summarised in Table 4 below.

Table 4: Summary of responses from interview participants

Category	Summarised Response from Participants.
Transnet Freight Rail Participants	All 10 participants interviewed, their roles and responsibilities involve railway technology. In fact, all participants work for the technology management department. This is a department in TFR that is responsible for providing innovative engineering solutions for TFR to achieve its goals whilst ensuring safe and reliable operations. Therefore, participants' roles include (but are not limited to) acquiring technology, introduction of advanced technologies, and technical support to ensure that technology benefits the overall business. The participants' experience level as well as the technologies that they were responsible for differ. For example, one participant specialises in locomotive electrical systems technology or locomotive onboard data monitoring technology, while the other participant specialises in locomotive wheelsets or train wayside monitoring technologies. Thus, even though participants may have the same role (e.g. engineer), they however work with different technologies, thus bringing unique insights for this study.
Transnet Engineering Participants	All eight participants interviewed, their roles and responsibilities involve railway technology. Core to their duties is developing innovative solutions to help with the maintenance of technology being used for TFR rolling stock. Therefore, they are responsible for field support, which requires a deep understanding of technology to alleviate failures that may hinder the trains from moving. Similar to TFR participants, the interviewed participants work with different technologies, and have different experience levels even though they might have the same title.

External to Transnet Participants	The retired Participant 1 was employed as a Principal Engineer for TFR at the time he retired. He worked for TFR, technology management department for 36 years and his role also involved being a technical fleet owner for the heavy haul locomotives for locomotives running in Transnet's coal and ore line. Thus, he was responsible for high-level decision making in technology acquired for these locomotives and overall improvement of TFR business operations. External participant 2 resigned from TE after 10 years of service. During the time of resignation, he was a principal engineer responsible for field and product support where he was required for engineering intervention to provide product life support to the availability of trains.

When the participants were asked how the novel technologies, they work with improve the rail business, they all attested to technology improving the rail business by giving examples of how the respective technologies they are involved with benefited Transnet. The key findings are summarised below. According to the findings, railway technologies have the following benefits:

- Enables the organisation to operate and run a cost-effective and reliable business.
- Enables an agile and swift response to operational needs, significantly reducing derailments, and delays.
- Helps achieve customer engagement and satisfaction.
- Significantly contributes to making business efficiently reach targets (i.e. total planned tonnages to be transported), consequently increasing revenue generated.
- Increases availability of trains and ensures smooth, safe movement of trains from one location to the other.

4.4.2. Evaluating the Technological Capability

As alluded to by Wu et al. (1991), foreign technology acquisition is the beginning of secondary innovation. Therefore, it was important to discover if this exists in Transnet. The findings show that Transnet is indeed procuring foreign technology. The bulk of the technology used is internationally sourced, and the rest is local. The international OEMs also have local subsidiaries. However, this does not change the fact that the technology originates internationally. Participants could not quantify the proportion of local and/or foreign technology Transnet uses. They only gave an overview of the respective technologies they have been involved in, which do not represent the overall set of technologies that Transnet uses. When asked, *what strategies and /or initiatives are in place to learn and upskill engineers and technicians from the imported technology to build capabilities?* Here are the key findings:

Table 5:Summary of responses from interview participants

Category	Summarised Response from Participants.
Transnet Freight Rail Participants	There are formal and informal training programs that are available for technical staff. However, they mainly focus on understanding the end-user side and maintaining the technology rather than building the capability to invent such technology in the future. As one participant said, *"Our role as TFR is not to develop and industrialise technologies"*. In addition, the other participant said, *"Aim is not to do it inhouse and introduce to the market, as a state-owned company we must create jobs"*. Therefore, engineers and technicians mainly learn the operation and maintenance of the technology from relevant documentation (e.g., manuals), their involvement in design reviews, and direct involvement during the testing and commissioning of the newly introduced technology. Some were also granted an opportunity to travel overseas to visit the OEM's manufacturing factory to get exposure. Overall, participants learn from "on-the-job" training, and the more they operate, maintain, and do fault-finding investigations on the technology the more they are knowledgeable about it and begin to master the technology. Where required, bursaries are

	granted for TFR employees to further their studies and attain professional certifications.
Transnet Engineering Participants	There are formal and informal training programs that are available for technical staff. TE participants mentioned that they do a lot of desktop research to understand the technology. Most participants alluded to having been involved in reverse engineering of the currently used technology to find and develop solutions because some components have been obsolete. This helps a lot with mastering the operation of the system and learning about the core technical aspects of the technology. There is also a continuous engagement with the OEMs, and training provided by OEMs. Bursaries to support technical staff to acquire the required skillsets from academic institutions are also granted. A majority of the participants highlighted that engagement with OEMs helps with the transfer of skills and helps with learning fast. As one participant said, *"We aim to be the OEM of choice in Africa, so it helps to learn from the leaders in the industry".*
Participants External to Transnet	Retired Transnet employees also reference direct involvement in design reviews, foreign technology acceptance testing, and on-the-job learning from specialists. Participants 1 and 2 stated that in the past, the organisations had agreements with OEMs, which gave technical staff an opportunity to travel overseas where they went to the factories where the technologies are manufactured and learned from foreign specialists. Participant 1 gave the GE initiatives as an example, where foreign suppliers provided local training opportunities in addition to the travel to their respective countries. He highlighted though that in his view, *"Not much effort was done from internal engineers".*

According to the South African National Infrastructure Plan (2012), the expansion of rail and port capacity accompanied by the procurement of an increased number of trains to fully utilise the infrastructure was identified as a core enabler of economic

development. This procurement of new locomotives was through a collaboration with OEMs such as CSR Zhuzhou Electric Locomotive with specific conditions that enforced that the manufacturing of some of the locomotives to be in South Africa. This was aimed at building the local manufacturing capacity of the domestic rail industry and investing in skills development (Presidential Infrastructure Coordinating Commission, 2012). In 2015, former president Jacob Zuma confirmed that 85 out of the 95 electric locomotives supplied to TFR had been built at TE's facility. This assembly process included components sourced from local companies. This was the government's initiative to transfer technology and specialised skills from countries such as China (The "Technology" of People, 2015; Creamer Media, 2015; Transnet Engineering, 2020).

When the participants were asked if they have mastered the operation of the technology, all of them responded yes. Some participants were not comfortable with the term "master" as they believe that there are some aspects of the operation of the technology that they do not fully understand. In such cases, they mentioned a lack of adequate documentation to help acquaint themselves with the technology. To evaluate whether the participants have attained the next phase of catch-up, they were asked: "*Have you mastered the technology to the level of being able to independently imitate it (granted all required resources)? Please elaborate"*. The findings are summarised graphically as shown in Figure 5 below:

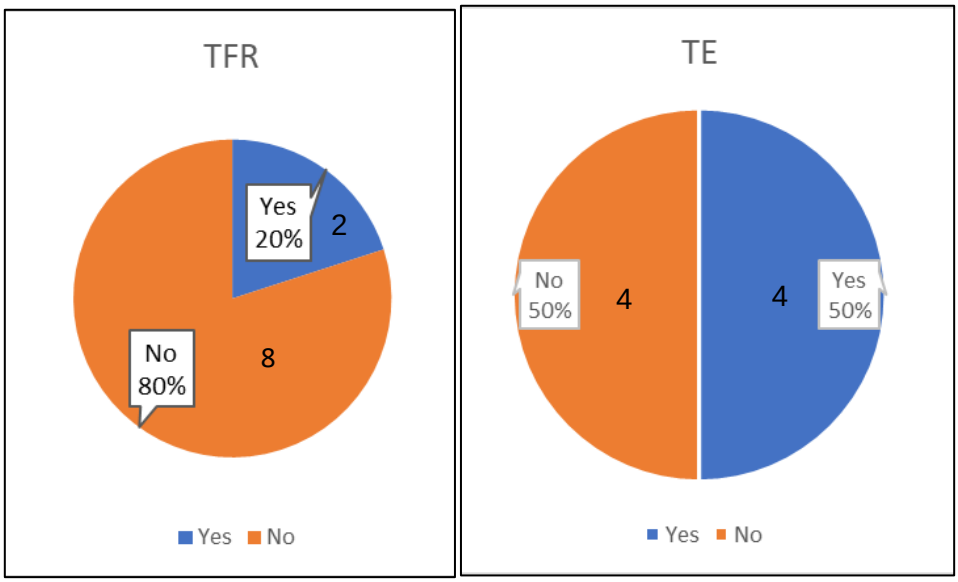


Figure 5: Participants' response on the capability of imitating foreign technology

TE participants mentioned that granted intellectual property (IP) they can imitate the technology. One participant mentioned that they managed to register a patent and thus they can imitate and develop the technology. The other participants said no because they mentioned that the technologies are highly specialised and, in some cases, the skill and expertise are not available in South Africa.

The majority of the TFR participants answered 'no' to being able to independently imitate the technology because of the lack of skills and expertise required for the development of the technology. One participant emphasised, *"We develop the technical specifications and go out to the market"*, thus the intention was never to learn to imitate the technology. The focus has always been on understanding the functionality and how to maintain the technology and leave the development to the suppliers. External participants also share the same views but highlighted the importance of experience. As mentioned by one external participant, *"It takes years of working with the technology to fully understand its functionality. You master the technology by working with it over years".*

To get an understanding of the level of capability building, the participants were therefore asked*: Have you developed the capability to improve imported technology to suit domestic requirements? Please elaborate:*

Three participants from TE confidently answered "Yes, we have the know-how" and the rest of the participants answered, "*not yet"*. The main reason was the hindrance posed by IP, and the lack of specialised skills and required resources. However, the participants mentioned that their activities associated with reverse engineering are their way of slowly building internal capability. Thus, currently, they can improve minor things on foreign technology which have to do with operations and maintaining the technology. It is important to highlight that TE engineers in conjunction with the CSIR successfully developed a TAL locomotive condition monitoring system that is most suitable for African conditions and terrain. This control system can provide data that can be used to further improve the operations of the locomotive. Even though some of the interviewed participants were not directly involved in this project, they however referenced it as an example when responding to this question. TFR participants mostly answered no, and one participant answered yes. The majority said they mainly

contribute to the improvement by sharing their experience with using the technology, insights, and findings from investigations/studies done. This is because the aim was never to build internal capability to eventually develop the technologies internally.

4.4.3. Evaluating the Technology Level

Overall, Transnet has technologies and innovations that they have developed internally and/or plans to develop more. When asked to give examples the following technologies were listed LCMS, TAL locomotive control system, port hauler, CS90, additive manufacturing, composite development, optimisations of welding processes, locomotive data system OTF technology, and cracked wheel detector, among others. These technologies are the results of successful R&D projects. Therefore, the participants were asked, *How does your division promote and support R&D activities?*

Table 6: Summary of responses from interview participants

Category	Summarised Response from Participants.
Transnet Freight Rail Participants	*"TE is Transnet's source of R&D. TFR is mostly into the application, we want to see how this technology works, rather than sitting in the lab and developing something novel"* -quoted directly from a TFR participant's answer to this question. Therefore, the division supports and promotes TFR's contribution to R&D projects by ensuring there is enough financial support and other resources. Overall, participants mentioned that there is support for R&D. However, development is still reliant on OEMs and is not done internally. Consequently, there is susceptibility to corruption, resulting in wasteful expenditure of R&D funds. Therefore, R&D is not entirely promoted internally at TFR, and projects hardly get to the development stage due to the red tape, as mentioned by one participant. There is no drive for R&D, the focus is on making sure trains are running, by making sure that faults are quickly identified and fixed.
Transnet Engineering Participants	TE participants mentioned that the organisation Transnet is currently facing challenges (most referenced after the covid pandemic) which have since affected TE's capability to promote and support R&D activities. Before there were programs to drive TE to become the OEM

	of choice, through adequate funding, and availability of resources. However, due to the current challenges, strategic direction is now focused on revenue-generating initiatives which take away the support for R&D activities. *"Transnet is now focused on trying to survive. In the past, there was support for R&D"* as mentioned by one participant. The findings also indicate that adequate funding is one of the most important ways a division promotes and supports R&D activities, and now there are budgetary constraints which does not only result in minimal R&D work being done currently but also result in highly specialised people resigning.
External to Transnet Participants	Retired Transnet employees say there was financial support from the organisations and government for overall Transnet R&D projects. The programs that were in place then allowed engineers the freedom to come up with ideas and initiate and discuss opportunities with OEMs. According to them, in the past, the organisation put in considerable effort into promoting R&D activities through availing funds and allowing partnerships with organisations like the CSIR and industry leaders, which helped to push all the smart ideas to prototype.

The participants were asked *How does the division collaborate with external stakeholders, such as customers, suppliers, and partners, to foster the development of new or significantly improved technologies?*

The findings show that TE and TFR had partnerships, and relevant agreements with their customers, suppliers, partners, and external stakeholders such as the CSIR, the University of Pretoria, mining companies, Eskom etc., which allowed parties to work together to foster the development of new or significantly improved technologies. TE participants gave the development of the LCMS for the TAL locomotive as one of the examples of a fruitful collaboration with the CSIR.TFR participants mentioned the On-the-Fly project and locomotive onboard monitoring technology as examples of when a partnership was done with one of their suppliers to develop significantly improved technology. This collaboration entails engineers and technicians being intensely

involved from the design phase up to the final testing of the prototype. Participants highlight the importance of their involvement in these collaborations because as repeatedly mentioned by most participants, *"no one knows the South African railway environment as we do"*. Retired participants also share the same insights, since they were also involved in these collaborations.

To establish the effectiveness of this collaboration, the participants were asked this follow-up question: *What impact does this collaboration have on the organisation's ability to effectively develop new or significantly improved products?* The key findings are summarised in table 7 below.

Table 7:Summary of participants' responses on the impact of external collaboration to effectively develop new or significantly improved products.

TE Participants	TFR Participants
• Alleviates IP-related issues • Skills transfer. Helps to learn from industry experts and experience from others external to the company. • Fast tracks execution of some of the projects. • Robust technical support, and reliable adherence to local and international railway standards. • Reduces the financial risk in terms of investigating since all parties sponsor the project. • Procurement becomes quicker.	• Helps with benchmarking. • Gives more insight and exposure to the advanced technology used worldwide. • Helps with skills transfer. • Helps with finding optimal solutions to operational challenges. • External parties have more specialised equipment, which helps to fast-track the development of significantly improved products. • Improves customer satisfaction

Overall findings demonstrate that the collaborations positively contribute to the organisation's ability to effectively develop and introduce significantly improved products.

Now, has Transnet (TE/TFR) developed and introduced any new inventions to the railway market? The common answers were "NO", "No, not for now", and "Not to the

market, but internally yes". There has been difficulty to commercialise. We have products that are completed and used internally, e.g. TAL locomotive, however, they are not industrialised as mentioned by TE participant. According to the participant's view, the challenge to commercialise is mainly due to the lack of appetite internally from TFR to adopt and use products developed internally by TE, so making it difficult to introduce to the market. Ex-employees also answered No, however, one participant mentioned "Suppliers/OEM take the knowledge and experience learned in South Africa and use it to develop novel products which they eventually sell as their own overseas to other customers without acknowledging Transnet." This finding implies that there is indigenous knowledge that is not recognised and protected in the organisation.

4.4.4. Evaluating the existence of core foundations: Policy, Finance, and Governance:

The last section of the interview focused on finding out whether the core foundations required for technological catch-up are available in Transnet. Even though some of these foundations emerged while answering the previous section, it was important that the following questions are asked so that a thorough evaluation can be done. The first question was: *What policies and procedures does your division have in place to support technological advancement, and how effective are these policies in fostering technological development/advancement within your division?*

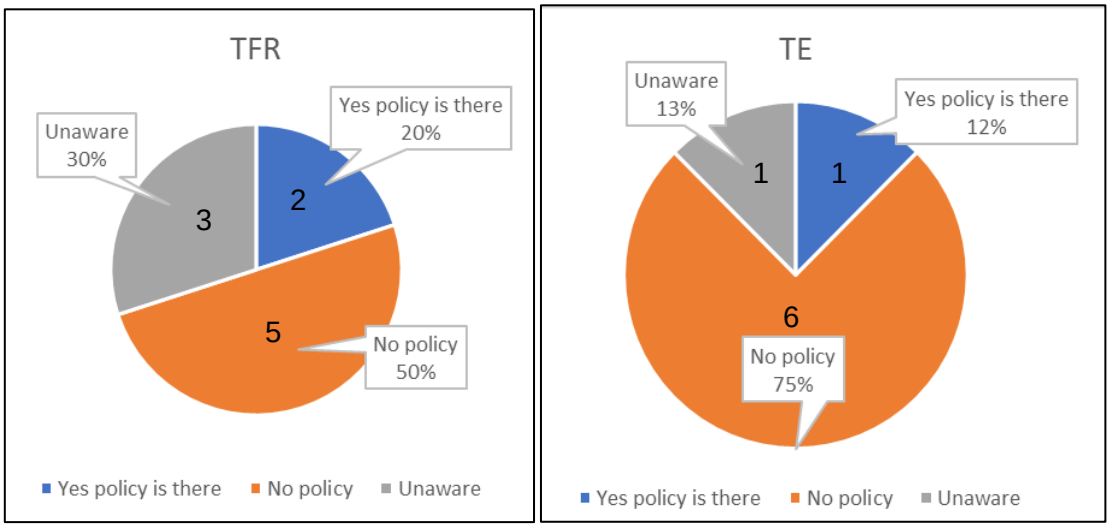


Figure 6: Participants' response on policy and procedures that support technological advancement.

The majority of the participant says there is no policy to support technological advancement in their respective divisions. As one TE participant said, *"Currently, there*

is not much interest in driving technological advancement and pushing novel products." The findings indicate that there is no patent policy and no innovation policy. TE participant mentioned that the lack of patent policy poses a challenge to maintaining the few registered intellectual property instruments for products developed internally. This is because annually, a license fee must be paid, and this is difficult since the products are industrialised and generating revenue. A TFR chief engineer mentioned "I am starting one", with respect to the fact that he is currently working on an innovation policy for the TFR technology management department. Most participants stated that the existing procurement policy does not support technological advancement. The participants who answered "yes" referenced the localisation program and its plans as one of the ways the organisation aims to support technological advancements. However, they mentioned that this programme has not been practically materialised or implemented, as stipulated on paper.

Based on archival data, it is evident that the DST (Department of Science and Technology) implemented the Technology Localisation Programme (TLP) to align with the government's objective of enhancing local production in both public and private procurement. The TLP aims to provide technological support to businesses and industries, enabling them to improve their competitiveness and capabilities in securing contracts related to public procurement. These contracts can be secured either through direct engagement with State Owned Companies (SOCs) or by collaborating with international Original Equipment Manufacturers (OEMs) who have been awarded substantial contracts by SOCs. (Department of Trade and Industry , 2017). The industrial policy action plan done by the DTI stipulates that between the year 2017/18 to 2019/20 the rail recapitalisation programme was meant to focus on leveraging and deepening local industrial capabilities. The government placed a significant emphasis on its priority to reduce import leakage within the rail manufacturing industry, with the aim of subsequently increasing the level of local content. This was to be achieved through the National Industrial Policy Framework and Preferential Procurement Policy Framework Act (Department of Trade and Industry , 2017).

The next question asked was: *Is there adequate financial investment to support capability building and keeping up with new or significantly changed railway technologies? Please elaborate*

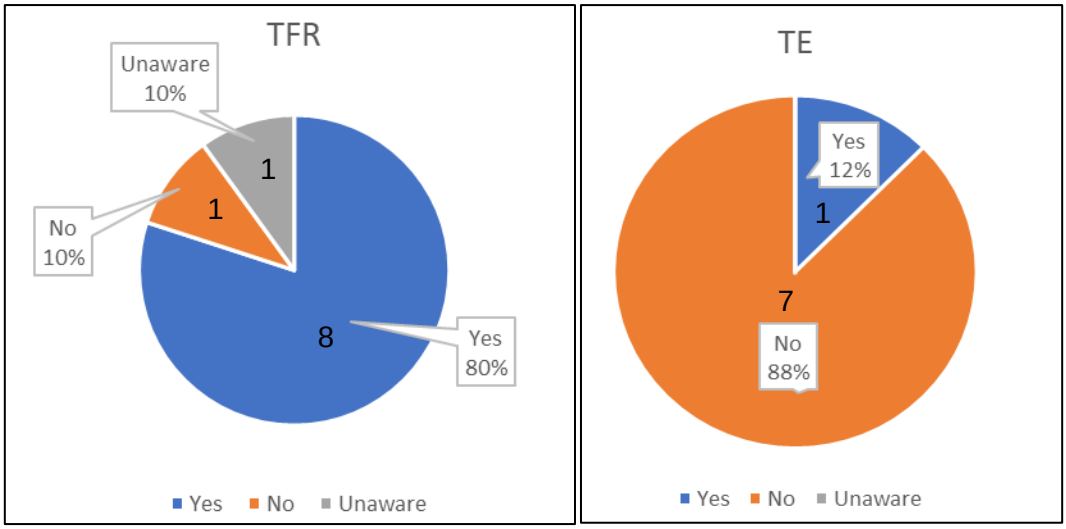


Figure 7: Participants response on adequate financial investment that supports technological advancement and capability building.

As shown in Figure 7 above, 80% of TFR participants (i.e., 8 out 10 participants) say that there is adequate financial investment to support capability building and keeping up with advanced technology. However, the funds are not used properly. One participant mentioned that TFR is the main sponsor for railway conferences and relevant knowledge bodies in the railway sector in SA. TE participants' common answer was "*In the past, there was an adequate financial investment, however, now there are huge budget cuts"*. Therefore, over the years the financial investment to support capability building and keeping up with advanced technology at TE has significantly decreased. TE participant mentioned "Do we have the will? Do we see value? Is R&D part of the current organisation strategy? If all those questions are answered in the positive, then you will avail the required funds." Thus, in this view, the decline in financial investments for R&D at TE over the years, is a sign that the R&D programme has been abandoned. Amid the current decline in performance the organisation is currently facing, the Transnet Group Chief Executive has since announced Transnet's Recovery Plan. Transnet wants to use resources and capital from the private sector, as outlined in the recovery plan, to revitalise its port and rail logistics offerings in the core commodities areas in which it competes (Transnet Investor Relations, 2021; Transnet's Plan To Support The Economic Reconstruction And Recovery Plan, 2021). Therefore, this might impact the organisation's ability and strategic intent to ensure adequate financial investment to support internal capability building and keeping up with new or significantly changed railway technologies.

What is the division's present governance structure, and how does it affect its capacity to promote new or significantly changed railway technologies?

Table 8: Summary of responses from interview participants

Category	Summarised Response from Participants.
Transnet Freight Rail Participants	The common answer was governance structure is for digitalisation and transformation to keep up with the advancement of technology. However, so far, it is not practically executed with noticeable results, especially now with the current challenges that the organisation is facing. Leadership is supporting the desire to transform TFR, but processes and procedures are blocking the effective implementation of strategic intent which promotes new or significantly changed railway technologies. Participants mentioned the difficulty Transnet overall faces as a state-owned company in terms of governance, because politics often interferes with the decision making.
Transnet Engineering Participants	The majority of the TE participants highlighted the existence of a dedicated department solely for R&D in their division as a good initiative for TE to promote the use of new or significantly changed railway technologies. However, with the current challenges the organisation is facing, participants say leadership is no longer putting enough effort into supporting R&D and keeping up with advanced technology. As mentioned by one participant *"Parastatals have the worst governance structures. It's difficult to talk governance without policy"*. Thus, the lack of policy to foster innovations consequently affects the organisation's governance, which as most participants alluded to, makes R&D difficult. Another participant mentioned that on paper the models, frameworks, strategies, etc. are there, but are not practically implemented due to bureaucracy.
External to Transnet Participants	A retired participant said that the governance structure was adequate to foster the organisation's capability to promote new or significantly changed railway technologies. He mentioned that, engineers were encouraged to get involved with R&D activities and have direct

	engagement with suppliers as an opportunity to transfer knowledge. Participant 2 said that the governance structure is currently not suitable for R&D and catching up with advanced technology. This is due to many limitations on the procurement processes, that usually hinders agile development of a product from ideation stage to final prototype stage. So, many ideas do not get to the execution and industrialisation stages. “In the past people were brave enough to bend the rules to get R&D going” the participant added.

It is critical to note that Transnet is a state-owned company in South Africa, thus it is governed through a combination of legal frameworks, regulations, and oversight mechanisms by the Department of Public Enterprises. The primary legislation that governs state-owned companies is the Public Finance Management Act (PFMA) of 1999. The PFMA sets out the requirements for financial management and accountability of public entities, including state-owned companies (Wang et al, 2022). Thus, Transnet’s governance capability to promote new or significantly changed railway technologies is directly influenced by the government.

4.5. SUMMARY OF FINDINGS PRESENTATION

Chapter 4 presents the key findings of the research study on technological catch-up and railway innovations in South Africa’s railway industry, focusing on Transnet as a case study. The chapter begins with an overview of the research objectives and provides a comprehensive summary of the gathered information, analysis, and interpretation. The research design used is explained, emphasising the qualitative and exploratory nature of the study.

The background profile of the participants is provided, highlighting that a total of eight participants from Transnet Engineering and ten participants from Transnet Freight Rail were interviewed. To ensure the validity and dependability of the conclusions, three additional participants external to Transnet were included, and various data sources such as documentation, archival data, and participant observations were used to supplement the interview data. The presentation of findings is structured according to

the research questions and objectives outlined in Chapter 1 and guided by the developed conceptual framework in Chapter 2. The key findings for TFR and TE are graphically summarised in figure 8 and figure 9 respectively. Overall, the findings shed light on the current state of technological progress at Transnet specifically focusing on its key divisions TE and TFR. As shown below, TFR and TE are in the duplicative imitation stage of the secondary innovation continuum. The data presented here also provides insights into the dynamics and different challenges faced by the organisation in its efforts to catch up with the advanced railway-specific technologies which will be briefly discussed in the next chapter.

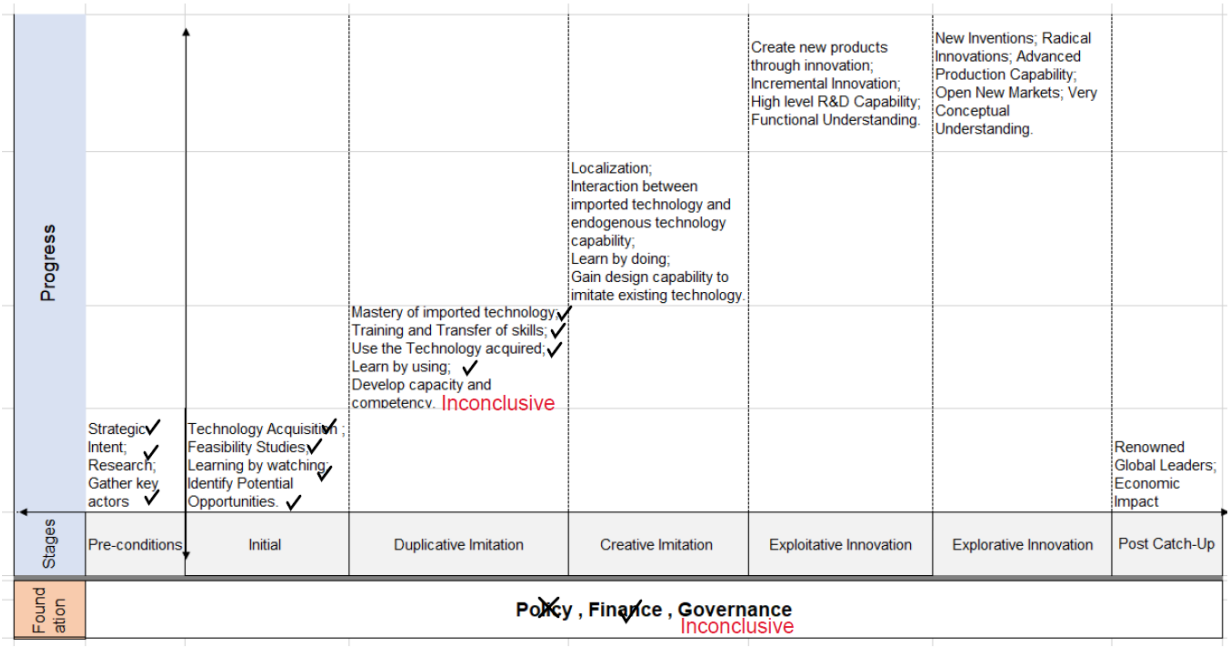


Figure 8: Summary of findings for TFR

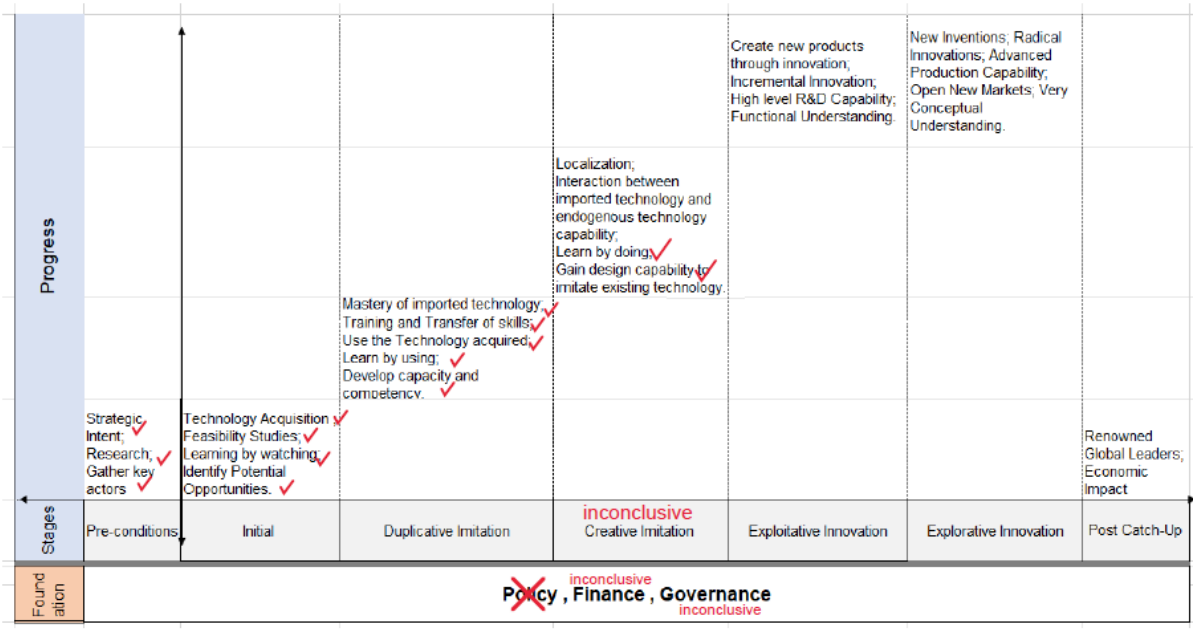


Figure 9: Summary of findings for TE

5. CHAPTER FIVE: ANALYSIS AND DISCUSSION OF THE RESEARCH FINDINGS

5.1. INTRODUCTION

Chapter 5 delves into the analysis and discussion of the research findings obtained from the research study. This chapter aims to provide a broad understanding of the data collected and present insightful interpretations in light of the existing literature that contribute to the overall objectives of this research. The research findings were obtained through a carefully designed research methodology, which included data collection techniques such as interviews, archival data, and other relevant documentation. The collected data was then organised, analysed, and synthesised to draw meaningful conclusions.

To carefully explore the technological catch-up phenomena and impact of railway innovations at Transnet, the interview questions were tailored to focus on evaluating the technological capability, technological level, and the existence of the core foundations required for catching up. At a high level, Transnet overall has progressed when it comes to adopting railway-specific technologies and innovations that are currently in use, albeit still relatively behind the industry forerunners. This is due to several challenges the organisation is experiencing which are further discussed in this chapter. This chapter also deliberates on the research findings in the context of the relevant literature and underscores the findings that contribute to the body of knowledge.

5.2. BACKGROUND

The conceptual framework guiding this study is based on the secondary innovation model for catching up by Wu et al., (2009) and the sectoral systems framework by Lee and Malerba (2017). The secondary innovation model posits that latecomer firms can overcome the disadvantages of being behind in technological advancements by leveraging existing knowledge and capabilities, adapting and improving upon technological innovations developed by global leaders, and establishing strategic partnerships to acquire necessary resources and expertise. Thus, secondary innovation is a more suitable catch-up model for the South African railway industry because this industry still heavily relies on foreign imported technology (Wu et al.,

2009). Moreover, this model entails a lot of learning and understanding through collaborations and interplay between these foreign technology and local technological environment (Wu et al.,2009). The sectoral systems framework plays a critical role in ensuring efficient and effective interrelations and interactions between key actors in the railway sector. For example, the transfer of critical skills and knowledge from developed countries is not solely dependent on Transnet as an organisation, but it also relies on how other key actors in the sector (e.g., government, local suppliers, academic institutions, etc.) leverage on existing resources, international networks, foreign direct investments, and trade relationships (Malerba, 2002; Malerba , 2005; Malerba and Lee, 2017).

Findings demonstrate that Transnet has made considerable effort to keep up with railway technology. The majority of its current rolling stock is made up of foreign-developed technology, which consists of advanced technologies that have significantly improved the operation of the railway business. During the technology acquisition process which was driven by the MDS strategy way back in 2012, there were agreements in place between the supplier and the organisation to transfer skills and equip engineers and technicians with relevant knowledge to be able to operate and maintain the technology. There was little to no emphasis on building internal technological capability to enable mastering foreign technology to the level of being able to independently create new innovative technology to suit domestic requirements where required. Therefore, this leaves Transnet stuck at the duplicative imitation stage of catch-up. TE is relatively more advanced than TFR in terms of building technological capability. They are involved in in-depth technical research, reverse engineering and were more involved in R&D activities. Hence, they have more success stories of technologies they managed to develop from ideation to prototype testing. These success stories were made possible by collaborations with external stakeholders and came with tangible benefits. No novel technology has been introduced to the railway market so far by Transnet. Most developments materialised internally as upgrades or innovations which helped solve TFR's operational challenges. Findings indicate that the strategic intent for the TFR division is not set for building technological capability to allow for the R&D of products that can be industrialised. Transnet as an organisation aims to achieve this through TE. TFR's mandate is the development of technical

specifications detailing all SA railway business environment requirements. TFR then uses these specifications to go on an open tender to find external suppliers to produce their desired asset/technology which will ensure the smooth running of the trains. Finding local suppliers has been a priority to align with the government's goal of economic development. However, the findings show that this has not effectively materialised because Transnet still heavily relies on international suppliers for their spare parts. Now, why is Transnet stuck at the duplicative imitation stage? The upcoming subsections elaborate this, through an in-depth analysis of the findings, putting an emphasis on answering the study's research questions.

5.3. RESEARCH QUESTION: WHAT IS THE CURRENT STATE OF TECHNOLOGICAL DEVELOPMENT AT TRANSNET'S RAILWAY OPERATIONS?

To evaluate at which state is Transnet in the catching-up process, each stage as shown in this study's conceptual framework (see Figure 5) is discussed below.

5.3.1 Stage 0: Preconditions

The strategic intent to modernise and expand Transnet's locomotive fleet to improve railway operations and meet the growing demand for freight transportation has been driven by the MDS since 2012. Tied to this strategy was the development of Transnet employees because at that time, TFR had an aging workforce that consisted of predominantly old white males as engineers and technicians (The "Technology" Of People, 2015). Around 2015 the modernisation of the general freight fleet which was characterised by several new technological features with benefits and implications for rail operations was acquired. This was achieved through extensive research on understanding the history of the business, its goals, and keeping up with prevailing technology in the railway industry. The key agents, government (DTI, DPE etc.), and other stakeholders were present in this process. What seems to be lacking from this strategic direction taken by Transnet since 2012, is the focus on building technological capabilities. Remarkable technological capability has been found by many scholars to be an enabler for a rapid technological catch-up (Clark and Juma, 2002; Lee, 2005; Wu et al., 2009; Malerba and Lee., 2021). As alluded to by Wong (1999) latecomer firms' need to consciously select their strategic direction, prioritising the development of technological capabilities. This may involve improving an existing core competency

or striving to establish new core competencies. For instance, consider China's commitment to fostering ‘high-risk’ manufacturing sectors and cultivating its own innovation capabilities in ‘high-end’ industries in the initial stages of developing their high speed rail industry (Sun, 2015).

Malerba and Lee (2021) postulate that effective national and sectoral systems are required to enhance learning and capabilities building for latecomer firms (Clark and Juma, 2002; Malerba, 2002; Malerba, 2005). Moreover, this process is enabled by a fully developed innovation system and public policies that actively foster innovation, learning, and capability building (amongst others) (Malerba and Lee, 2021). Intervention policies, a fully developed innovation system, and an effective rail sectoral system are key pre-conditions for a rapid technological catch-up and these are missing in this case of Transnet. The study’s findings indicate that there is no policy intervention programme dedicated to promoting R&D, patenting, and building technological capability. Moreover, the absence of a National Rail Policy for over a century demonstrates that there was a lack of national determination to keep pace with other progressive nations, thus making it difficult for technological development and catching up (National Rail Policy - Green Paper, 2015). Existing policies and legal frameworks such as PFMA, PPPFA, and NIP indirectly incapacitates technological catching up. Thus, one can deduce that the preconditions for catching up partially exist. As alluded by Lee and Malerba (2017) active government policies and regulations are essential for catching up of developing countries in several sectors. South Korea is an example of a country that has effectively encouraged technology advancement and innovation through active public policy. The global success of companies like Samsung and Hyundai can be attributed to the intervention of the South Korean government through the establishment of R&D programs that support learning and increase the capabilities of domestic firms through various means such as subsidies, tax reduction, public standards, export support etc (Lee and Park, 2006).

Conversely, Transnet owns the largest railway network in Africa and is responsible for the transportation of the world’s most critical and profitable metals and minerals (Wanjiku-Wangai et al., 2020; Transnet Investor Relations, 2021). This is a precondition that the Global South has, unlike other industrialised countries, which can

be used as an opportunity to make catching up simpler to accomplish. It is just not effectively tapped into as yet.

5.3.2 Stage 1: Initial

Transnet's new locomotive fleet was acquired from four different OEMs that are international pioneers. Since this was relatively new, world-class technology, agreements were in place to enhance local supplier development and provision for technical and engineering training, as well as the assembly of locomotives to be done locally so that engineers and technicians can learn by watching (The "Technology" Of People, 2015). Findings show that requisite training was provided both abroad and locally and it involved the OEM, Transnet School of Rail, and TE School of Engineering. In addition, the organisation had collaborations with the CSIR, local suppliers, and academic institutions to facilitate knowledge exchange, help with extensive research, and identification of potential opportunities. These interactions and interrelations between the listed key actors helped engineers and technicians to gain an understanding of the operation of the technology. Moreover, this direct involvement helped technical staff to rapidly diagnose faults and rectify them, as well as contribute ideas on how to improve the technology to suit domestic railway requirements. At that time, employees were also granted funding to further their studies at universities, where their master's research contributed to foreign knowledge and feasibility studies could effectively be done under the guidance of academic experts. A considerable effort was put in place in developing programmes that enabled the diffusion of new technology and learning.

5.3.3 Stage 2: Duplicative Imitation

The findings show that basic assimilation has been achieved for both TFR and TE. The majority have mastered the operation of the technology through descriptive manuals, and direct exposure to the manufacturing and testing of the new locomotives. The capability to operate and adapt foreign technology was formed over the years of working with the technology and improved functional performance was achieved. At this stage the organisation is 'learning by using' and engineers and technicians were involved in a low level of design which is mainly sparked by common failures encountered while using the technology.

TAL locomotive is a by-product of basic assimilation because TE did the assembly production of final goods using mostly imported parts, then internally developed other products like the LCMS. Therefore, TE has gradually learned to design the existing products with some modifications, which is the path followed by most latecomer firms (Lee, 2005). During this period of modernising the fleet, the organisations' priorities were on the acquisition and diffusion of these foreign technologies over internal technological capability development. As alluded to by Maleki et al. (2019), this leads latecomer firms to underinvest in capability building and upgrading their already existing competencies. The difficulty with adopting this approach lies in the fact that, if the foreign technology fails to meet expectations, it would negatively impact the business since there are no available spare parts or convenient alternatives to sustain operations. This predicament is evident in the case of 'long-standing' locomotives within Transnet, where contractual problems with China's CRRC have prevented repairs, leading to a shortage of spare parts that cannot be produced internally. (Ayanda Shezi, Transnet's Spokesperson, 2022).

5.3.4 Stage 3 Onwards: Creative Imitation, Exploitative and Explorative Innovation

Almost 10 years later, when the new technology was introduced, the organisation's performance significantly dropped, and this led to major knowledge networks, key partnerships, and collaborations to halt. This, consequently, drastically impacted the organisation's absorptive capability and technological capability building, which was slowly starting to develop. According to the SSI perspective, this is detrimental to the catching-up process for latecomer firms, especially in developing countries (Maleki et al., 2019; Malerba, 2005). This is because the catch-up process is a long-term evolutionary process and this means that knowledge should be continuously transmitted, absorbed, and generated (Malerba and Lee, 2021; Lee, 2005; Wu et al., 2009). Hence, one cannot deduce that Transnet has fully developed its technological capabilities and competency because the findings show that R&D, new product development, and innovation activities are currently stagnant. Moreover, the organisation has since lost its critical skills, and highly specialised experts through retirement and/or resignation due to a lack of skills retention programs. Thus, the current knowledge base is questionable. Hence making it difficult to evaluate Transnet's 'learning by doing' and the level of 'structural understanding'. Findings

show that TE has made considerable effort in gaining design capability to imitate the existing technology. Granted all resources, TE may improve foreign technology and over the years eventually get to develop novel products. However, challenges that hinder technological capability development remain, and there is still heavy reliance on foreign technology. Hence It is difficult to tick core elements in the creative imitation, exploitative, and explorative stages of the secondary innovation model because the findings are inconclusive. The TAL locomotive, port hauler, LCMS, 3D additive manufacturing, etc are promising examples of developments underway at TE that in the future could progress Transnet to the next stages, given full attention and that all required support is available.

5.4. RESEARCH QUESTION: WHAT ARE THE FACTORS INFLUENCING THE TECHNOLOGICAL CATCH-UP PROCESS AND INNOVATION IN THE SOUTH AFRICAN RAILWAY INDUSTRY?

The first factor pertains to acquiring fundamental technological competence and capability, which is closely tied to the development of human capital. Findings indicate that Transnet's intended use of knowledge acquisitions is mainly for operating and maintaining the technology to avoid any adverse impact on the business, should the technology fail. This is counter-progressive to the technology catch-up progress. A company lacking the necessary technical expertise is unlikely to achieve consistent progress in technological advancements (Salisu, 2019; Lee, 2005; Clark and Juma, 2002). The lack of key skills retention interventions worsens this situation. The insufficient focus on acquiring and enhancing technological capabilities can be attributed to various factors, including a lack of clear strategic direction, absence of intervention policies, inadequate investment, and lack of effective sectoral system (amongst others). Transnet has, through TE urged R&D activities, utilising knowledge transfer from specialised R&D firms (e.g. CSIR), academic institutions, and patrnerships with suppliers. However, due to the financial constraints the business is currently facing this access to external knowledge has been affected.

As a state-owned company, policy, governance, and financial investments are guided by the government. The latter introduces a hindrance in adapting the core foundations to foster innovations and keeping up with advanced technologies. This is another factor that acts as a barrier to successful catching up. Moreover, the lack of a fully

developed rail innovation system poses a challenge to technological development within Transnet and the railway sector overall.

5.5. RESEARCH QUESTION: WHAT ARE THE PATHWAYS TO STRENGHTEN TECHNOLOGY CATCH-UP PROCESS IN THE RAILWAY INDUSTRY IN SA?

As a key enabler of the South African economy, the findings show that business recovery should be a top priority for Transnet's current situation. This recovery should include the use of technological innovations as an enabler. Thus, technological catch-up becomes key to the recovery and growth of the business. New interventions are required to strengthen progress in technology catching up and keeping up with rail technological advancements. Findings indicate, a strong focus on technology capability building, acquisition of specialised skills and retaining them, thereafter, encouraging learning and innovation, partnership with key actors (e.g., Universities, R&D firms, suppliers, government, etc), policy interventions and strengthening in-house R&D capacity as essential interventions required to boost the technological development and enable the catch-up process. As much as these new interventions rely on external sources, there's a lot that Transnet can do internally to foster technological innovations and development. One key intervention is changing the traditional organisational structure to enable a more flexible, collaborative, and agile structure aimed to make the organisation be innovative. Moreover, a change in the old traditional methods and procedures will empower employees at all levels to contribute their ideas and take ownership of innovation initiatives. This will also help deal with the issue of losing critical skills.

5.6. SUMMARY OF THE DISCUSSION

This chapter focuses on the analysis and discussion of the research findings related to the technological catch-up phenomena and the impact of railway innovations at Transnet. The background section of the chapter highlights the conceptual framework guiding the study, which includes the secondary innovation model for catching up and the sectoral systems framework. The research findings are then analysed based on the study's research questions. Overall, the findings reveal that Transnet has made progress in adopting prevailing railway-specific technologies and innovations, although it still lags behind industry leaders. The organisation has focused on acquiring foreign technology and diffusion of this technology, but little emphasis has

been placed on building internal technological capabilities and leveraging existing competencies. The findings also indicate that Transnet's TE division is more advanced in its efforts to build technological capability compared to Transnet Freight Rail (TFR). This study evaluated Transnet's progress in the catching-up process using the developed conceptual framework with different stages. The findings indicate that Transnet is in the duplicative imitation stage, where it has mastered the operation of foreign technology and made some modifications. However, the organisation faces challenges in knowledge transformation, upgrading competencies, and maintaining knowledge networks, which are crucial for successful catch-up. Intervention policy as well as the support of an effective sectoral system can significantly improve building technology capability and foster innovation.

6. CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1. INTRODUCTION

Rail has historically served as the fundamental pillar of the logistics and transportation value chain in South Africa, and its significance is expected to intensify in the post-COVID-19 era. Thus, it is crucial to always have a best performing railway system for the benefit of the economy. This research contends that embracing innovation and staying abreast of the latest technological advancements can profoundly enhance the performance of the rail business. Hence this research examined the technological catch-up phenomenon and the impact of railway innovations using Transnet as a case study. Based on the conceptual framework developed for this study, which encompasses the secondary innovation model for catching up and the sectoral systems framework, Transnet's progress in the catching-up process was evaluated. The findings suggest that Transnet currently resides in the duplicative imitation stage and is struggling to move beyond this stage. This chapter will delve into the major findings of this research, which shed light on the factors contributing to Transnet's stagnation at its current stage.

As alluded to by several scholars, technology has been identified as a key ingredient of growth and economic transformation, thus it’s imperative for latecomer firms to bridge the technological divide by catching up. Recommendation to help improve the current challenges faced by Transnet are made. The technological catch-up process is a dynamic, complex, and continuous process which is not deterministic, thus an

extensive exploration into the path taken by Transnet helped contribute to the literature.

6.2. MAJOR FINDINGS

The major findings of this study are as follows:

The current state of technological development at Transnet

- The South African railway system's strength is its largest, well-connected rail network. Transnet has made considerable effort to keep up with prevailing railway technology such as ECPB, RDP, and WDP and has since deployed modern locomotives which have significantly improved rail operations.
- Transnet still heavily relies on foreign imported technology, even though they have mastered the operation of this technology, they still have a long way to go to get to the 'creative imitation' stage of the secondary innovation process.

Factors influencing the technological catch-up process and innovation in the South African railway industry.

- Transnet's primary focus is not directed toward building technological capabilities and enhancing innovation capacity.
- The organisation has limited access to knowledge and relevant knowledge networks which badly affects their current knowledge base.
- There is a lack of innovation-related policies within Transnet to promote and foster innovation activities and keep up with advanced technology, thereby improving the business. Additionally, there is a scarcity of public policy interventions in this regard.
- Currently there is insufficient investment in attracting, leveraging, and retaining critical skills in the organisation.
- Transnet's governance is heavily influenced by government entities which pose challenges for effective decision-making.

Opportunities to strengthen technology catch-up process in the railway industry in SA

- The organisation is not leveraging on its geographical position to form partnerships (local and international) that will enhance the technological catching-up process.
- The presence of Transnet Academy and other training centres, along with collaborative training programs with South African universities, can significantly contribute to the development of technological capabilities and the promotion of innovation.

6.3. KEY CONCLUSIONS OF THE STUDY

The research indicates that Transnet's current stage of technological development can be characterised as being in the duplicative imitation stage of the secondary innovation process. While the organisation has made progress in adopting foreign technology and making modifications, there are challenges in areas such as knowledge transformation, competency upgrading, and maintaining knowledge networks. Therefore, Transnet has not yet progressed beyond the duplicative imitation stage, raising questions about its current path of catching up.

Factors influencing the technological catch-up process and innovation in the South African railway industry are multifaceted. The research findings highlight several critical factors. Transnet's focus on building technological capabilities and enhancing innovation capacity is limited, with little emphasis placed on internal technological capabilities and leveraging existing competencies. Access to knowledge and relevant knowledge networks is also restricted, hindering Transnet's learning and capability building which is key to the technological catch-up process. The absence of innovation-related policies, public policy interventions, and underinvestment in critical skills further impede the catch-up process. Additionally, governance is heavily influenced by government entities, and the lack of motivation to learn acts as additional barrier. Transnet also fails to fully leverage its geographical position (i.e., 'resource-rich' country, and largest rail network in Africa) to form partnerships that could enhance the catch-up process.

In terms of pathways to strengthen the catch-up process, it is crucial for Transnet to shift its focus toward building internal technological capabilities and enhancing

innovation capacity. This entails investing in research and development, fostering a culture of innovation, and attracting and retaining critical skills within the organisation. As a developing country characterised by knowledge deficiencies; access to knowledge and knowledge networks should be improved through strategic partnerships with industry leaders, research institutions, and technology providers. Additionally, the development of innovation-related policies, along with relevant public policy interventions, can provide a conducive environment for technological catch-up and innovation. It is also essential to address governance challenges to enable effective decision-making and establish a supportive national and sectoral system to facilitate technological catch-up. Transnet has the potential to advance its technological catch-up process and contribute to the growth and competitiveness of the South African railway industry.

6.4. RECOMMENDATIONS FOR BUSINESS / STAKEHOLDERS

6.4.1. Enhancing Internal Technological Capabilities: Transnet should prioritise the development of its internal technological capabilities by investing in research and development, fostering a culture of innovation, and nurturing technical expertise within the organisation. This will enable Transnet to reduce its reliance on foreign technology and increase its ability to create and adapt innovations.

6.4.2. Strengthening Knowledge Transformation: Transnet needs to establish effective and continuous mechanisms for knowledge transfer and transformation. This can be achieved through knowledge-sharing platforms, collaborative partnerships with global leading industry players, and the creation of specialised training programs. By actively disseminating knowledge and upgrading competencies, Transnet can bridge the gap between duplicative imitation and exploitative innovation.

6.4.3. Building Strategic Knowledge Networks: To accelerate its catching-up process, Transnet should prioritise the establishment of strategic knowledge networks. These networks should include collaborations with universities, research institutions, and other industry stakeholders, both domestically and

internationally. By actively engaging in knowledge networks, Transnet can leverage external expertise, upgrade internal competencies, access cutting-edge research, and foster a culture of continuous learning and improvement.

6.4.4. Allocating Resources for Technological Catch-up: Transnet should allocate sufficient resources, including financial, human, and infrastructural, to support its technological catch-up endeavours. Adequate funding should be provided for research and development initiatives, skills development programs, and the acquisition of state-of-the-art technologies.

6.4.5. Government Interventions through Newly Introduced National Rail Policy: The newly introduced National Rail Policy in South Africa presents an opportunity for the government to support the railway industry in its technological catch-up efforts and promote innovation to maintain its competitive advantage. The government can allocate resources and funding specifically towards research and development initiatives in the railway sector. This can include investments in advanced technologies, infrastructure upgrades, and the establishment of research centres or innovation hubs dedicated to rail technology. By providing financial support and incentives, the government can encourage private sector participation and collaboration in technological development projects, driving innovation and progress.

The government can also (through policy interventions) facilitate knowledge sharing and collaboration by promoting partnerships between industry players, research institutions, and technology providers. Additionally, the government can establish networks and clusters focused on rail technology, bringing together key stakeholders to share best practices, lessons learned, and cutting-edge research.

6.5. SUGGESTIONS FOR FUTURE RESEARCH

While this study has provided valuable insights into the technological catch-up process and innovation in the South African railway industry, there are several avenues for future research that can further enrich our understanding of this field. Some suggestions for future research include:

6.5.1. Comparative analysis: Conduct a comparative study of the technological catch-up processes and innovation strategies in the railway industries of different countries or regions. However, it should be noted that this study focuses specifically on the South African railway sector using Transnet as a case study and does not intend to investigate the national innovation system or catch-up at a national level.

6.5.2. Organisational performance: Investigate the factors contributing to poor performance in railway organisations, taking into consideration the influence of technological advancement. Although this study does not imply that poor performance at Transnet is solely due to a lack of technological advancement, future research can explore the relationship between performance and technological catch-up in the railway industry. Moreover, the competition between Transnet and industry leaders in developed countries can be examined to gain a comprehensive understanding of the competitive landscape.

6.5.3. Passenger rail operators: Conduct a separate study that specifically focuses on passenger rail operators, as this study primarily examines the case of Transnet, a freight railway company. The technological catch-up and innovation processes may differ in passenger rail, warranting a distinct exploration of this sector.

6.5.4. Knowledge base and market conditions: Investigate the knowledge base, variety, and complexity of learning within the railway industry, considering their impact on technological catch-up and innovation. Furthermore, explore the market conditions and external factors influencing the innovation dynamics in the industry. However, it should be noted that this study did not intend to extensively investigate these aspects.

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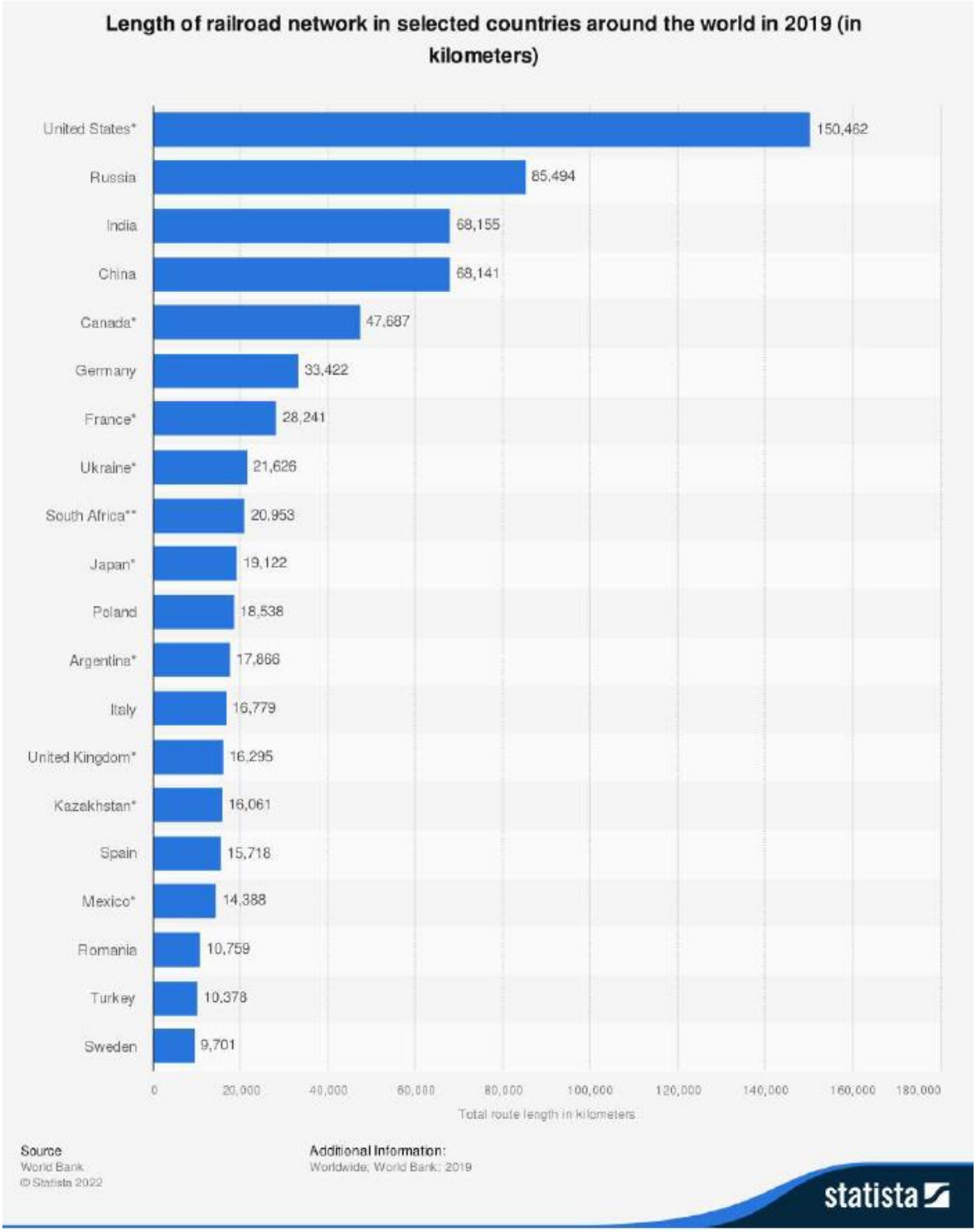
APPENDICES

APPENDIX A



SOURCE: Statista: https://www.statista.com/statistics/262743/20-countries-with-the-highest-quality-of-railroad-infrastructure/

APPENDIX B

SEMI-STRUCTURED INTERVIEW QUESTIONS:

A. <u>Understanding the participant's involvement in railway innovations and technology:</u>

1. Please tell me about your role and responsibilities?
2. What activities relating to new or improved technologies have you been involved in?
3. Did these novel technologies improve the rail business? If so, how?

B. <u>Evaluating the technology level, innovations, and knowledge base</u>

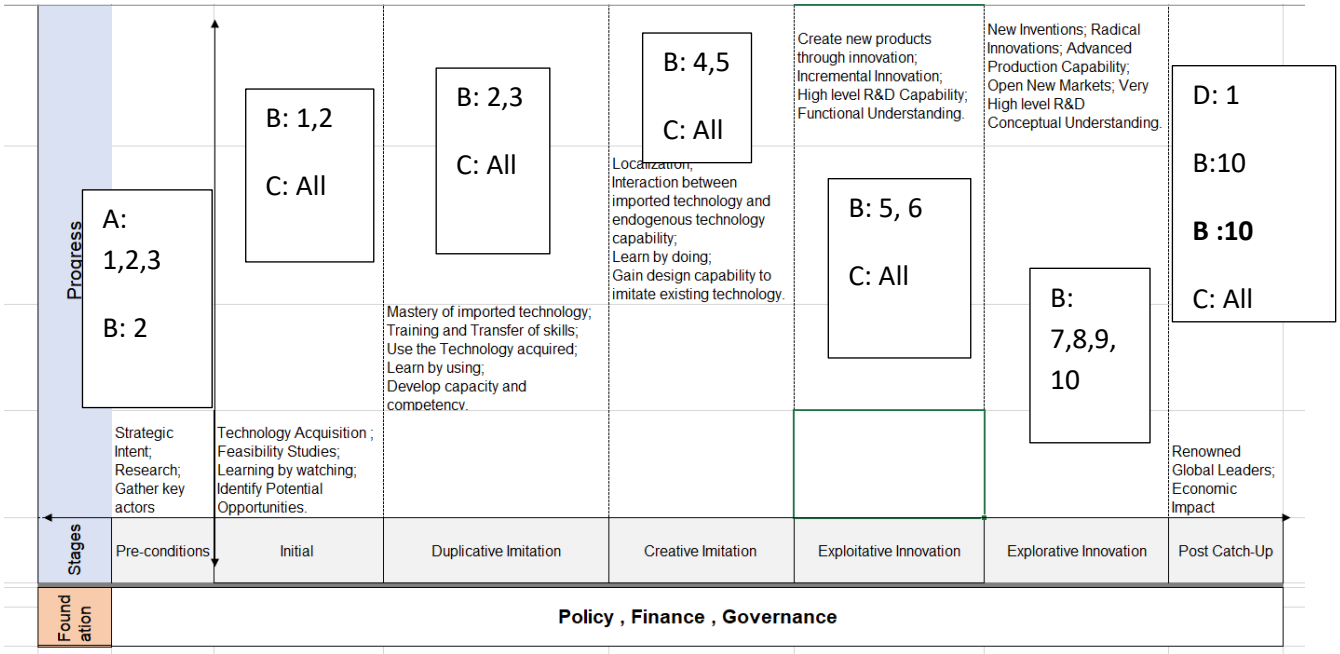
1. Are railway-specific technologies or technological components used in Transnet typically procured locally or internationally? Could you roughly speak to the proportion of each?
2. What strategies and /or initiatives are in place to learn and upskill engineers and technicians from the imported technology to build capabilities?
3. Have you mastered the operation of this technology? Please elaborate
4. Have you mastered the technology to the level of being able to independently imitate it (granted all required resources)? Please elaborate
5. Have you developed the capability to improve imported technology to suit domestic requirements? Please elaborate
6. Could you please provide examples of any internally developed technologies that your division has produced? or plans to produce?
7. Can you provide examples of successful R&D projects that the division has undertaken in the past? How does your division promote and support R&D activities?
8. How does the division collaborate with external stakeholders, such as customers, suppliers, and partners, to foster the development of new or significantly improved technologies?
9. What impact does this collaboration have on the organisation's ability to effectively develop new or significantly improved products?
10. Please provide examples (if any) of new inventions your division has introduced to the market?

C. <u>Evaluating the existence of core foundations: Policy, Finance and Governance:</u>

1. What policies and procedures does your division have in place to support technological advancement, and how effective are these policies in fostering technological development/advancement within your division?
2. Is there adequate financial investment to support capability building and keeping up with new or significantly changed railway technologies? Please elaborate
3. What is the division's present governance structure, and how does it affect its capacity to promote new or significantly changed railway technologies?

D. <u>General</u>

1. What can be done to improve your division's performance and maintain its competitive advantage?
2. Do you have any relevant documents you can share with me, or refer me to other professionals who can assist with my research? If so, do please share.



Graduate School of Business Administration
University of the Witwatersrand, Johannesburg

Wits Business School Ethics Committee
Constituted under the University Human Research Ethics Committee (Non-Medical)

Ethics Clearance Certificate

Ethics protocol number: WBS/IS463610/538
This certificate is only valid with a legitimate ethics protocol number and signed by the Researcher (below)

This certificate is only valid if accompanied by formal permission from the relevant stakeholder(s).

Project title	Technological catch-up and railway innovation at Transnet in South Africa
Investigator / Researcher	Mrs Itumeleng Mtebele
Nature of Project	MM (Innovation Studies)
Decision of the Committee	Approved, provided stakeholders and participants are guaranteed confidentialty.
Issue Date of Certificate	2023-03-10
Expiry date	Date of submission of the project / research report
Chairperson	Dr Pius Oba ☎ +27 11 717 3976 +27 82 733 6587 ✉ pius.oba@wits.ac.za

Declaration by Researcher

One copy must be signed by the Researcher and returned to the Chairperson of the Wits Business School Ethics Committee.

I fully understand the conditions under which I am authorized to carry out the abovementioned research and I guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I undertake to resubmit the protocol to the Committee.

Signature

10 March 2023
Date: