DEVELOPMENT OF A SUSTAINABLE FREIGHT TRANSPORTATION SYSTEM IN THE CENTRAL REGIONS OF SOUTH AFRICA

By

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DECLARATION

I, Boiki Johannes Mokobori, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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ABSTRACT

Freight transportation involves the movement of cargo from various destinations using several transportation modes such as rail, road, maritime and airline to meet the market demands. However, this industry faces issues such as traffic congestion, pollution, uneven freight distribution, and increased freight costs. Having realised the issues of freight transportation, this study aims to develop a sustainable freight transportation system with guidelines for an optimal modal split between the freight rail and road transportation system in the central regions of South Africa. The adopted objectives in this study were to assess the current status quo of freight transportation system by examining the economic and operational efficiency of road and rail to develop a model for balanced freight transportation system in the central regions of South Africa.

A quantitative research method was chosen as the best approach to address these objectives. This quantitative research method was chosen because it entails data collection via survey questionnaires and can emphasise objective measurement via statistical analysis. The data obtained were able to depict the current state and challenges of the freight transportation system in South Africa's central regions. Consequently, the current status quo reveals that freight road is utilised more compared to rail freight due to convenience and reliability, whilst rail freight proves to be operationally more viable due to large carrying capacity. Thus, road freight is operationally efficient as compared to rail freight; however, road freight is used more for the demand aspect of freight movement whereas freight rail is used more for the supply aspect of freight movement. Correlation, significance test, variance inflation factor, and multiple regression analysis were used in inferential statistical analysis to determine the relationship that exists between dependent and independent parameters and to identify the coefficients of influential parameters to be used in modelling. Furthermore, under various future scenarios, an empirical model known as the Binary Logit model was used to determine the modal split between freight road and rail in terms of freight shares and generalised freight costs. Finally, guidelines were developed from the developed and empirical model used in this study to achieve a balanced and optimal freight transportation system by addressing key features such as service reliability, decreased travel distances, cost efficiency, operational efficiency, safe handling of goods, and optimum loading capacity.

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CHAPTER 1: INTRODUCTION AND RESEARCH DESIGN

1.1. Introduction

Freight transportation consists of extremely important activities that take place both in urban and rural areas to enhance the economy. The most common activity is for people occupying these areas, such as the adequate supply at stores as well as the delivery of goods at home. However, sustainable freight transportation ensures a seamless functioning of all the freight and logistics operations with a balanced use of available transportation modes to meet the clients' requirements. The other activity that can be discussed is for firms established within the city limits as it forms a vital link between suppliers and customers. Further, the freight transportation industry is known for employment empowerment because it creates millions of jobs through the movement of these goods using either trucks or trains. However, the most obvious disadvantage of freight is its contribution to congestion and environmental nuisances as vehicles that carry goods move on the same roads and highways used by both private and public vehicles. Additionally, there is also a belief that freight traffic contributes to crime which usually causes numerous citizens to move out of the city limits, as observed in the United Kingdom (Grainic, Ricciardi & Storchi, 2004).

On the contrary, there are considerable opportunities to improve the efficiency of freight transportation globally and even locally, especially in urban areas, but relatively limited chances to shift volumes of longer-haul freight from one mode to another without imposing additional costs on businesses and consumers involved (Brogan *et al.*, 2013). Although there are technologies such as containerisation which can reduce cost, the variation in capacity of each mode of transportation may result in cost implications during unloading and loading of cargo, especially between rail and road. Subsequently, freight transportation is simply defined as the movement of goods from one area to another by using different modes of transportation (Crainic, Perboli, & Rosano, 2019; European Conference of Ministers of Transport, 2001; National Cooperative Freight Research Program [NCRP], 2011). In South Africa, as with other countries, the freight system and its links with sub-regions are a collection of truckload and intermodal rail networks that deliver a range of services with varying performances, depending on the infrastructure and operations, and the specific modal challenges in that area. Nonetheless, the growth of freight traffic has been argued to have surpassed most of the 20-year growth forecasts made by Moving South Africa (MSA), at least 14 years before they were expected, and this has placed massive pressure on infrastructure and operations to deliver acceptable services (Transcom, 2017).

From 1970, road transportation started to replace most of the rail freight carriage as the dominant form of long-distance freight movement in all the South African provinces (Stander & Pienaar, 2002). As the years went by, it began to show the split of freight movement between the road and rail network in most of the central regions, such as the Northern Cape, due to accelerated road infrastructure. During the same time period, it was found that road users contributed more in tax incentives as compared to other modes of transportation and thus subsidised local markets. Additionally, the relative service quality and the extent to which the two modes were able to serve the same markets were important factors in the increased congestion and accidents brought on more by road as compared to rail freight transportation. Concurrently, *Steyn et al* (2012b) revealed that the rand per ton of freight shipped by road is higher than that of rail, due to rail and road competing in markets that favour relatively short distances for rail but long distances for road. Hence, it is essential to take into account that when goods or services are traded, a voluntary exchange occurs between a firm and a consumer, therefore, cost per ton for both road and rail and benefits are involuntarily imposed on and received by others (Mostert & Limbourg, 2016). Also, these costs need to be carefully monitored, otherwise the producers acting within a competitive environment might overproduce because of the understatement of the costs.

Furthermore, since these road freight carriers can transport certain biological items like wood, agricultural products, semi-finished commodities, and most finished goods, they have essentially replaced rail carriage as the predominant mode of long-distance freight transport. It also plays a significant role in the freight industry due to its flexibility as compared to other modes of transportation being able to offer point-to-point service between almost any origin and destination. On the other hand, rail may be dominant in some countries in Eastern Europe and Asia, for instance, because most of the services are available between almost all metropolitan areas. However, the concerning factor in relation to rail transportation is its limitation to fixed routes and the lack of flexibility and accessibility as compared to other available transportation modes. Despite the drawbacks of using rail to convey goods throughout the world, most rail carriers globally are doing so in significant numbers, especially for intermodal freight transportation (Stander & Pienaar, 2002). According to the First State of Logistics Survey for South Africa (2004), road and rail only compete for about 45% of the freight transport market with the remaining

65% resulting from exported and imported freight share by maritime. It further explains that road is the dominant mode of transport in urban areas, whilst rail is almost exclusively responsible for the haulage of export coal and iron ore transportation. Therefore, the competition between the two modes for the conveyance of general freight is restricted to the major transport corridors and rural areas.

Consequently, it is essential to know that the ability to get goods to market at the right time and at reasonable cost is a cornerstone of any economy. Therefore, freight movement is a vital component of economic activity, and an accessible and efficient freight transport system is a basic requirement for economic growth. Thus, if freight transport is not managed properly, it may also result in significant negative impact on the economy in terms of high energy use, Greenhouse Gas (GHG) emissions, congestion, and traffic accidents.

Therefore, this study entails exploring a sustainable freight transportation system in the central regions of South Africa. In other words, the study will explore the most efficient mode(s) of freight transportation system in the central regions of South Africa based on operational and economic efficiency. In this context, the modal split between road and rail transportation for freight movement will be investigated with the purpose of making the freight transport system more cost and operationally efficient and sustainable. The Binary Logit model, which is one of the modal split models found in transportation engineering, will be used to aid in creating the balance between freight road and rail transportation within the central regions of the country by allowing a 70:30 share of freight and utility of the two transportation modes under investigation.

1.2. Problem Statement

Most cities need freight transportation, but this specific category of urban transport is largely ignored even though it provides thousands of jobs and services (NCHRP, 2011). Cities like Bloemfontein and Johannesburg, which are in South Africa's core regions, have high freight demand (as shown in Figures 1.1 and 1.2.). Figure 1.1 displays the annual tons of freight transported by road and rail along the various corridors in South Africa's central regions with the highest being Johannesburg-Durban (14 m/ton/km by rail and 18 m/ton/km by road); Johannesburg-Bloemfontein (7 m/ton/km by rail and 13 m/ton/km by road) and East London-Bloemfontein (16 m/ton/km by rail and 11 m/ton/km by road). The annual average percentage of freight movement within South Africa's central areas is also shown in Figure 1.2, and it indicates a 14/86 split between freight road and rail. However, freight movement faces challenges regarding cost, capacity and transit speed and equipment availability (Rodrigue, 2020). In these regions, there are defects in terms of reliability, degree of certainty, and predictability in travel times due to deteriorated road infrastructure. Further, congestion is often the result of systems near capacity which further increases the travel costs to surrounding regions. Other challenges that are visible in the central regions are authorities having to increase fuel prices by 37.5% between 2020 and 2022, the transport, warehouses and storage sector growing by 7.6% in the first six months of 2022, compared to the same period in 2021 and along with 30% shortage of locomotives and spare parts in rail freight from criminal activities and vandalism (Department of National Treasury [DNT], 2022). Most of these challenges make it difficult for most freight companies to offer sustained freight transportation.

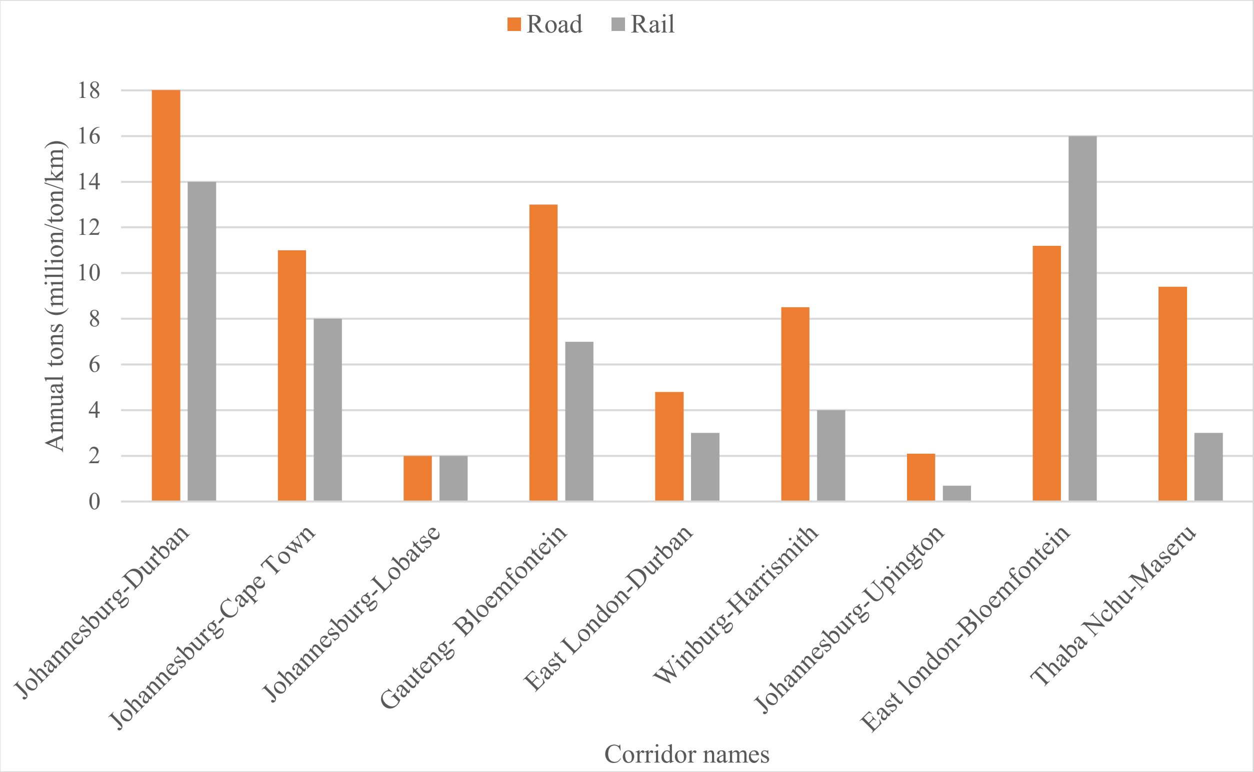


Figure 1.1 Estimated annual tons on road and rail corridors in the central regions of South Africa (Source: NATMAP, 2019).

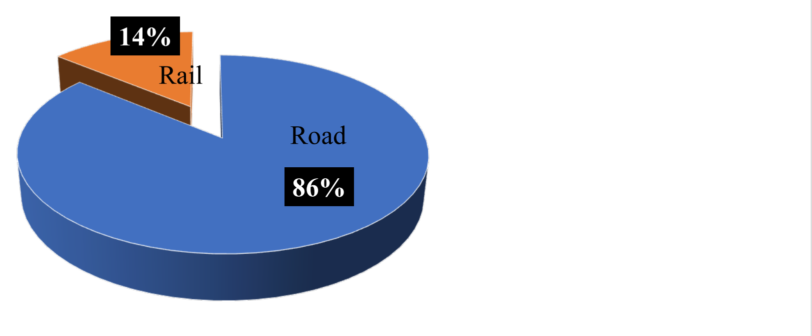


Figure 1.2 Average annual ton percentages for road and rail in the central regions of South Africa (Source: NATMAP, 2019).

Primarily price, capacity, transit speed and equipment availability are the most prominent underlying challenges that have been experienced by investors from the central regions of this country. Despite infrastructural barriers, congestion and increased costs are often the results of systems distance capacity which further increases the travel costs to surrounding regions. Therefore, this has reflected poorly on the economic growth of the country as some stakeholders have withdrawn from the utilisation of freight transportation services and relying more on their own personal form of transportation such as small cars and pick-up trucks (Laurance *et al*., 2014).

Transnet Freight Rail recently attempted to transport large volumes by rail to other southern African regions but encountered issues such as a lack of spatial differentiation, a financial budget, a lack of resources, and deteriorated infrastructure. Furthermore, some specific volumes of inter-regional trade appeared to be declining in recent years, resulting in poor market potential and transportation viability (Transnet Freight Rail, 2018a). As a result, this is largely due to poor rail infrastructure, a lack of rolling stock, road competition, and high volumes that exceed expected tonnages produced in South Africa's central regions. Despite a significant loss in volume growth, there is still some hope for high volumes of railway development in African countries that are aligned on the basis of growth and development, such as the famous Maputo corridor. This corridor is inter-connected to other international corridors and thus increasing the business relationship in terms of freight transportation internationally (Transnet Freight Rail, 2018a).

Moreover, the sustainability of freight transportation in South Africa is the primary role of the government to specifically facilitate the development of a long-term logistics strategy that optimally equilibrates demand and supply (Dollery & Wallis, 1985) through 'anticipation' of the market character (Antonowicz, 2011). This simply suggests that the products or goods that need to be transported to different regions must be equivalent to the quantities and rate at which they are required by clients using these two modes of transportation. Further, there is supposed to be an intermodal connection flow which ensures the neutrality across modes by taking full account of all relevant social, environmental, economic, and land-use factors. However, studies on the effective freight transportation system, particularly in the context of South Africa, are limited. Therefore, this study focuses on the development of a sustainable freight transportation system by considering both rail and road transportation in the central regions of the country. Additionally, the sustainability of freight transportation is the primary role of involved stakeholders in the freight and logistics industry to specifically facilitate the development of a long-term logistics strategy that optimally equilibrates demand and supply. Hence, this study will contribute methodologically by using the estimated model which can equilibrate freight shares in terms of supply and demand for commodities such as coal, steel, food, and more, between road and rail (that contributes significantly to the economic growth of this country).

1.3. Significance of the Study

1.3.1. Aim of the study

The aim of this study is to develop a sustainable freight transportation system by the application of optimal modal split between freight rail and road transportation modes in the central regions of South Africa. This optimal modal split is envisaged to bring an efficient intermodal operation of the two modes under varying scenarios. Contrastingly, the practical implication of this study envisaged to assist the involved stakeholders together with the government in freight mode choice and understanding the impact that it has on the environment and infrastructure. Further, relevant organisations can use this study to improve the railway infrastructure to accommodate an equal demand of freight movement by road and rail within the central regions and other parts of the country.

1.3.2. Objectives of the study

For the above aim to be achieved, the following specific objectives were set. The specific objectives of this study are to:

- Examine the current economic and operational efficiency of freight transportation by rail and road (trucks): This objective is intended to examine the economic and operational efficiency of road and rail in terms of freight movement and to determine which freight transportation mode between road and rail is much more efficient than the other (economically and operationally) within the central regions of South Africa.
- Assess the status quo of the freight transportation system and challenges encountered in the central regions of South Africa: The implication of this objective is to identify the scenarios and challenges that exist between road and rail in the central regions of South Africa based on the historical records provided by freight and logistics companies.
- Develop an empirical model(s) for balanced and optimal freight transportation by rail and road transportation in the central regions of South Africa: The implication of this objective is basically to develop an estimated model that would allow for an optimal and balanced modal split between rail and road within the central regions of South Africa.
- Evolve guidelines for the balanced and optimal freight transportation by using both rail and road transportation systems: This objective is aimed at providing guidelines that can be adopted in future by stakeholders involved in the freight and logistics industry to sustain the balanced and optimal freight transportation system within the central regions of South Africa.

1.3.3 Research questions

The following research questions are adopted in this study to assist in addressing the objectives mentioned in 1.3.2:

- What is the importance of having sustainable freight transportation?
- In the central regions of South Africa, what are the current operational and economic efficiencies between freight road and rail?
- What is the impact of the challenges of freight road and rail contributing to the current status quo of freight transportation systems in these regions?
- Which model can be developed in achieving a balanced and optimal freight transportation by road and rail?
- What guidelines can be evolved from the developed model for providing a sustainable freight transportation system?

1.4. Scope and Limitations of the Study

The scope of this investigation is focused on developing a sustainable freight transportation system in the central regions of South Africa with evolving guidelines for balanced and optimal freight transportation using both rail and road transportation modes. The case study was based specifically on four central regions which are Gauteng (as presented in Figure 3.2), Mpumalanga (as presented in Figure 3.3), Free State (as presented in Figure 3.4), and Northern Cape (as presented in Figure 3.5), as they have high production of market related products, high levels of businesses, high demand of freight transportation commodities, and fairly high population growth. Further, these regions were chosen as a study area due to the following:

- **Free State**: This region creates lucrative markets as its road connects Gauteng to both Durban and the development zone at Coega near Port Elizabeth using the N3 that runs through Harrismith.
- **Gauteng**: There is a high development of road, air and rail transportation in Gauteng resulting in a significant investment spectrum, thus it is now recognised as a freight and logistic hub region.
- **Mpumalanga**: Mpumalanga has a Northern Functional Area and MR385 corridor which is located on the south-western side of the N3 in the outer west of the eThekwini Municipality and it forms the most active road for freight transportation.
- **Northern Cape**: This region consists of a logistic hub situated in De Aar and about 60% of the commodities from large producers are moved from Hotazel by rail through this region to Port Elizabeth or Free State.

The delayed response from the board with regard to the proposal, late availability of funding, the COVID-19 virus which led to company lockdowns, stringent policies and regulations on some companies, and time-based masters' programme contributed to adequate data, but surplus data would have enhanced the regression model. Consequently, another limitation is that the model may be effective for regional freight movement in the context of the central regions of South Africa but may not be generalisable. This entails that this study was based on a distinctive sample size and not for the entire population of the freight and logistics industry.

Furthermore, another limitation to this study is that the freight and logistics industry is an emerging field in South Africa, so there were limited historical data on this field as compared to other countries which then led to limited sampling of data. Hence, further research suggestions are provided in Chapter 7, Section 7.3 of this study.

1.5. Research Design

1.5.1. Methodology of the study

This study makes use of quantitative research methods which follow the below steps:

- **Data required** to be able to assess the current status quo of freight transportation systems in the central regions, such as:
  - Time dimension freight data: This data is retrieved from freight and logistics firms that involves tracking of freight movement information for origin and destination trips.
- **Data collection method** to obtain sufficient and realistic previous data and current information on freight transportation systems, including the following:
  - *Primary data*
    - Self-administered questionnaires: These questionnaires were conducted to address the objective of examining the current economic and operational efficiency of road and rail. The details of the questionnaire are provided in Chapter 4, Section 4.2.
  - *Secondary data*
    - Surveys of the past records from freight transportation companies: This data was used to address the objective of assessing the current status quo of the freight transportation system and challenges experienced by road and rail in the central regions of South Africa.
    - Statistics over the years that involve graphs, pie charts and calculations: This provided the trends that exist in the transportation system in terms of freight movement in these central regions. The details of the past survey and statistical data are presented in Chapter 5, Section 5.2-5.3.
- **Development of a Binary Logit model** to reach a balanced and optimal freight transportation system in the central regions of South Africa, also involving the use of the IBM SPSS software program for the purpose of statistical analysis (IBM Corp., 2020).

- **Simulation** of the developed model in order to see its effectiveness by adjusting percentages on various parameters such as load cost, fuel cost, and more, through varying scenarios.
- **Validation** of the developed model to prove its accuracy by comparison of the generalised freight costs with the actual freight cost obtained from involved stakeholders in this industry.
- **Outcomes** involve plausible inferences which were drawn for the development of an optimal and balanced freight transportation system and providing a set of guidelines in achieving the objectives.

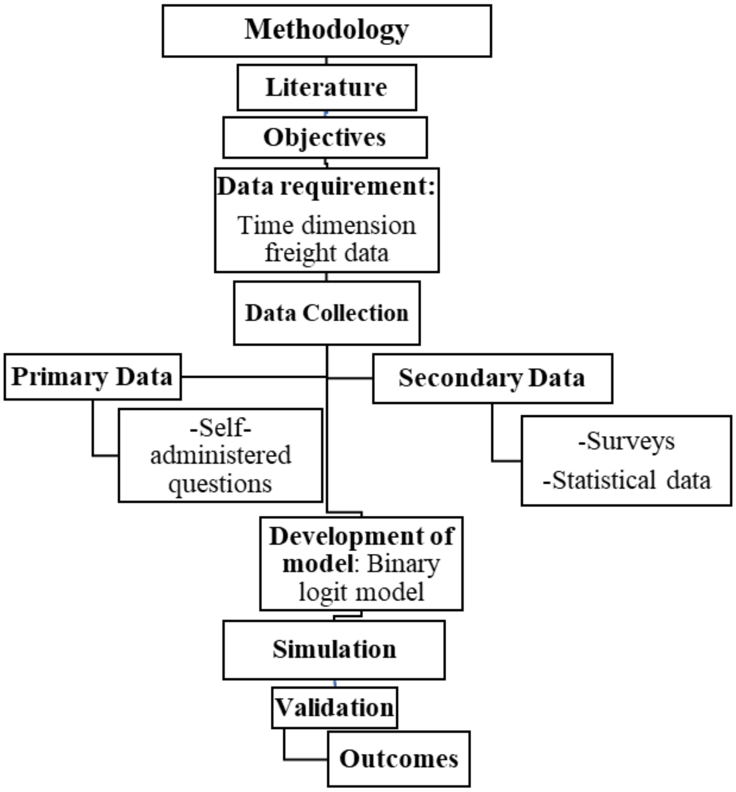


Figure 1.3 Schematic presentation of the research flow

1.6. Ethics in the Freight Transportation System

Ethics basically define the correctness and legality of a research study under varying phases. The reality is that there can be ethical concerns at almost every step of the research process (Bickman

& Rog, 2009). A positive attribute of research ethics is that they have been gaining paramount importance across the research community.

According to Resnik (1998), research ethics are the common denominator for researchers' relations with the respondents and colleagues, especially in cases where interviews and questionnaires will be conducted with the clients and involved stakeholders. In this regard, all the involved personnel in this investigation will be informed of the study and its expected outcomes. It is imperative that researchers must possess adequate knowledge regarding the characteristics of ethical problems in any research programme. Thus, this study protects the right of all the individuals who completed the questionnaire with respect and provides assurance and transparency in the information being collected.

Beneficence, as principle, should be adhered to during a research study as it is the action that is usually done for the benefit of others, which simply means that the developed model should benefit the surrounding regions with common parameters in South Africa since it is an empirical one. The principle operates by ensuring that the data being collected does not by any means harm the rights of citizens and only provides solutions that can enhance the freight transportation in the country. In terms of justice, there should be fairness in the manner which this research is conducted, without exploiting the accessibility or availability of the participants involved. Hence, an ethical clearance letter was obtained from the Assessment and Graduation Unit (AGU) Department at the Central University of Technology (CUT) as this research involved human interaction and participation. This principle further indicates that the questions being asked should be of relevance to the community or individuals participating in the study.

1.7. Chapter Scheme

Chapter 1: The chapter is made up of an introduction, problem statement, scope of the study, aims and objectives, research methods, and limitations of the research.

Chapter 2: This chapter is an overview of the existing literature.

Chapter 3: This chapter consists of the study area profile, including the background of the study area, demographical profile, social and environmental aspects, freight demand, economic impact, and the degree of transportation modes.

Chapter 4: In this chapter, the focus was on the collected data and the discussion of the different types of data analysis methods used.

Chapter 5: This chapter contains the data analysis and discussion of the results.

Chapter 6: This chapter consists of model development and simulation for both freight road and rail.

Chapter 7: This chapter is the conclusion of the whole study, discussion on future contributions and recommendations as evolved guidelines.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

Most human activities involve the movement of goods or passengers, and freight movement within cities is far more complex than passenger transport. This is due to freight movement involving interactions between firms and destinations at differing temporal scales along the process of production (Allen *et al*., 2012b). On the contrary, there is limited research and understanding when it comes to the spatial and temporal nature of goods movement within urban cities and even rural areas (Giuliano *et al*., 2017). Frankly, freight encapsulates a multiplicity of movement types such as bulk materials transport, freight couriers, consumers moving goods, commercial vehicles, and waste management services (Ellison *et al*., 2017). Although all this is true, freight environment is highly variable and fundamentally influenced by a wide spectrum of stakeholders and governments which typically provides the infrastructure and manage externalities associated with freight movement (Visser & Hassal, 2010). In South Africa, the new firms based in special economic zones exhibit unique freight carriage characteristics, thus smaller businesses produce proportionately more freight trips because they require a similar number of different inputs, in smaller quantities and resulting in more frequent deliveries (Holguin-Veras *et al*., 2013).

Subsequently, urban freight and logistic researchers observed that, recently, both geographical and spatial studies have not sufficiently contributed to the development of new methods of freight transportation management (Hence, 2012). However, there is a study which demonstrated that several geographical, spatial and land use factors, such as facility's location, the city's size and the location in the city network, street design, settlement size and density, city layout, and commercial and industrial land-use patterns, are likely to influence the efficiency and intensity of freight journeys (Allen *et al.*, 2012b).

Further, Lindholm (2012) stated that the spatial approach for urban freight has never been explored in detail by urban freight researchers or parcel providers. Also, local governments underestimate the use of urban freight studies and diagnosis prior to making decisions regarding urban distribution, which may lead to unpredicted and sometimes even negative long or short-term effects (Diziain *et al*., 2013). Since there are various available modelling approaches in the freight transportation industry, clustering analysis and zone definitions from a freight and logistics point of view have nonetheless received increased attention in recent years (Macario, 2013).

2.1.1 Sustainable freight transportation system

Sustainable freight transportation system refers to freight activities that involve equal distribution among various modes of transportation such as road, rail, and aviation, resulting in a balanced supply and demand among industry stakeholders. It helps to achieve cost-effective movement and prompt availability of freight commodities as needed by clients (Crainic, 2004.) Furthermore, the main goal of having a sustainable freight transportation is to reduce deficiencies such as pollution, accidents, and poor freight distributions, as well as to improve the country's quality of life and economic status (Havenga *et al*, 2011e). This means that through proper implementation and management of a sustainable freight transportation system, coordinated freight movement to and from economic centres with esteemed collaboration of transportation modes is possible. Furthermore, transportation mode collaboration through intermodal or multimodal freight transportation will result in a balanced freight share among various modes, resulting in a sound transportation network (which is discussed in the succeeding sections) (Oudani *et al*, 2014). As a result, the timely transfer of the appropriate quantity and quality of commodities from origin to destination via various modes of transportation, in this case, road and rail, contributes significantly to a country's economic growth.

2.1.2 The management of freight transport systems

In all freight and logistic systems, there is a fundamental component which is usually referred to as a transportation sub-system. Each transportation system consists of a set of components, such as transportation infrastructure (roads, railways, stops, passenger terminals), fleet of vehicles (cars, buses, trains, and boats), human resources (drivers, terminal staff, on-board crews), and governing rules (traffic regulations, service standards) that ensure a coordinated and efficient movement of goods from the origins to destinations in certain areas (Garret, 2014). Concurrently, it is important to note that transportation systems can be classified differently based on the following criteria: scope range, modal diversity, category of movement, and environment in which the system operates (Hall, 2003). Further, the same system of transportation may cover a specific group of countries, one or several countries, or even the whole world, and combining the various transportation modes which all have an impact on international trade, cross-border freight movements and goods' exchange between countries (Colembska, 2008).

In the United States, Chicago is known to be the biggest hub for freight movement because of its importance as a manufacturing and distribution centre and as it allows the eastern and western USA railroad lines to converge. Additionally, railroad traffic is the most used mode of freight transportation in USA through the Chicago hub to the eastern and western parts of the country (Colembska, 2008). Alternatively, there is a major transfer system point for truck trailers between individual railroads which carries either partial-or-completely-cross-country trailer-on-flatcar (TOFC) shipments. Hence, the rail transfers for these TOFC shipments were handicapped for some time by the high volume of trailer traffic at interchange points, rail congestion, and difficulty in maintaining enough flatcars, so the shipments were temporarily transferred by trucks either to their destinations or to other ramps for continued transportation by rail (Road Freight Association [RFA], 2014). Over time, there was an increase in the use of 'new truck-only facilities', which provided alternative truck routes in Chicago, some of which were intended to divert from existing routes to new facilities and added to time-saving management. As a result, this implementation was integrated with a Chicago Area Transportation Study (CATS) travel forecasting model, which used project team input to estimate traffic impacts proposed by truck-only roadway on Chicago's regional traffic flow pattern (Garret, 2014).

2.1.3 Application of freight transportation in South Africa

The primary goal of all freight transportation is to achieve efficiency in the movement of goods, but it should also be primarily directed at controlling and monitoring the shortcomings in the movement of these goods (Lafkihi, Shenle & Eric, 2019). In South Africa, a limited proportion of freight transport movement is provided by parastatals in railways, pipelines, and aviation. Havenga, le Roux and Simpson (2013) affirmed that the annual tonnage handled by major freight transport infrastructures indicated that 1.53 billion tons of freight were transported annually by road, representing 76% of the total amount of freight transported between 2011 and 2012 and with the balance of freight in the country having been transported through ports (13%), rail (10%), pipelines (1%) and airports (0,02%) (Havenga *et al.*, 2013b). As a result, road basically carried the majority share of freight when compared to other modes, followed by shipping and rail in South Africa. Although road freight delivery has significant advantages, the great number of freight vehicles on the road contributes to overloading, subsequent road network deterioration, and traffic congestion in urban and rural areas. Subsequently, this led to the development and formulation of Transnet's road-to-rail strategy, which had the primary aim to reduce the number of heavy trucks on roads to decrease overloading. However, there were challenges in this strategy as road freight origin and destination (OD) information seemed to be unavailable in South Africa as no legislation was in place to compel the disclosure of this data (King & Ittman, 2012).

Moreover, there were few inputs involved such as the South African National Roads Agency (SANRAL) and Council of Scientific and Industrial Research (CSIR) on traffic counts which helped to determine the road freight flows and actual rail data for rail freight flows (CSIR, 2011; Transnet Freight Rail, 2018a). However, this model showed to be commodity biased as it was based on actual traffic counts but provided only a measure of verification for the results of the commodity-flow model (RFA, 2014). Also, Madubanya (2016) proved that freight transportation by road is much more polluting than freight rail transportation due to exhaust combustion through assessing the environmental considerations of freight transportation modes. In addition, the Road Freight Association (2014) identified that the freight transportation system faced both economic, and environmental challenges which require collaboration between various stakeholders involved in the freight industry. Hence, in this study, an investigation for achieving an optimal transportation system by considering the economic, environmental, and socioeconomic impacts of both rail and road freight transportation will be conducted.

2.1.4 Different modes of freight transportation

In freight transportation there are various modes of transportation involved, such as road, rail, waterway, and airway. Although there are several freight transportation modes, in this study, the focus is between road and rail in relation to their economic and operational efficiency. However, consideration should be made regarding fixed costs involved in the determination of the correct mode of freight transportation within the transport network. Additionally, consideration should also be made in terms of the independence of inventory management such as packaging, loading, and unloading, preparation of mode, invoicing, organisation and even the transaction costs (Savy, 2009).

Therefore, when it comes to road and rail freight transportation, a growing proportion of shippers (clients) tend to seek to optimise their comprehensive logistic costs and not just aim to minimise the transportation costs. As a result, this entails that a more expensive transport solution can lead to lower inventory volumes and providing overall cheaper logistics solution. This means that introducing technological inventions to transportation, such as automated freight trucks, may be costly to the company but will result in reduced inventory processes, resulting in faster cargo ordering, packaging, delivering, and dispatching. Furthermore, road is frequently selected for long distance freight movement as it is usually the only available solution to shippers with the other modes showing no improvements in service quality (Madubanya, 2016).

2.2 The Impact of Freight Transportation Systems

In every country, the impact on the environment should be one of the most important criteria considered when selecting the mode of transportation for goods. However, the adverse effects of transport vary depending on the geographical location area, sensitivity of the environment, and the economic development. According to the Environmental Plan Act (EPA) study, transport has been the main source that contributes to the greenhouse gas emissions affecting the environment negatively and at a level of 27% to the industrial and power sectors (EPA, 2018).

Concurrently, poor freight performance leads to lower overall economic growth, and in some city centres, this is typically caused by congestion due to a low share of paid parking spaces, leading to illegal parking that disrupts normal freight activities around distribution centres. Thus, this destroys the natural environment and may be disturbing to the daily activities of the local community, especially during freight movement (Mezyk & Zamkowska, 2016). Additionally, freight road transportation leads to high degrees of congestion especially in areas with poor road infrastructure development and contributing to poor service delivery. Hitchcock and Carslaw (2016) proved that transport contributes to real social costs which not only result from air pollution (31%) but also from congestion (27%) and road accidents (20%).

2.2.1 Market demand

In essence, innovative freight models are needed to deal with increased congestion in urban areas and freight hubs and to maintain the reliability and efficiency of freight transport systems. It is known that efficient movement of freight is very crucial to the overall economic vitality of a metropolitan area, as well as nationally; however, it is usually difficult to expand or even upgrade freight facilities. Hence, there are high costs, lack of land, and increasing public opposition to freight related environmental and health externalities that have stalled freight infrastructure expansion and upgrades. Hensher and Figliozzi (2015) affirmed that some market industries should provide advancements in modelling which consider the supply chain relationships and logistical constraints that are needed to significantly increase the understanding of freight system operations.

Otherwise, the movement of groceries, consumer products, industrial supplies, and other staples of modern life is very critical to the economy and quality of life of urban economies especially when done efficiently. Subsequent to that, urban freight is predominantly dependent on trucking and characterised by shorter trips and multi-stop tours which are traditionally based on the four-step freight models such as trip distribution, trip assignment, trip generation and modal split. Additionally, changes in information and communication technologies have not only affected consumer purchasing patterns but allowed the adoption of new real-time mechanisms to increase the efficiency of delivery and the freight transport system. Once a freight market analysis has been done, the available real-time information helps to reduce the number of empty trips and transport costs and significantly reduces the transport tariff that may trigger an adjustment in the replenishment pattern of shippers (Hensher & Figliozzi, 2015).

In large cities, there are obvious problems such as lack of space and the interaction of multiple actors that show different interests and these are referred to as freight stakeholders. Freight stakeholders basically ranges from producers, sellers, operators, inventory control managers, and more, that all have a distinguished role in the freight industry. As a result, these stakeholders should form a collaborative partnership in freight movement to ensure economic and operational efficiency, particularly in the country's most influential economic hubs. Moreover, consideration should also be made on the attributes of freight movement that include factors such as type of vehicle, time-of-day when they circulate, and the payload which are all determined by the interactions between stakeholders (Sànchez-Diaz *et al*., 2017). Although this is possible, retailers, wholesalers and manufacturers are offering goods through multiple channels to provide a seamless customer experience. Hence, most of the successful carriers and logistics companies are adopting complex costing models to meet efficient and productive freight transportation needs. However, in many cases, the use of obsolete management methods and outdated planning processes and tools exacerbates the challenge of improving delivery performance in this changing environment. Thus, advanced transportation management systems designed for multi-stop deliveries and ever rising customer expectations can provide the capability, flexibility, and tools to successfully meet the demands of freight transportation systems (Stevenson, 2017).

2.2.2 Employment opportunity

Simultaneously, consideration should also be made of the fact that the urban freight transportation industry is a major source of employment in most countries. This is merely because freight is carried by vehicles that move on the same streets used by private and public vehicles transporting people (Crainic *et al*., 2004). On the contrary, transport policy and planning decisions often have significant economic development impacts by affecting government and consumer expenditures, employment opportunities, resource consumption, productivity, local environmental quality, property values, affordability, and wealth accumulation. Further, some of these impacts are widely recognised and considered in conventional policy and planning analysis, but others are just overlooked and undervalued (Litman, 2010). Therefore, it directly benefits the disadvantaged people and improves access to employment by expanding the pool of lower-wage workers and improving the ability to access medical services and healthy food, which reduces healthcare costs.

2.2.3 Resource contribution

It is imperative when evaluating economic impact to make a distinction between resource impact in terms of a change in the supply of scarce resources such as time, land or fuel, and economic transfers such as shift of resources from one person or group to another. An increase in fuel consumption is a resource cost, but an increase in fuel taxes is an economic transfer since the additional cost to consumers is offset by an increase in government revenue. Therefore, in general, the changes in resource consumption affect economic productivity and efficiency issues, while economic transfers are equity issues (Litman, 2010). It should be noted that improving accessibility for disadvantaged groups provides both efficiency and equity in resource benefits.

2.3 Chronological Evaluation of Freight Transportation System

In modern times, the strong competition between companies necessitates the adoption of modern and advanced production systems such as the lean production and just-in-time. In the freight industry, the use of previously mentioned systems allows the enhancement of the competitive power of various companies. This simply entails that the involved investors would consider the transport time and the regularity as important capital and labour for production functions. Also, the evolved system of freight transportation in an open and modern economy plays a vital role in enhancing domestic production that subsequently affects the economic growth positively (Jin & Rafferty, 2017).

Furthermore, the freight and logistic providers are an important factor in business success of companies engaged in trade activities at national and international level. There is a primary objective which aims in engaging the freight and logistic intermediaries such as freight service providers to facilitate the operation of companies that deal with buying and selling of goods (Skender *et al*., 2016). About 80% of today's transportation is largely dependent on oil, as most vehicles are driven by engines which combust petroleum products. This is more relevant to road, air, and water transportation because most rail transportation is now powered by electric traction motors; however, while these electric traction motors still use some oil, the proportions of consumption are less significant when compared to the other modes (Kendra *et al*., 2018). Subsequently, international companies are becoming more and more aware of the need to improve and adjust their supply chains to meet the current market trends. This involves the employment of intermediaries such as service providers with the specialised skill in their field of service to provide the needed expertise and thus forming improved supply chain management between different companies (Skender *et al*., 2016).

2.3.1 Global regions

Freight transportation infrastructure and related transport elements such as trains, ships, and trucks, form an integral part of society, especially towards the Gross Domestic Product (GDP) growth. An initial example can be made of the USA which has an extensive freight transportation system, with a network of 4 million miles (6 437 376 km) of roadway, nearly 22 539.83 km of rail, more than 350 000 intermodal terminals, almost 10 000 km coastal and inland waterways, and over

5 000 public-use airports. It also enables the expedient movement of raw materials, other resources, and end-products between suppliers, manufacturers, wholesalers, retailers, and customers (Miller-Hooks *et al*., 2011). Global freight transportation systems are often arranged in the form of global or international transportation corridors that ensure the movement of significant freight traffic flow between distant geographic regions in a very coordinated manner between a selected origin and destination (Waters, 2003). Faber (1998) stated that these corridors are based on the concept of global sourcing or global physical distribution and fit global configuration of procurement, manufacturing, and distribution systems. Additionally, freight transportation on the global level constitutes moving goods or products between supply chain links on a desired scale with the application of either a single-mode, multi-modal or inter-modal transportation solution. This has a good impact of developing minimised cost strategies that are necessary in the supply solutions involving geographic regions that are featured by low labour, material, and manufacturing costs (Aggarwal & Newland, 2015).

Subsequently, China is the anchor country that offers more products to Europe and the USA as it features less labour, material and even manufacturing costs. However, there seem to be some trade-offs that are usually associated with South Africa due to its decreased sourcing costs that are achieved by relocation of local supply facilities. This has further led not only to the increase in transportation and storage costs but also to the extension of delivery time. Alternatively, there is also an application of Information and Communication Technology (ICT) that basically leads to improvements in warehousing activities and customer service (Zeimpekis *et al*., 2010). This, then, results in different types of economic benefits including reduced costs of logistical operations that are usually achieved through this initiative (Chan *et al*., 2012). Also, the most important advantage of ICT is improved safety and efficiency in freight transport operations resulting from improvements in the exchange of information between the actors in supply chains (Vilko *et al*., 2012). Therefore, these ICT applications and services in the field of freight transportation can support the integration of intermodal transportation.

2.3.2 Local regions

The World Bank revealed that, in 2016, South Africa ranked 20th out of 160 countries on the Logistic Performance Index, also known as the LPI. This is due to countries experiencing higher corridor logistics costs because of the low economies of scale based on infrastructure or structure imbalance of freight volumes (World Bank, 2016). Furthermore, there seems to be a growing interest in freight transport's impact on the global climate and on local air and noise emissions (Tavasszy *et al.,* 2011). This resulted in new freight transport models being developed which include both responses to changes in the transport system in each environment and usually forecasts future transport and traffic flows, transport costs, and so forth. Most of these freight transport models are used to assess the impacts of different types of policy measures, such as changes in national regulations and taxes or even infrastructure investments in specific links, nodes, and corridors (De Jong *et al*., 2004a). Hence, Martner and Garcia (2015) stated that to improve freight logistics performance, there should be the availability of reliable indicators to quantify the efficiency and capacity of the logistics network over the intermediate and long term, thereby enabling an evidence-based policy and investment environment.

Moreover, there are four-modelling structures which were adopted from transportation utilised by passengers (generation, distribution, modal split, and network assignment) and used in freight transport modelling with some success, although some additional steps are often required to transform trade flows in money units to physical flows of goods in tons. The processes involved can also be modelled as fixed rates, but explicitly representing the choice of logistics made. Hence, it is important to note that, at the local level, most of the logistical aspects that are related to the trade-off between transport and inventory costs are usually not included in freight transport models, even though the logistics solutions of firms influence the mode split (De Jong *et al*., 2012b). According to Havenga, Pienaar and Simpson (2011e), South Africa's cost of logistics in relation to the gross domestic products (GDP) declined from 14.7% in 2008 to 13.5% in 2009, but it is still higher than in many developed countries. However, there was a national freight-flow model which was developed based on the truck movement observations in 2004 to define the core configuration of South Africa's transport system. Even though this model was developed, the flows were just for total freight without any indication of the commodity composition. Since an efficient movement of freight is vital for the growth of an economy, there should be proper planning which must in turn be based on regional commodity-level transport demand models to aim at informing the demand for regional transportation facilities and services (Mesenbourg, 2011).

2.4 Existing Models for Sustainable Freight Transportation

There are various models to be adopted in freight industry and other research shows the modality theme which covers and focuses on the combination of road freight transport with other modes of transport. As a result, it was designed to substitute road by other modes in terms of the critical qualities of flexibility, speed, and time considering the implications for the last mile dependency on road freight (Tob-Ogu *et al*., 2018). According to Kaack (2018), the importance of modal shift which is the transition from road-dominated freight transportation to rail-dominated freight transportation, as to elucidate the potential of modal shift and attain sustainability in the freight transport sector, is possible.

2.4.1 Intermodal freight transportation network

Intermodal transportation is defined as the concept of utilising two or more modes of transportation, in combination, to form an integrated supply chain (Lowe, 2005). In other words, the primary goal of intermodalism is to be able to utilise the most cost-efficient modes of transportation to move freight from its origin to its destination. It can also be defined as the transportation of cargo with the same load using two different freight transportation modes between the place of dispatch and the destination; therefore, freight and logistics stakeholders can use this approach in the central regions of South Africa to reach a sustainable freight transportation system (Agamez-Arias & Moyano-Fuentes, 2017). Once intermodal freight transportation is adopted by freight and logistics stakeholders in the central regions, there will be less freight traffic congestion, faster service delivery, lower operational costs, decreased waiting times, and reasonable load costs which can remain in use for years to come. However, there are certain aspects which contribute to the application of this intermodalism such as the route selection, which is mainly based on environmental criteria, as opposed to traditional criteria of cost and time-of-delivery. On the contrary, the impact of freight is becoming more widely noticed and this is due to its broad association with the environment in terms of energy and resource delivery (Facanha & Horvath, 2005). There are prior models which were developed to study freight flow across intermodal networks, but the challenge was with building intermodal models that are efficient to accurately connect the entire transportation network. Subsequently, there were measures in place which involved the employment of ‘artificial’ nodes and links to connect water, rail, and highway networks. Continuously, this was done by also using the best available data to capture actual intermodal transfers and apply custom evaluators to find freight routes based on energy and environmental attributes (Hawker *et al*., 2007).

Levinson (2003) noted that to evaluate the performance of a transportation system, it was necessary to devise measures of efficiency of the system in moving people to places they wish to go, and in shipping goods to where they are in demand. However, there seems to be a very steady increase in long-haul trade with some pressure to reduce logistics costs, thus, intermodalism has become a prominent expression of logistics and supply-chain management in advanced economies (Slack, 2001). Hence, the transportation modes to be included in the intermodal network were limited to truck and rail shipping, with the exclusion of all waterways which revealed minimal information on intermodalism. In contrast, there is some confusion in the freight transportation industry about the terms multimodal and intermodal transportation, so it is important to understand that intermodal freight transportation refers to a specific type of multimodal transportation in which the load is transported from origin to destination in a single intermodal transport unit, such as a twenty-equipment-unit container, without handling goods when changing modes (UNECE, 2009). Multimodal transportation, on the other hand, refers to the movement of goods through a sequence of at least two or more different modes of transportation, but with a variety of units for handling goods such as a box, container, swap body, and so on, and it typically focuses only on long-distance pickup and delivery services (Crainic *et al.*, 2004).

The US Intermodal Surface Transportation Efficiency Act (ISTEA) revealed that intermodal networks enhance the accessibility although it may be weak overall when analysed from an infrastructural point of view. Moreover, it contributes to the spatial equity in accessibility which helps to increase the intermodal revolution in modest proportions for large cities such as in the United States. However, from the public policy standpoint, the implication is that the widely heralded economic development benefits of intermodalism are not quite reflected in the economic realities experienced by freight shippers (Thill, 2008). Alongside this, the implementation of tapered freight rates results in more realistic transportation costs between shipment of origins and destinations as cost-per-kilometre transportation usually declines with distance and does not reflect the current application of intermodalism. Furthermore, when the long-distance cost advantage of rail over trucking was considered, the results revealed that rail had greater accessibility benefits than road, resulting in a greater contribution to spatial development. Therefore, the simulation of the distribution and routing of container freight-flows on a national scale can improve the application of intermodal freight transportation (Thill, 2008).

The development of intermodal freight transportation involves the development of a general network that includes the integration of modal networks into a unified system which ensures the use of two or more transportation modes to provide optimum service. Therefore, this integral network must be designed in such a way as to allow any combination of intermodal routes, sequences, and links of the network to represent actual routes specified in the freight traffic investigation report (Transport Visuals, 2002). Thus, the objective of this model is to minimise the total costs in an intermodal freight system, including the capital costs, intermodal transfer cost and the GHG emission costs to ensure that various commodities are shipped from their origin to destination efficiently (Bektas & Crainic, 2007).

2.4.2 Multinomial freight transportation transit

The multinomial logit model uses some behavioural assumptions on how choices are made, so it can be fitted to the observed data under investigation. As compared to many other fields in logistics, multinomial freight transportation provides an unusual but direct and mathematically stringent link between the economic theory and the statistical model used to operationalise the freight transportation system (Dagsvik, 2000). Additionally, it is important to know that the multimodal freight transport network includes two kinds of networks, namely the physical network and the carriers' service network. This physical network is made up of nodes, such as road intersections and terminals, sidings, borders and so forth, such as road links and rail links. However, consideration must be made on the classification yard in multinomial freight transport which is basically modelled as a transfer node where inbound trains consisting of railcars intended for various destinations are sorted to depart in appropriate outbound trains (Mahnmasssani, 2001).

Interestingly, in today's marketplace, setting competitive but profitable service charges and minimising costs while providing good quality services present major challenges to carriers. These carriers are basically the port terminal operators that provide transportation services within a port complex and are based exceedingly on their unique behaviour. Thus, the same carriers are the ones that make the decision on prices and delivery routes at different parts of the multimodal network, interacting with each other hierarchically. Subsequently, the land carriers are responsible for transporting freight between the port terminal and inland destinations (Lee, 2014).

2.5 Techniques to Analyse Freight Transportation

Archetti and Speranza (2014) stated that matheuristic algorithms are becoming popular for solving complex combinatorial optimisation problems. Hence, the proposal for a matheuristic algorithm which was based on a set-partitioning formulation that chooses the best subset of routes was developed. Further, this set of routes was constructed through a route construction algorithm, where the basic idea was to generate all feasible routes from origin to destination for all shipments. This approach proved to be efficient, but the disadvantage was that it was based on one mode of transportation only – roads.

2.5.1 Survey technique

Conversely, the container rail (boxes or vessels that are used to carry cargo placed directly on rail-trailers) is known for its scheduled train traits, of which the frequencies and stopping patterns are optimised in advance. Therefore, the methods adopted in this technique were designed to optimise the benefit of these three parts: service providers, customers, and the public. The assumptions were made as follows (Zhang *et al*., 2019a):

- A train only starts at the departure station #1 and arrives at the intermediate station #N.
- For a rail line with N stations, there are N(N-1)/2 origin to destination (OD) pairs.
- The operating cost and stopping cost are fixed.
- The service level of transported goods.

To address the aforementioned assumptions, the formula below was created for the optimisation problem, which was to maximise the objective function that represents the operation optimisation involved in the freight industry:

$$0 = \sum_{i=}^{N-1} \textstyle\sum_{t=1}^{T} x \displaystyle\sum_{j=2}^{N} (\mathrm{p}_{ij}(\mathrm{t}) - \mathrm{m})(\mathrm{b}_{ij}(\mathrm{t}) - \mathrm{f}(\mathrm{t})) * K - \tau_i(t) * S_i) \qquad (2.1.)$$

where: N = rail network stations (1,2,3……, N)

$T \ = freight\, rail$

$K\ = fixed\ operating\ cost\ per\ train$

p_{ij} = the container transportation rice from station i to j at time t

$t\ =\ time\ it\ takes\ from\ station\ i\ to\ j$

m = the marginal cost per container

b_{ij} = reil freight volume from station i to j

f = binary indicator: $\mathrm{f} = 1$ if a train operates at time t, otherwise $\mathrm{f}\ =\ 0$

τ_i = binary indicator: $\tau_i\ =\ 1\ if\ a\ train\ stops\ at\ station\ i, otherwise\ \tau_i\ =\ 0$

S_i = fixed stopping cost at station i

Additionally, another model was designed for the detailed shipment flow assignment and real-time deployment of the service fleet. This model was planned in three parts: (1) the shipment flow re-planning for a capacitated network denoting the transportation of shipments; (2) the service rescheduling at the arc level, and (3) the shipment flow re-planning and service rescheduling which were connected through synchronisation at terminals, providing solutions within 24 hours (Zhang & Pel, 2016b).

Alternatively, some transport researchers used portable Global Positioning System (GPS) technology to reconcile data on location, duration, and routes of individuals' trips and, further, to evaluate the quality of data from self-reporting (Rodriguez *et al*., 2013). One other method of determining the position of mobile units such as freight hauling vehicles was the Dual Satellite Navigation System (DSNS) which was usually assigned to present the invention of the transportation system under investigation. This device incorporated trilateration which worked by first assigning one of the three fixed object location (hubs) to the central points. Then, it included an involvement of the standard geodetic planetary model that defined the distance from the earth's centre to any latitude and longitude location on the surface. Additionally, the second and the third object locations were given by two orbiting planes whose positions on earth were in form of coordinates, then the distance from each of these satellites to the vehicle of which the position was being determined could be ascertained. Therefore, once the distances from each respective satellite to the vehicle were known, together with the distance from the hauling vehicle, then the other dimensional position of the fourth object could be determined (Helms *et al*., 1999).

2.5.2 Cost calculation method

According Petro and Konećnȳ (2017), there are external costs which are involved in the freight transportation system, and these are basically costs associated with the negative effects of transport activities on the environment and human life. The categories of these external costs are usually identified as accident costs, air pollution costs, noise costs, congestion costs, and more. For this study, Petro and Konećnȳ's (2017) method of calculating the cost of emissions was used, which takes into account the distance travelled during the transportation and costs by determining the category of the vehicle, emission class, and the area through which the transportation was active.

Table 2.1 shows the external costs in Euro per kilometre for various land zones. This was important as it showed the external costs for urban, suburban, rural area, and motorway due to freight transportation, as assessed by Petro and Konećnȳ (2017). From Table 2.1, urban area was the land zone with the highest external cost compared to other zones. This implies that there were more externalities such as air pollution, noise pollution, emissions, and so forth being experienced in urban areas due to high industrial activities located there.

Table 2.1 Cost for emission in Euro (€) per km

Vehicle Category	Euro Class	Urban	Suburban	Rural	Motorway
>32tons haulage capacity	0	39.2	25.1	17.7	14.8
>32tons haulage capacity	I	29.8	18.1	12.5	10.5
>32tons haulage capacity	II	23.7	17	12.5	10.6
>32tons haulage capacity	III	19.9	13.9	10.1	8.4
>32tons haulage capacity	IV	10.9	8.7	6.8	5.8
>32tons haulage capacity	V	8.5	6.3	3.4	2.3

(Source: Transcom, 2017).

Therefore, in determining the amount of cost of emissions, consideration was made in terms of area, the motorway at 80% and 20% of the suburban area. However, urban areas were not considered as road freight transport vehicles are less likely to go straight through the urban areas.

Table 2.2 shows the travel distance and cost contribution of emissions by road and rail from Zilina to Hamburg. Additionally, it shows the costs which were obtained by multiplying the cost of emissions and the number of kilometres travelled by a selected car over a certain area. According to Petro and Konećnȳ (2017), this was important in establishing the average contribution of emissions between freight road and rail over an average distance. From Table 2.2, road contributed more cost emissions in Euro per kilometre as compared to rail due to rail using electricity as a form of energy for freight movement.

Table 2.2 The total cost of the emissions in €, transportation from Zilina to Hamburg

Mode	Mileage (km)	Cost of emissions (€/km)
Road	786.35	18.09
Rail	196.59	12.39
∑	**982.94**	**30.48**

(Source: Elaborated by Petro and Konećnȳ, 2017).

Furthermore, Petro and Konećnȳ (2017) stated that when the hauler used generationally newer vehicles with higher emission classes, the cost of emissions and tolls were lower.

2.6 Research Interest in Sustainable Freight Transportation

In the freight transportation industry, proper planning and making informed decisions about freight transported by trucks on the state highway system requires reliance on data and information that represents pavement, truck, and freight interactions under conditions that exist within the system (Steyn *et al*., 2012b). Steyn *et al.* (2012b) also stated that the primary data collected from the trucks and freight were vertical, horizontal, and longitudinal acceleration, which were measured using off-the-shelf accelerometers. It was further stipulated that the vehicle location and road condition were monitored using a GPS and a video camera, while the service delivery characteristics were calculated based on measured road profiles on site (Steyn *et al*., 2012b). Subsequently, there seems to be a growing focus on road freight transport sustainability with a variety of approaches that aim to mitigate its consequences. The chart below highlights the approximate annual publication trend for sustainable freight transportation during the period of 2001 to 2018 (Tob-Ogu *et al*., 2018).

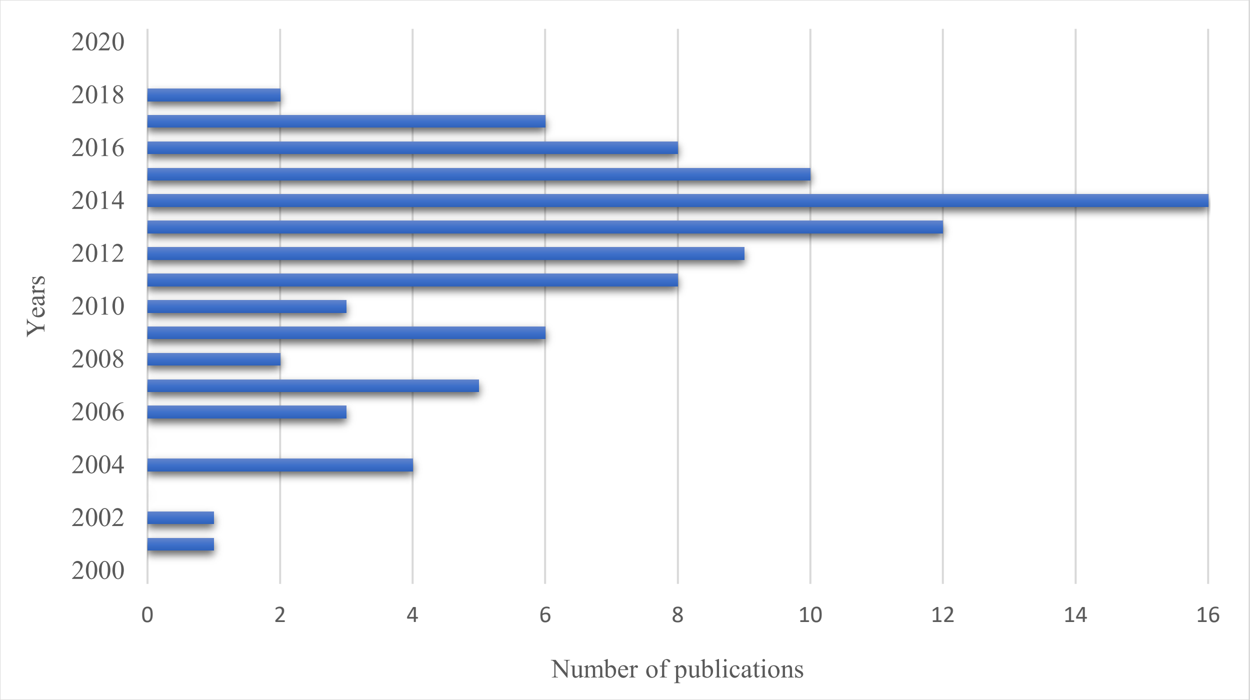


Figure 2.1 The number of sustainable road freight transport publications per year in South Africa (Source: Tob-Ogu *et al*., 2018).

2.7 Rail and Road Freight Competition in South Africa

There are trucks which exceeded the legal loading limits and increased the risk of traffic accidents and therefore led to unfair competition between the transportation companies. However, there were studies which aimed at quantifying the impact of this practice and possibilities in mitigation actions, such as the development of technologies to inspect overloading in a more efficient way. Subsequently, it is imperative to note that the frequent weighing of trucks slowed the supply chain discrepancies with an increase on operational costs, emphasising the importance of using ICT to share information. The South African overweight control centres do not have electronic tracking, so this led to overloaded trucks using road infrastructures and resulting in overload and damages to the existing pavement structures (Ghisolfi *et al*., 2019). In freight transport, the performance criteria revealed rail having better performance than road transport, except in terms of employment multipliers as road is more labour intensive. Although it creates more opportunities, it has poorer performance in terms of number of jobs generated by direct employment (Gardenete *et al*., 2018).

2.8 Summary

The freight transportation system is made up of a network that delivers a variety of services with varying performance depending on infrastructure and operations, and in South Africa, regions with higher transportation mode challenges are given consideration (Department of Transport, 2015b). Furthermore, as demand grows, the current shape and form of freight transportation is unsustainable, as it is primarily serviced by inefficient and reliant transportation options such as fuel costs, transit time, fare costs, waiting times, and travel distances (Lane-Visser & Vanderschuren, 2019). These challenges, however, cause a wide range of complexities in service delivery failures, which may have an impact on the country's economic growth. Furthermore, the central regions of South Africa (including towns such as Bloemfontein, Johannesburg, Nelspruit, and Kimberley) have a high demand for freight movement due to population growth and urban sprawl (Reyneker & Drent, 2012). Despite an increase in demand for freight movement in the central regions, there appear to be cost, capacity, transit speed, and resource availability challenges (RFA, 2014). These underlying issues in freight transportation, if not controlled and managed, may result in deficiencies such as reliability, degree of certainty, congestion, increased freight costs, and predictability in travel times (Antonowicz, 2011). As a result, proper freight transportation planning and informed decision making are required, particularly during data collection and information tracking of freight movement. Furthermore, to achieve a sustainable freight transportation system, some of these freight analysis techniques must be used to provide models for generating feasible routes from origin to destination for all shipments, which can be supplemented by implementing either intermodal or multimodal transportation systems.

CHAPTER 3: PROFILE OF THE STUDY AREA

3.1. Introduction

The study area is important in identifying the freight travel patterns that exist within the country and determining the influence of transportation modes on spatial interaction, such as recreational areas, commercial areas, industrial areas, and residential areas. Therefore, this study focused on the parts that form the central regions of South Africa, namely the Free State, Mpumalanga, Northern Cape, and Gauteng. These areas were considered for this study due to their significant contribution of freight movement and the large impact on the country's economic growth by sustained manufacturing results.

The case study was specifically based on the central regions of South Africa consisting of provinces such as the Free State which is made up of various towns such as Bloemfontein, Welkom, Harrismith, Bethlehem, and so forth. In order to provide more insight to this study and the results that contribute to the development of a sustainable freight transportation system in the central regions of South Africa, a thorough understanding of the study area was required for geographical background, infrastructure status, economic contribution, and freight movement within, to and from the region.

The red line in Figure 3.1 represents the central regions of South Africa used for this study. These chosen provinces provide freight movement within the central regions and other parts of the country. Subsequently, Gauteng, Mpumalanga, the Free State, and some parts of the Northern Cape form the central regions of South Africa with several freight routes and corridors for both road and rail transport. The major towns within South Africa's central regions contribute significantly to the country's economic growth as these towns produce and manufacture commodities such as minerals, materials, agricultural products, and more, that sustain the economic status of the country.

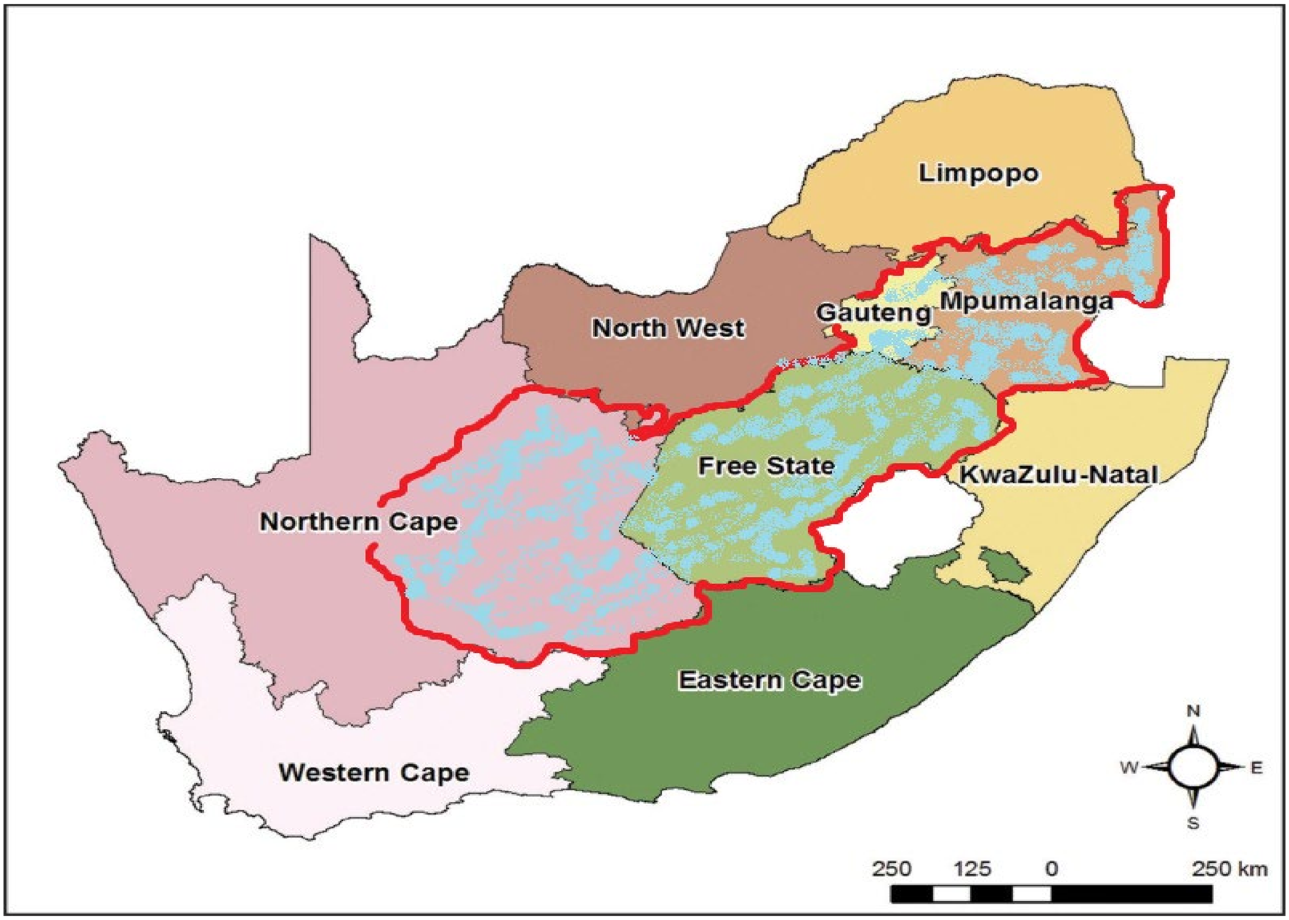


Figure 3.1 Central regions of South Africa (Baseline map source: Google maps, 2017b).

3.2. Geographical Background

3.2.1. Gauteng

This region is located in the central north-east of South Africa and covers an area of approximately 18 179 km^2 with a population of approximately 15 million people in 2021. Gauteng accounts for approximately 26% of South Africa's total population, making it the country's largest region in terms of population and contribution to all economic activities. Further, Gauteng is the economic hub of South Africa and has a mechanism in place to ensure a greater efficiency and economic productivity in the movement of freight within this region (Stats SA, 2021). Consequently, Gauteng is a fast-growing region so the demand for infrastructure, housing, food, energy, and sanitation is rapidly increasing, and the government is forced to meet these demands. Therefore, this expanding economy is also putting increased pressure on available land, road transport systems and energy resources. Gauteng has also contributed to the development of South Africa's transportation and logistics sector which forms a vital role in economic improvement and job creation. However, this has resulted in a positive spin off to the country in terms of the ability to export and import goods (Reyneker & Drent, 2012).

Additionally, Gauteng acts as an important gateway for key freight routes since it serves the central hub, and its hub infrastructure includes the freight ring, inland terminals and feeder corridors as follows: Gauteng to Durban which is the most important freight corridor in South Africa; Gauteng to Cape Town freight and passenger rail routes; Gauteng to Eastern Cape freight route; Gauteng to Musina via Polokwane towards Zimbabwe, and Gauteng to Komatipoort towards Maputo in Mozambique.

Figure 3.2 shows the main freight routes and corridors within the Gauteng region. From the figure, it is evident that there are high volumes of freight flow within this region as it consists of one of the greatest central hubs in South Africa, called The City Deep. It also forms more route links and corridor feeders within the transportation network of the country, and this further implies Gauteng is recognised as the distribution centre of freight movement in South Africa.

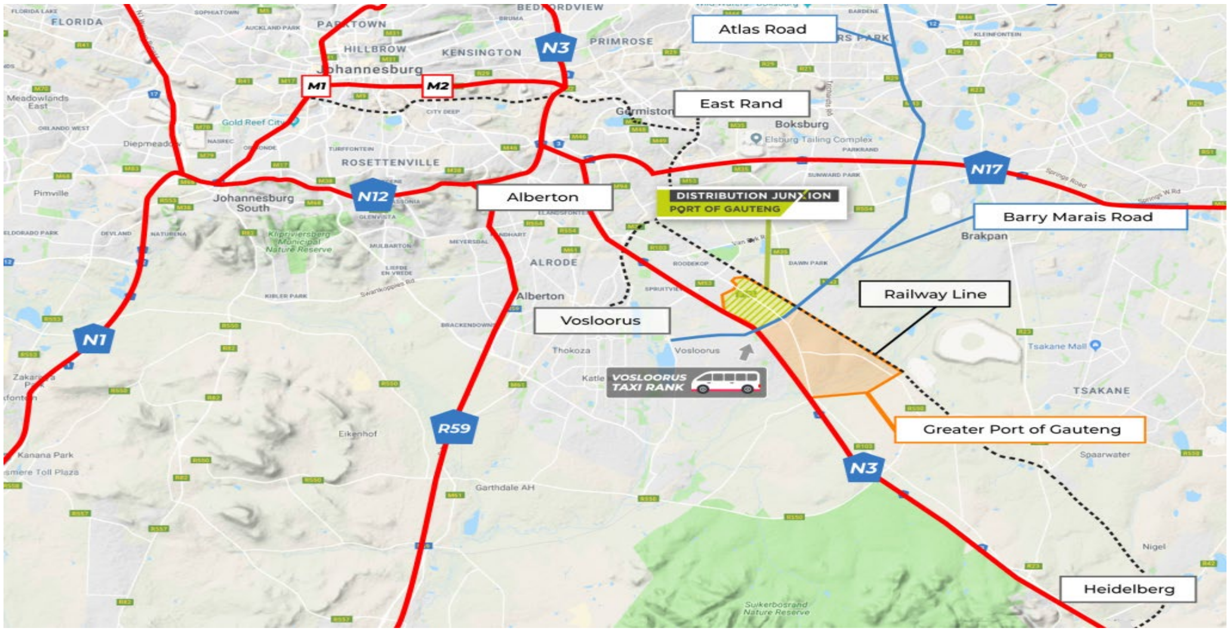


Figure 3.2 The map of the major routes and corridors in the Gauteng province (Source: Poverello Maps, 2014).

3.2.2. Free State

This province consists of various towns but, for the purpose of this study, the focus will be on Bloemfontein as it is the economic hub of this region. The city is centrally located in South Africa and is served by major roads such as the N1 which links Gauteng with the southern and Western Cape, the N6 which links Bloemfontein to the Eastern Cape, and the N8 which links Bloemfontein to Lesotho. However, there seems to be a major relocation of services from the Bloemfontein CBD suburbs, particularly to the west of the city and this has led to under-utilisation of the available office space in the central business district. Hence, it is a concern of the manufacturing industry as it is declining, and it is characterised as mixed land use (Integrated Development Plan [IDP], 2018/19).

Concurrently, Bloemfontein under the Mangaung Municipality is the largest contributor to the GDP of the province and is better regarded as the most economically diverse in nature (Pauw & van Schoor, 2005a). In the Free State, the overall growth in the manufacturing industry is closely linked to the fuel, petroleum, and chemicals sub-sector that is found in Sasolburg. Subsequently, in relation to the transportation sector, the modes mostly used by travellers from Bloemfontein are private vehicles and freight trucks. However, more than 40% of passenger trips are made by public transport as the demand pattern provides safe and reliable services (IDP, 2018/19).

Figure 3.3 shows the Free State region which consists of five district municipalities, as follows:

- Xhariep
- Lejweleputswa
- Northern Free State
- Thabo Mofutsanyane
- Motheo

Bloemfontein, which is the provincial capital city, is found in the Motheo District and is defined as the metropolitan city with the highest economic activities occurring in this area. Also, this capital city allows for freight movement distribution from Gauteng to other regions in South Africa as a high number of businesses are located in this area (Free State Development Corporation, 2018).

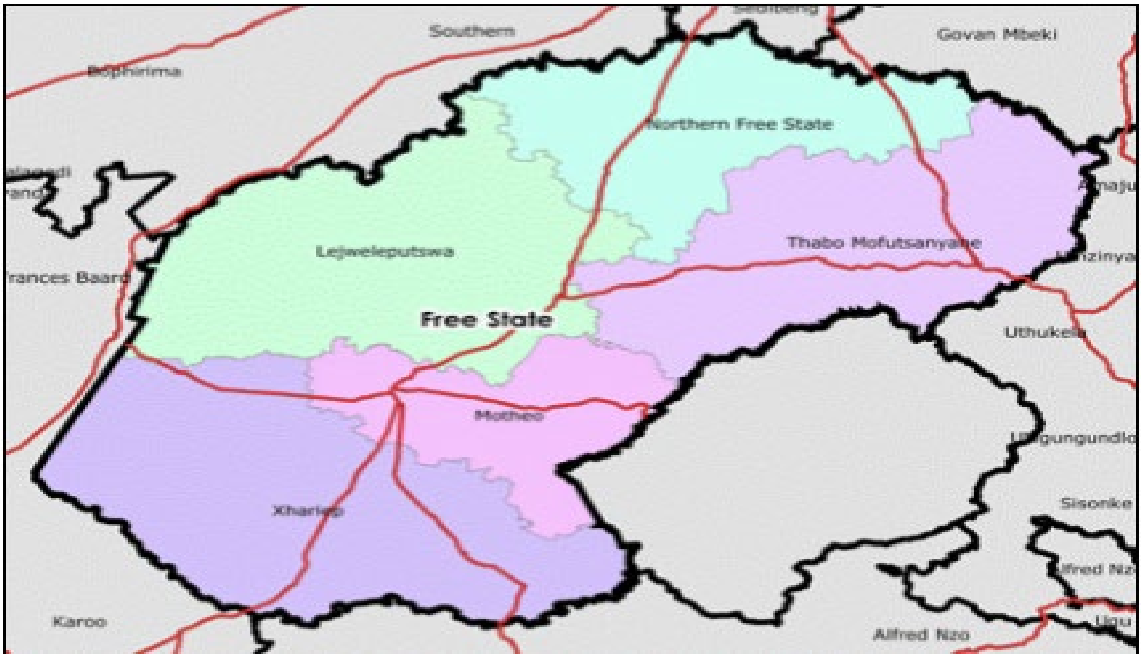


Figure 3.3 Free State districts' transport network (Source: Demarcation, 2010).

3.2.3. Mpumalanga

This is a relatively small province and shares its eastern border with Swaziland and Mozambique. Most of the inhabitants basically reside in rural areas and thus household agricultural activities are at their peak in this area. Hence, Pauw and van Schoor (2005b) stated that the income distribution found in Mpumalanga is not as skewed as compared to the rest of the country.

Otherwise, Mpumalanga has a Northern Functional Area and MR385 corridor which is located on the south-western side of the N3 in the outer west of the eThekwini Municipality. However, the eThekwini Municipality Plan (2018) stated that there is a mixed-use development corridor that structures and integrates the main economic centres and residential areas along the corridor including the Mpumalanga New Town Centre (eThekwini Municipality Corridor Plan, 2018). Therefore, this corridor provides the interface between the primary movement network connecting Mpumalanga to the broader metro areas and opportunities such as industrial, logistic, and business contributions are obtained in this area (eThekwini Municipality Corridor Plan, 2018).

Figure 3.4 shows the spatial development corridor for the MR385 corridor. This is important in showing the corridors and routes found in this region and that allow for freight movement. From the figure, rail freight transportation plays a significant role in transporting cargo using the MR385 corridor found in Mpumalanga, and this implies that sustainable urban mix use, including industrial expansion is possible through the incorporation of the optimal and efficient use of freight rail in this region.

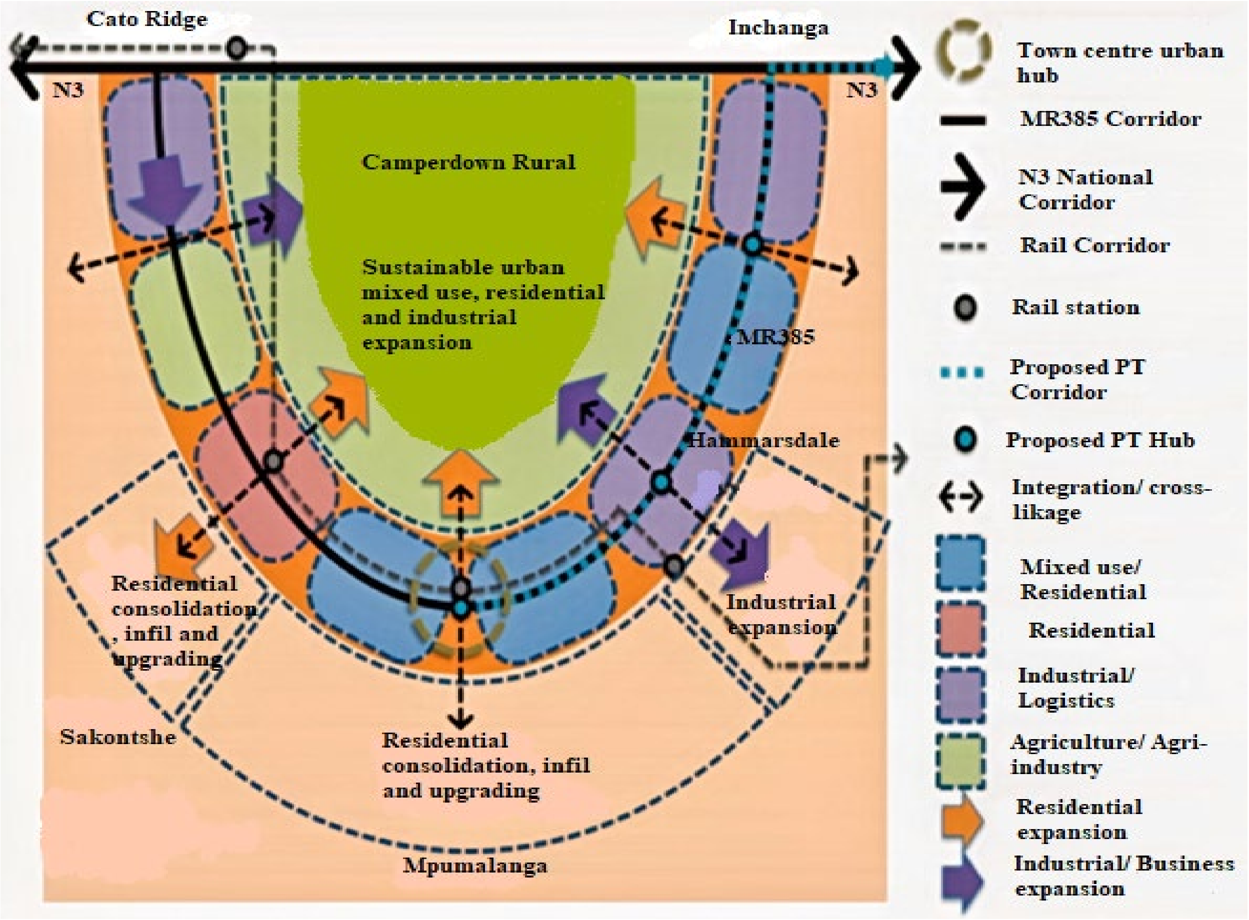


Figure 3.4 Diagram showing the Spatial Development concept for MR385 corridor (Source: eThekwini Municipality Plan, 2018).

3.2.4. Northern Cape

The Northern Cape contains one of the major exporters of grapes, fruit and meat and is an important distributor of cattle, sheep, and goat farming in South Africa. It is one of the regions that consist of elevated private sectors contributing through the mining industry which produces and distributes minerals such as manganese, iron ore, and coal to other regions in the country (Stats SA, 2018). This region covers the largest area of all the provinces and has the smallest population, but contains important towns such Upington, Kuruman and De Aar. Upington constitutes the centre of karakul and dried-fruit industries and contributes highly to the wine-making markets, and Kuruman consists of an important junction of South Africa’s railway network and comprises a vast number of mines.

Additionally, one of the largest hubs in South Africa is known as ‘The De Aar Logistics Hub’ which serves as the first step for the long-term solution sought by this region to optimise the freight strategies and combat the logistics challenges (Transport Infrastructure, 2014). Also, there are various commodities such as coal, lime, general cargo, and automotive components that are moved by rail through De Aar, and which are needed for domestic market. Therefore, this region is rich in minerals with mines such as Sishen being able to contribute the biggest source of iron, copper, manganese, and diamonds to the country. Consequently, this region contains high volumes of freight movement and distribution and thus forms a significant role in the economy of South Africa, hence it was chosen as one of the study areas.

Figure 3.5 shows the rail corridor map for freight movement within the Northern Cape region. Subsequently, the rail network runs through De Aar to Hotazel and to other regions in South Africa as indicated on the map. From Figure 3.5, it is evident that the Northern Cape does not only have an integrated rail corridor network but also consists of the central industrial zone known as Namakwa SEZ. This industrial zone contributes highly to the economic growth of the country through distinctive manufacturing and production of general cargo to other parts of the country.

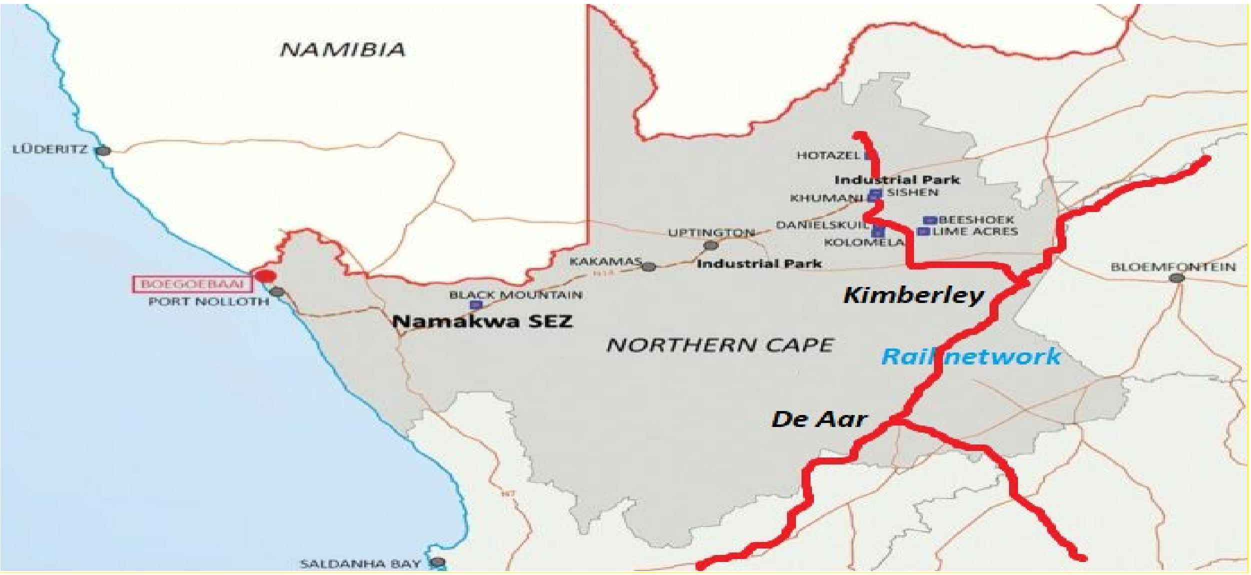


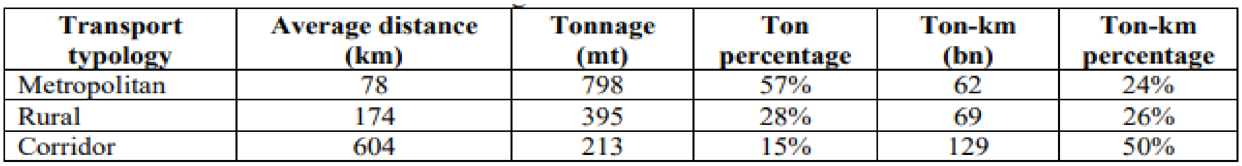
Figure 3.5 The rail corridors in Northern Cape for freight movement (Source: Google Maps, 2017b).

3.3. Freight Transportation Overview

In accordance with the 2016 South Africa Logistics Barometer, which has the cost of logistics for putting freight at the right place at the right time as a percentage of GDP, this number increased from 11.1% in 2013 to 11.2% in 2014 (Havenga *et al.*, 2016a). This trend is expected to continue, which will be higher than most developed countries but competitive when compared to other developing countries. Additionally, it further states that the demand for land freight transport in South Africa reached 848 million tons in 2014 – an increase of approximately 8.4% from 2013. Concurrently, these statistics revealed that the total volume of 76% was contributed by the primary economy (agriculture and mining) while contributing about 44% to the transportable GDP, with the secondary (manufacturing) sector making up the remaining 24% but added 56% value to the transportable economy (Myburgh, 2018). Concurrently, the fuel prices have affected a broad swathe of the economy, from public transport to freight, and in turn, consumer goods which drives the economic growth of the country. However, Bohlmann and Crompton (2020) revealed that when amendments could reduce fuel prices by 10.82 cents/litre, there will be 0.67 increase in the GDP leading to an improved freight transportation status quo in South Africa.

On the contrary, in South Africa, there is a heavy reliance on road transport for movement of goods, which can be seen in Table 3.1, and this places a burden on infrastructure maintenance and delivery, especially on the long-distance corridors between major cities and ports. Table 3.1 also shows the road freight volumes on three different typologies, namely based on percentage of freight load contributions. Therefore, from Table 3.1, there is high freight load movement for the corridor transport typology due to rail transportation mode being able to carry large quantities of freight. However, this proves that there is a lack of proper and regular maintenance which is negatively affecting the economy as well as the ability of the country to contribute or even compete globally. Consequently, this has led to a serious backlog on total logistic costs and the competitiveness of South African freight contributions (Havenga *et al.*, 2010d).

Table 3.1 The road freight volumes on 3 transport typologies in South Africa (Source: Havenga *et al.*,2010d)



Transport typology	Average distance (km)	Tonnage (mt)	Ton percentage	Ton-km (bn)	Ton-km percentage
Metropolitan	78	798	57%	62	24%
Rural	174	395	28%	69	26%
Corridor	604	213	15%	129	50%

Furthermore, Steyn *et al.* (2010d) discovered that road quality can potentially affect vehicle operation and operational costs, which can eventually translate into negative or positive effects on freight transportation costs, which further affect the economy. Their comprehensive study also concentrated solely on increases in the total repair cost of suspension and trailer components of trucks traveling on deteriorated roads, which resulted in higher logistics costs for the affected logistics companies.

3.4. Challenges of the Study Area

In a broad perspective, the integrated railway must be innovative in order to make greater economic use of its infrastructure, and all this can be possible through the provision of creative service offerings that require coordination of infrastructure and operations strengths (Dube, 2014:7). Moreover, the ability to access railway infrastructure has a significant bearing on the movement of freight for most sectors of production that make use of rail, especially where there is mixed use of minerals and non-minerals that demand similar rail lines (Dube, 2014:13). Also, the underlying challenge that the provincial road departments face in South Africa, is to establish an integrated sustainable transport system that will contribute to the provision of safe, reliable, effective, efficient, and fully integrated transport operations and infrastructure that will best meet the needs of freight and passenger customers at improved levels of service (Transport Infrastructure, 2014). Although road transportation is the most common mode for freight, there seems to be the challenge of overloading freight vehicles, especially on secondary roads where law enforcement is ineffective. Therefore, this problem is not only detrimental to the quality of South African roads, but it poses a major risk to road users as well (Department of Transport [DOT], 2011a).

CHAPTER 4: METHODOLOGY

4.1. Introduction

This study adopted quantitative research methods which will assist in achieving the objectives set out. The quantitative method was applied due to an emphasis on objective measurements such as statistical and mathematical analysis of data collected through questionnaire surveys and analysing pre-existing statistical data using computational techniques. Since there are a variety of quantitative methods, in this study, focus was more on the survey type as it encompasses the use of a scientific sampling method which involves the utilisation of road versus rail transportation with a designed question to measure a given population such as the efficiency of using either rail or road for movement of goods. However, data was collected using one type of survey method known as self-administered questionnaires which was supported by historical and statistical data (as presented in Appendix A & B). This approach was significant as it provided the complex description of freight transportation in terms of its efficiency and economic contribution based on involved stakeholders' perception in the central regions of South Africa. Self-administered questionnaires, according to Porter and Bhattacharya (2005), are effective in revealing problems because they incorporate trial-techniques that allow more freedom of expression and quick response because they can be conducted independently and in pairs, overcoming problems encountered by other survey methods such as focus groups.

This study employs the quantitative research method, which follows the steps outlined below; however, specifics on these steps are presented in the following sections, as well as in Chapter 5:

- Data for this study were obtained by tracking freight movement information for both road and rail from origins to destinations using parameters such as time, distance, and so on.
- This information was gathered through primary and secondary sources. A survey questionnaire was used to collect primary data in order to address the current economic and operational efficiency of road and rail. Secondary data related to historical and statistical data that addressed the current state of freight transportation in South Africa's central regions.

- These collected data were subjected to a variety of data analysis methods, including inferential statistical methods and descriptive methods.
- Following inferential and descriptive analysis, a model was developed because they provided parameters that are significant for this model. This model was created using multiple regression analysis.
- Based on the model, simulation scenarios were run to provide the anticipated freight share between road and rail in this study. This was accomplished using an empirical model known as the Binary Logit model, which could aid in determining the modal split share of freight and cost between rail and road through probability selection.
- To confirm the model's reliability, it had to be validated, which was done by comparing the estimated freight costs obtained from this model with the actual costs from the current marketplace.
- Once the validation had been conducted and the model proved to be valid, the outcomes of these results were used as guidelines for providing a balanced freight transportation system in the central regions of South Africa.

4.2. Data Requirement

Time dimension freight data has been the most important area of data which identified and measured the productivity of freight transportation within regions. It provides the time recognition and tracking information from freight companies with regard to the movement of goods around and outside the regions. Also, an imperative aspect about this data involved issues such as just-in-time and next-day delivery, as well as time-sensitive commodities that were prioritised to help for future activity planning in freight and logistics.

Although for the purpose of this study, time dimension freight data was used, there is a variety of data that are currently available from smaller, local survey data to larger platforms such as national commodity flow data that involves hard-copy improvement plans to digital sets stored on electronic databases. Below are some of the data that were used in previous studies of freight and logistics relating to the central regions. These data were extracted in use for the purpose of this research.

4.2.1. Small area commodity flow data

This is the degree of detail that allows one to record small area commodity flow, for example Bloemfontein, in this case, and the obtained data must be modelled and assigned to regional highway and railroad networks. However, most agencies such as Transnet Freight Rail refused to release information for public use unless it is aggregated and requested by their clients, so this contributes to limited data being collected.

4.2.2. Regional and local truck trips

This is the data on truck trips from different warehouses to retailers within the central regions of South Africa which were needed to measure the demand on local infrastructures. This data helped to evaluate the total number of trips to designated areas such as grocery stores, gas stations, and similar facilities which may not vary greatly among cities depending on the population sizes.

4.2.3. Regional freight databases of metropolitan planning organisations

It was applied to large areas by collecting data that includes corridor travel, cordon-line checks and inflow/outflow imputations. Therefore, it provided the correct systematic representation of the network links involved in freight transportation around any region under investigation.

4.3. Data Collection

As scenarios and challenges of freight transportation can differ from region to region, the assessment was done by obtaining historical and statistical data from reliable internet sources such as Stats SA which keep records of the annual freight and logistics projections within the selected region (Stats SA, 2011a-2021*l*). Furthermore, some freight and logistics companies provided historical data through company magazines and inventory management records. All this data was consolidated by the researcher in order to make a viable assessment of the scenarios of freight transportation systems and challenges encountered in the central regions of South Africa. Regarding examination of the current economic and operational efficiency of freight transportation by rail and road, the researcher obtained 41 samples of data from different stakeholders in the freight and logistics industry. This was done by scheduling physical appointments with the operational managers, operators and inventory managers of various freight and logistic companies.

Subsequently, these self-administered questionnaires consisted of a set of 20 questions that examined factors such as travel distance, cost of load per tonnage, travel time, and so forth (refer to Appendix B). Furthermore, these questionnaires were designed to cater for freight feeders and distributions, which included the entire freight movement from one feeder to the other in terms of service delivery for both transportation modes. Consequently, stakeholders involved in this industry indicated that their feeder and distribution is from point of loading at one station/hub(origin) to the point of offloading at the other station/hub (destination) comprising of feeder from goods source to the mode of transportation then distributed to the end user and with road being from one warehouse (origin) to the other (destination) inclusive of the door-to-door service delivery. This further entails that respondent provided the total freight movement, including feeder and distribution, based on tonnage per kilometer for the entire route or corridor of both freight road and rail. As a result, the stakeholders involved were required to respond based on their knowledge of the economic and operational efficiency of using either road or rail freight transportation modes but providing the entire freight movement of their major routes. This data was gathered from various regions within South Africa's central regions to provide a comprehensive picture of the past and current freight transportation system.

Once primary and secondary data were obtained, it was consolidated and represented in graphs and tables, then assessed and analysed to address the relatable objectives of this study. Various inferential statistical analysis methods, such as correlation, t-test, and multiple regressions, were conducted based on the results obtained in order to develop an estimated model. Concurrently, as the consolidated data had different parameters with varied significance, a disutility function had to be developed. This disutility function or generalised cost was an empirical model which could allow various independent parameters to have a common unit of measurement that would later be used in inferential statistical analysis. Furthermore, from inferential statistical analysis, the model was estimated which provided an optimal split of freight share by rail and road (trucks) within the central regions of South Africa. As a result, this objective was addressed from the results obtained from the developed model. The developed model, called Binary Logit model, provided the freight share between road and rail under varying scenarios within the central regions and other parts of South Africa. This was done by developing various simulation scenarios and determining the freight share as well as the generalised freight cost between the two transportation modes under study. Furthermore, from the obtained simulation scenario results, the most feasible scenario was obtained which can provide a balanced modal split between freight road and rail in terms of freight share and generalised freight cost. Consequently, based on this feasible scenario and findings of the study, guidelines were then developed to allow for the balanced and optimal freight transportation system by using both rail and road transportation modes.

4.3.1. Primary data

There are a couple of survey techniques used to collect primary data, including establishment survey, freight operator survey, driver survey and vehicle traffic counts. Description of these techniques is presented below:

- Establishment survey

This is the survey technique used in urban freight to collect data about total goods vehicle trips to and from establishments and variation by time, day, and month. It is usually conducted face-to-face and self-completion. This type of survey is meant for gathering samples such as vehicle delivery, goods flows, service trips and origin location of goods (Allen & Brown, 2008).

- Freight operator survey

It provides the opportunity for collecting wide ranging data about the pattern of the companies' vehicle activities in the urban area. It is also conducted face-to-face and telephonically but covers small aspects of freight such as trip details and patterns of goods vehicles, movements of goods between vehicles and origin location of goods flow (Allen & Brown, 2008).

- Driver survey

This is the most common type of survey as it is used to gather data about the driver's overall trip pattern as well as the loading and unloading activity in the street in which the survey takes place. It is usually conducted at establishments receiving collections or deliveries and is most suited to addressing the trip details and movement of goods (Allen & Brown, 2008).

- Traffic counts

This has been adopted by many freight and transportation companies including government institutions as it involves the simple counting and disaggregating by vehicle type and can range from a variety of transportation modes up to an entire urban area. It can be achieved either by manual counts or automated counts. It is important to consider the fact that for manual counts the extent of disaggregation may be limited by the degree of expertise of the surveyor whilst for automated counts it is through the sophistication of the technology (Allen & Brown, 2008).

4.3.2. Secondary data

In secondary data, there are various survey techniques that are available in collecting data, namely GPS survey, vehicle trip diaries, and service provider survey. These techniques are briefly explained below:

- GPS Survey

This kind of survey consists of a specialised device that can provide data at frequent intervals as well as speeds. It is usually conducted by fitting the transmitter in the vehicle. As a result, the GPS survey covers the trip details and patterns of goods vehicles, the loading and unloading activity of goods, and parking activity of service vehicles in the urban area (Allen & Brown, 2008).

- Vehicle trip diaries

As the name suggests, this survey technique basically consists of detailed information about the activities of a single vehicle and provides data about exact locations served, route, arrival and departure times, and type of goods. It is conducted by self-completion of surveys by the driver. It covers aspects such as parking activity of service vehicle, loading and unloading of goods and trip details of service vehicles in the urban area (Allen & Brown, 2008).

- Service provider survey

Service provider survey is quite similar to freight operator as it provides wide ranging data about the pattern of the companies’ service activities and supporting vehicle activity in the urban area. It also allows the opportunity to obtain data about the entire fleet rather than a single vehicle. The service provider survey consists of trip details and patterns as well as the parking activity of service vehicles in the urban area (Allen & Brown, 2008).

4.4. Data Analysis

4.4.1. Cross-sectional study

This is the survey that is usually carried out at just one point in time, and it provides a snapshot of what happens in a group for that specific time (Mathers *et al*., 2009).

4.4.2. Longitudinal study

Longitudinal survey is the most adapted data analysis method as, unlike the cross-sectional survey, it paints a picture of events or attitudes over a certain period. It usually consists of two forms as either cohort or trend survey (Mathers *et al*., 2009).

4.4.3. Explanatory study

This type of data analysis method allows the researcher to try exploring existing relationships between two or more variables under investigation. It incorporates the use of statistical tests which can reveal the significant differences between various groups in a survey (Mathers *et al*., 2009).

For this study, a quantitative method was used in conjunction with longitudinal and explanatory study because it included stakeholders who provided a broader perspective and investigated the relationships between road and rail transportation. This quantitative method is advantageous because it provides both historical and current quantitative data for the study under investigation, resulting in excellent research content.

4.5. Assessment of the Status Quo and Challenges of Freight Transportation Systems

Both descriptive (percentage, mean, and standard deviation) and inferential statistical methods such as correlation, variance inflation factor, significance tests and multiple regression analyses were conducted to assess the current scenarios and challenges of freight transportation. For the descriptive statistical method, standard deviation was used to measure the consistency by determining the data points' relationship with the mean, kurtosis and skewness were used to measure the symmetry probability distribution of random variables in relation to their means and, lastly, Cronbach's Alpha was used to determine the reliability by studying the relationship of variables as a group for the obtained primary data set. Therefore, the obtained primary data set underwent disutility function matrix which provided viable results to be used for inferential statistical methods. Additionally, the disutility function method involved the process of assigning independent parameters with weights and ranks to obtain the same unit of measurement for the dependent parameter (generalised freight cost) (Mathew & Rao, 2007). Consequently, significance tests (t-tests) and multiple regression analysis will be used to examine factors that influence the freight transportation in the study area. The mentioned inferential statistical methods are described hereafter.

4.5.1. Correlation

Correlation is defined as a statistical tool that is used to assess the degree of association of two quantitative variables measured in each group (Maurage *et al*., 2013). It usually assumes that all the observations are independent of each other and, thus, are not supposed to be used if the data include more than one observation on any individual. This degree of correlation between any two variables on a continuous scale is mathematically expressed as the correlation coefficient (also known as Pearson's correlation coefficient) and which is further described as a number of which the values can vary between -1.0 and +1.0 (Maurage *et al*., 2013). For this study, the correlation was adapted by assessing the haulage or mass loads delivered when using either freight road or rail transportation in the central regions of South Africa.

4.5.2. Variance

The purpose of this analytical method is to measure the dispersion of a set of variables by simply describing the extent to which they differ from each other. In this study, the variance was established between the utilisation of road and rail by the identified stakeholders. The analysis was conducted in such a way as to determine the most preferred mode of transportation between the two, especially for the movement of goods within the selected provinces. There are three types of variances that the researcher should align themselves with, namely experimental variance, extraneous variance, and error variance. The experimental or systematic variance was used in this study, particularly, because it helped to maximise the variance of the variables for substantive research hypotheses (Murray *et al.*, 2012). It further allows the identification of type of freight data under research, such as fuel type, loading method, delivery time, and so forth, which provided distinctive information and thus maximised the hypotheses (Kothari, 2004). The variance of independent variables also assisted in determining the Cronbach's Alpha which assisted in determining the reliability of the data set.

4.5.3. Significance tests

This is the formal procedure for comparing observed data with a hypothesis in which the truth that is being assessed consists of the statement about the perimeter under study. It is important to note that the results of a significance test are expressed in terms of a probability that measures how well the data and the claim agree. Tests of significance take four steps, described as follows:

- *State the null and alternative hypotheses*:

This is the first step in conducting a test of statistical significance as the claim tested is called the null hypothesis and is usually referred as the "no difference" statement as it is designed to assess the strength of the evidence of the hypothesis (Mindrilla & Balentyne, 2014).

- *Calculate the test statistic*:

This is the part where the sample mean of the data is being determined and is called the "z" score. It is then computed by considering the population standard deviation for the designated variable. Once the sample mean has been classified and computed, then the steps that follow are to find out the probability of obtaining the same results if the hypothesis is true (the p-value).

- *Find the P-value*:

Before the p-value can be observed, the significance level is found on the computed graph as the alpha value. If the p-value is less than the alpha value, then the null hypothesis can be accepted and the alternative hypothesis rejected. So, if the p-value is larger than alpha, then the null hypothesis must be rejected, and the alternative accepted. The significance test was used in this study to identify significant parameters from all the parameters chosen for model development. This was accomplished by comparing a set of independent parameters (fuel consumption, load cost, travel time, and so forth) to a dependent parameter, also known as the hypothesis (generalised freight cost), with the p-value of these independent parameters (null hypothesis) having to be less than 0.05 (alpha) for them to be deemed significant and chosen for development of the model.

4.5.4. Multiple regression analysis

In this analytical method, the art and science of fitting lines to patterns of data was practised. It is important to know that in a multiple linear regression model, the variable of interest, also known as the dependent variable, is predicted from *k* other variable using a linear equation. The equation for the assumption of Y value is as follows (Kothari, 2004):

$$\acute{Y} = \beta_c + \beta_1 X_I + \beta_2 X_2 + \cdots + \varepsilon \ldots \tag{4.1}$$

where:

$\acute{Y}$ = calculated parameter

$\beta_c = intercept\ or\ constant\ beta\ coefficient$

β_1 = beta coefficient with subscript 1 for first

β_2 = beta coefficient with subscript 2 for second

$X_I = parameter\ with\ subscript\ 1\ for\ first$

$X_2 = parameter\ with\ subscript\ 2\ for\ second$

$\varepsilon =$ epsilon denoting 5 th parameter in a series

4.5.5. Variance Inflation Factor

This is the step were the VIFs are used to detect collinearity among predictors in a multiple linear regression model. In most cases, the high VIFs reflect an increase in the variances of estimated regression coefficient and may be due to collinearity among predictor variables (Kutner *et al.*, 2004). The formula for calculating VIF for the multiple regression is as follows:

$$VIF = \frac{1}{1 - {R_i}^2} \tag{4.2}$$

where:

$R^2 = percentage\ of\ the\ varience$

I = independent parameters (Murray *et al.*, 2012)

Furthermore, an existing empirical model will be used to examine the economic and operational efficiency of the current freight transportation under both rail and road freight transportation. It should be noted that equations 4.3 and 4.4 are more commonly used for passenger transportation; however, they were also used in this study because the 'travel time' and 'travel distance' include walking distance to and from the warehouses and stations. This means that in the freight context, "h" walk time from parking to destination refers to the time the operators take during mode inspection and when they exchange operators (during shifts) to the time they get in the mode itself and begin movement. The models that will be used to determine the relative travel time and travel cost are as follows (Salonen *et al.*, 2013):

$$Relative\ Travel\ Time\ (RTT) = \frac{a+b+c+d+e}{f+g+h} \qquad (4.3)$$

where:

a = in-vehicle travel time
b = transfer time between transit vehicles
c = waiting time for transit service
d = walking time to transit service
e = walking time from transit service
f = personal vehicle driving time
g = parking delay
h = walk time from parking to destination

$$\text{Relative Travel Cost} = \frac{i}{(j+K+0.5P)1/m} \ldots \qquad (4.4)$$

where:

i = Transit Fare
j = Cost of Fuel
K = Cost of lubricants
P = Parking Cost at Destination
m = Average Car Occupancy

After finding the values for the Relative Time and Cost calculations, then they were used as inputs in the following formula to determine the probability of using either freight road or rail transportation system using a Binary Logit model (as shown in 4.6.4).

4.6. Development of the Model

A Binary Logit model was developed for the assessment of the efficacy of future scenarios under different models of freight transportation. The model development will follow the following steps:

- Initial setting of the model
- Attributes selection
- Attribute indicators and measurements
- Model fit and validation
- Simulation and scenario analysis

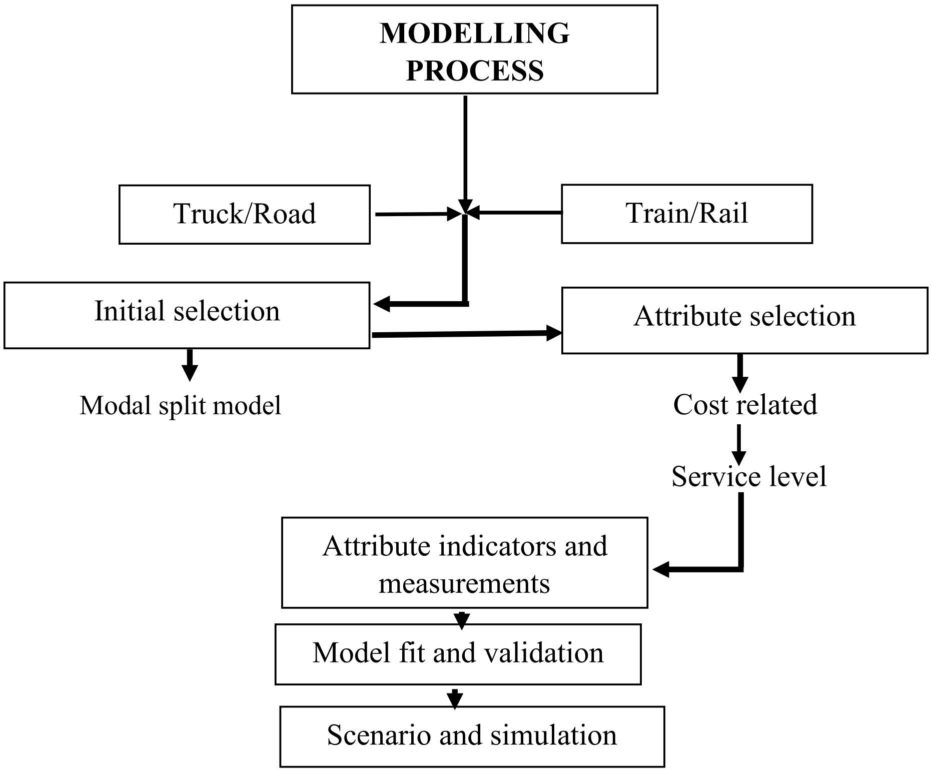


Figure 4.1 The modelling process used for the development of a Binary Logit model

4.6.1. Initial setting of the model

As this is the first stage, a description of the sample and characterisation of the analysis is provided. During this phase, the idea is to fit a modal split model that would consider the key attributes determining the choice between road and railway transport in the central regions of South Africa and by considering the transfer operations between specified ports and distribution centres. According to the Department of Transport (2015b) there is a demand for general freight to the main transport corridors in the central regions of South Africa. Therefore, the identified demands are then divided into two groups of general cargo of high aggregate value (AV1) and general cargo of low aggregate (AV2). Consequently, there will be a selection of the corridors with the greatest flow, such as the one on the N5 which links Bloemfontein to Bethlehem, and to the most operational logistic city in the Free State, the Harrismith Hub.

4.6.2. Attributes selection

This step incorporates all the selected attributes into the modal split model. The previous studies show that these attributes are usually due to high incidence of cost-related matters, and some are from service level. Subsequently, based on the provided information and prior knowledge of the problem of imbalanced freight transportation system, the decision to choose the one cost attribute, logistic cost and two service level attributes is made to ensure an ease detection of any unforeseen challenges in this industry. This means there is a standard rate provided to each mode of transportation based on their service delivery and economic impacts.

4.6.3. Attribute indicators and measurements

This stage is usually referred to as an “eyelid” stage as indicators associated with freight transportation system and measurements are found here and are used to determine the time series of logistics and the levels of the road and railway transport supply. Hence, to get the measurement of logistics correct, the sum of the transport, stock, handling and storage between an origin and a destination must be determined. Furthermore, for the transport supply to be measured, the assumption must be made on the supply for general freight in a specific transport corridor to be proportional to the amount of general cargo under investigation.

4.6.4. Model fit and validation

This is the most crucial stage in modal split as it contains an equation known as the Binary Logit model. This equation was used before in academic and transport planning research to find some correlations between road and railway transportation. The market share had to apply this effective equation adapted by Basuroy and Nguyen (1998) and Tran (2003) as it showed some development in the adaptation of logit-type models that assumed the probability of choosing a transport alternative as equal to market share.

$$p_{t1/t2}^{mode} = \frac{e^{-\mathbf{Cijt_1}}}{e^{-\mathbf{Cijt_2}} + e^{-\mathbf{Cijt_1}}} \quad \cdots \tag{4.5}$$

where:

$P_{t1/t2}$ = is the probability of choosing either mode 1 or 2

$e^{-\mathbf{Cijt_1}}$ = the exponent of cost of mode 1

$e^{-\mathbf{Cijt_2}}$ =the exponent of cost of mode 2 between zone i and j.

It is evident that freight transportation provides traffic congestion problems to the commuter on urban streets of each region in South Africa due to improper road widths and irregular traffic behaviour on the road. Therefore, in this study, the Binary Logit model was used to evaluate the most efficient mode choice by means of trips and distinguished mode behaviour. For mode split analysis, data on staff, clients and suppliers must be collected. Additionally, tables were created to provide the percentage freight share of each mode of transport. However, focus was made more on the overall freight cost that can be used to distinguish the mode choice based on various travel factors (Tejaswi, Kumar & Kumar, 2015).

4.7. Simulation and Scenario Analysis

Figure 4.2 shows that there is no unified approach that is developed for modal split calculation in the community, but there are some terms that can be defined and implemented in achieving this model. Comprehensibly, there should be a development of a scenario that allows two modes and, in this case, rail and road to be utilised simultaneously in the transportation of cargo leading to intermodal freight transportation. Therefore, this will then allow the participation of both transportation modes without one of them being unfairly utilised and not being used at all in the freight transportation system.

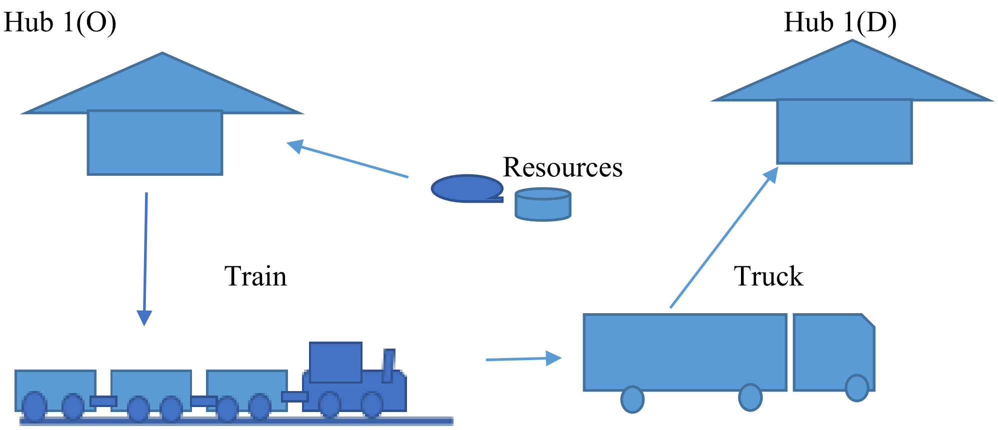


Figure 4.2 Example of a scenario that incorporates two modes of transportation

Consequently, to develop a more optimal modal split model, the design of the Trip Interchange Model referred to as the Diversion Curve Model can also be adopted. In this model, the typical services included are basically the in-vehicle travel time (IVTT) and the out-vehicle travel time (OVTT) (Matulin *et al.*, 2005). The terms in-vehicle travel time and out-vehicle travel time are applied to freight as the total travel time of each trip used in this study, which includes the time from the station or warehouse after vehicle loading/unloading and inspection until the initial movement of the transportation mode. Therefore, during the split of two transportation modes (road and rail), an assumption between each pair of zones, including a function, contained the following variables:

- Relative Travel Time
- Relative Travel Cost
- Relative Travel Service
- Economic Status of the Trip Maker

4.8. Simulation

In this study, statistical logic simulation was adapted as the final phase which involved the abstraction of data through social processes. The collected data from the freight and logistic companies allowed for the development of the model using a set of equations which includes parameters such as coefficients of fuel consumption, load type, and so forth, which formed the second phase of the simulation process. Further, this information assisted in determining the magnitudes in performing the estimations such as survey data of the variables that are listed in the set of equations. Therefore, two important steps were considered in this analysis which are the determination of whether the estimated data have tolerable variation (<10) from the actual data and the measurement of the magnitude of the parameters under investigation. Lastly, from the data obtained, clear insight was provided which contributed significantly to the estimated model.

CHAPTER 5: RESULTS AND DISCUSSIONS

5.1. Introduction

This chapter consists of a basic profile of the results and discussions of the data analysis conducted in addressing the set of objectives under study. In order to determine the current freight transportation system, assessment of the freight movement route network, freight demand, freight origin-destination matrix and freight quantity was done for rail and road transportation. Also, in obtaining the current economic and operational efficiency of freight transportation by rail and road, operational efficiency, perception for freight movement impact, service delivery and economic efficiency were assessed. For the model estimation, inferential statistical analysis such as correlation, significance test, kurtosis and skewness, Cronbach's Alpha, Variance Inflation Factor (VIF) and multiple regression had to be performed from the collected data. It is important to perform these statistical tests to select major parameters influencing freight movement within the central and other parts of South Africa to avoid future discrepancies of the model being developed. Thus, these statistical analysis methods were necessary in providing the following:

- The correlation relationship that exists between generalised freight cost and independent influential parameters.
- To determine the reliability, normality, and consistency of the data set.
- To determine the co-linearity that exists between the influential parameters through the VIF test.
- To determine the significance of the independent parameters in relation to the dependent variable through the significance test.
- To determine parameter estimates from the regression model.

Once the analysis is performed, objectives of this study will be addressed to provide the efficiency of the current freight transportation system within the central regions and other parts of South Africa in terms of operational and economic contribution. Furthermore, the results obtained from the regression model contributed to the model being developed in this chapter. This model was used to simulate scenarios that assessed under which a balanced freight transportation model can be achieved. As a result, the scenarios obtained from the simulation will further add to the guidelines under development to reach an optimal and balanced freight transportation system within the central regions and other parts of South Africa.

5.2 The Scenarios and Challenges of Freight Transport in the Central Regions of South Africa

The freight transportation system is a complex transportation network that consists of private and public entities and involves the use of various transportation modes in the movement of freight (National Cooperate Freight Research Program [NCRP], 2011). The importance of freight is to allow for its movement across different parts of the country in order to achieve optimal economic growth, less environmental damage, more job opportunities, and reduced traffic impact. To establish the freight transportation system in the central regions of South Africa, the assessment was made on the following elements:

- Freight movement route network;
- Freight supply;
- Freight demand;
- Freight load movement costs, and
- Freight origin-destination matrix.

5.2.1. Freight movement route network

The freight movement route network consists of available connected routes within the country that allow for free-flow movement of cargo using different transportation modes such as rail, road, maritime, and so forth. It forms an integral part in the freight transportation system by establishing the route network that enables optimised movement of cargo within the central regions and other parts of South Africa. In addition, this also provides the scenarios and challenges that exist within the freight transportation system. Subsequently, the freight movement route network was divided into two groups, namely freight movement rail route network and freight movement road route network, giving a layout of the freight movement that exists within the central regions and other parts of the country.

5.2.1.1. Freight movement road route network

The freight movement road route network identifies the available types of road routes that allow the movement of cargo within the central regions and other parts of South Africa. In order to address the challenges that exist within the road infrastructure and improvements that can be made, it was essential for the assessment of the freight movement by road to be conducted.

Table 5.1 shows the freight movement road route network within the central regions and other parts of South Africa illustrated by the distance covered, national route travelled, origin to destination locations and freight time travelled by road transportation modes. According to Table 5.1, the N1, N12, N3, N4 and N5 are the major routes providing two-way freight movement patterns with less travel time within and outside the central regions of South Africa. Therefore, the regions in which these major routes exist are Gauteng (Johannesburg) – Free State (Bloemfontein) with a 4-hour travel time per trip over a distance of 398 km; Gauteng (Johannesburg) – Northern Cape (Kimberly) with a 5-hour travel time per trip over a distance of 484 km; Western Cape (Cape Town) – Free State (Bloemfontein) with a 11-hour travel time per trip over a distance of 1005 km; Free State (Bloemfontein) – Free State (Harrismith) with a 3.5-hour travel time per trip over a distance of 337 km, and Mpumalanga (Nelspruit) – Mozambique (Maputo) with a 5-hour travel time per trip over a distance of 377 km. However, the findings revealed Free State (Bloemfontein) to be the major centre of freight movement as it forms 43% of links with other regions for freight movement in South Africa. Additionally, the Free State (Bloemfontein) shows to be the shortest and most convenient road route with an average of 5.3 hours of travel time per trip and an average distance of 559 km for freight movement, primarily due to most enterprises located in this area receiving cargo from surrounding regions in South Africa.

Subsequently, Figure 5.1 shows the freight road route network within the central regions and other parts of the country as indicated in Table 5.1. This is important in showing the direction and movement of freight within the central regions and other parts of the country. From Figure 5.1, the one arrow indicates a one-way freight movement pattern whilst the two arrows indicate a two-way freight movement pattern. The findings also reveal that N1 is the longest road route with a total distance of 1 796 km and a total travel time of 18 hours for freight movement running from Gauteng to the Western Cape, but with the Free State being the centre of this freight movement route.

Table 5.1 The freight movement road route network (Stats SA, 2021*l*).

Route	Type of road	Origin	Destination	Distance (km)	Freight travel time (hrs)	Movement pattern
N1	National	Johannesburg (Gauteng)	Bloemfontein (Free State)	398	4	Two-way
N1	National	Cape Town (Western Cape)	Johannesburg (Gauteng)	1398	14	One-way
N12	National	Johannesburg (Gauteng)	Kimberly (Northern Cape)	484	5	Two-way
R31	Regional	Kimberly (Northern Cape)	Kathu (Northern Cape)	280	3	One-way
N12 & N18	National	Kimberly (Northern Cape)	Hartswater (Northern Cape)	118	1.25	One-way
N1	National	Cape Town (Western Cape)	Bloemfontein (Free State)	1005	11	Two-way
N6	National	Bloemfontein (Free State)	East London (Eastern Cape)	635	6.5	Two-way
N3	National	Durban (KwaZulu-Natal)	QwaQwa (Free State)	321	3.25	One-way
N8 & A3	National	Bloemfontein (Free State)	Maseru (Lesotho)	276	4.6	One-way
R700	Regional	Bultfontein (Free State)	Bloemfontein (Free State)	102	1	One-way
N1 & N5	National	Harrismith (Free State)	Bloemfontein (Free State)	337	3.5	Two-way
R30	Regional	Theunissen (Free State)	Bloemfontein (Free State)	100	1.5	One-way
R719 & R700	Regional	Wesselsbron (Free State)	Bloemfontein (Free State)	159	2	One-way
N4	National	Nelspruit (Mpumalanga)	Maputo (Mozambique)	377	5	Two-way

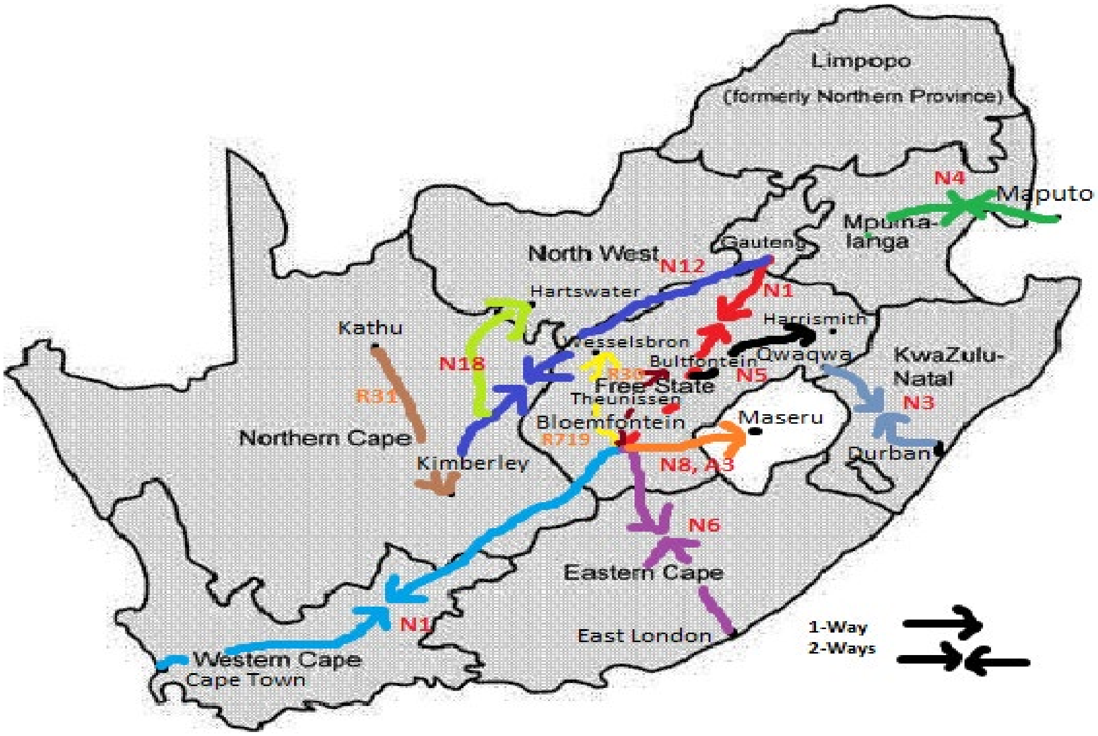


Figure 5.1 The freight road route movement within the central regions and other parts of South Africa (Base map source: Google Maps, 2022a).

5.2.1.2. Freight movement railway route network

The freight movement railway route network involves the movement of freight by rail within and outside the central regions of South Africa. It consists of a connection of railway terminals and corridors to allow for free movement of cargo from one port to another. Therefore, it is important to assess the current scenarios of freight movement by rail to identify the railway route terminals with a great volume of freight movement.

Table 5.2 shows the railway network for freight movement within and outside the central regions of South Africa. According to the freight movement railway route network, the major railway terminals providing two-way freight movement are between Gauteng (Johannesburg) – Free State (Bloemfontein) with a 7-hour travel time per trip over a distance of 398 km; Gauteng (Johannesburg) – Eastern Cape (Port Elizabeth) with a 25-hour travel time per trip over a distance of 1045 km; Gauteng (Johannesburg) – Eastern Cape (East London) with a 19-hour travel per trip time over a distance of 758 km; Gauteng (Johannesburg) – Northern Cape (Kimberley) with an 8.25-hour travel time per trip over a distance of 557 km; Free State (Bloemfontein) – Eastern Cape

(East London) with a 12.7 hour travel time per trip over a distance of 635 km, and Western Cape (Cape Town) – KwaZulu-Natal (Durban) with a 32-hour travel time per trip over a distance of 1200 km. Consequently, Johannesburg, which falls under the Gauteng region, is the major distribution centre forming about 67% of railway routes with other surrounding regions for freight movement. Additionally, Gauteng (Johannesburg) is the major distribution centre providing an average of 14 hours of travel time per trip and an average distance of 689.5 km for two-way freight movement with other terminals. Furthermore, based on travel hours, the average trip speed for road freight is nearly double that of rail freight, as shown in Tables 5.1 and 5.2.

Figure 5.2 illustrates the freight rail route network for the movement of freight within the central and other parts of the country as indicated in Table 5.2. This is essential in identifying the freight movement pattern within the central regions and other parts of the country, where one arrow indicates a one-way freight movement pattern, and the two arrows indicating a two-way freight movement pattern. From Figure 5.2, railway lines 1 and 6, with a total distance of 1 598 km and total travel time per trip of 39 hours, forms the longest railway route for freight movement with Northern Cape and Free State being the central ports.

Table 5.2 The freight movement railway route network (Stats SA,2021*l*).

Railway Line	Origin	Destination	Distance (km)	Freight travel time (hrs)	Freight movement pattern
1	Johannesburg (Gauteng)	Bloemfontein (Free State)	398	7	Two-way
2	Johannesburg (Gauteng)	Port Elizabeth (Eastern Cape)	1045	25	Two-way
3	Johannesburg (Gauteng)	East London (Eastern Cape)	758	19	Two-way
4	Johannesburg (Gauteng)	Kimberley (Northern Cape)	557	8.25	Two-way
5	Bloemfontein (Free State)	East London (Eastern Cape)	635	12.7	Two-way
6	Cape Town (Western Cape)	Bloemfontein (Free State)	1200	32	Two-way

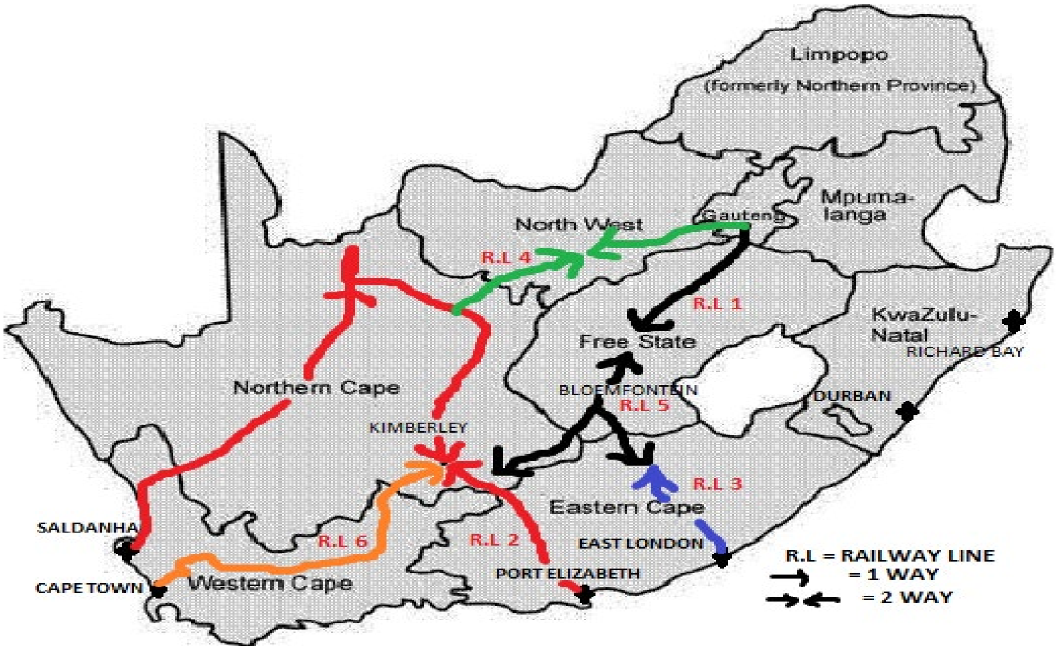


Figure 5.2 The freight rail route movement direction within the central regions and other parts of South Africa (Base map source: Google Maps, 2022a).

5.2.2. Freight supply

Freight supply involves the quantity which, in this study, refers to the determination of freight load being transported or conveyed by either freight rail or road transportation modes. It is vital to examine which freight transportation mode between road and rail carries more load, to be able to know the current scenario of freight supply in terms of actual load in the central regions and other parts of South Africa.

Figure 5.3 shows the freight supply in terms of load percentage within the central and other parts of South Africa. This is important in order to determine which freight transportation mode between road and rail supplies more commodities. The freight road carries 47.7% more load than freight rail for supply of between 0-25 000 ton/km, and freight rail carries 30.4% more load than freight road for supply between 25 000-50 000 ton/km. Furthermore, freight rail carries 16.7% more load than freight road for supply of over 50 000 ton/km (refer to Appendix A, Table A which shows the freight load percentages for road and rail). Consequently, this implies that freight rail supplies a higher load of commodities than freight road which is demanded by clients in the freight and logistics industry. This is due to freight rail being able to carry large quantities of goods for supply as compared to freight road. However, freight road is demanded for supply of less load quantity of commodities mainly for door-to-door services.

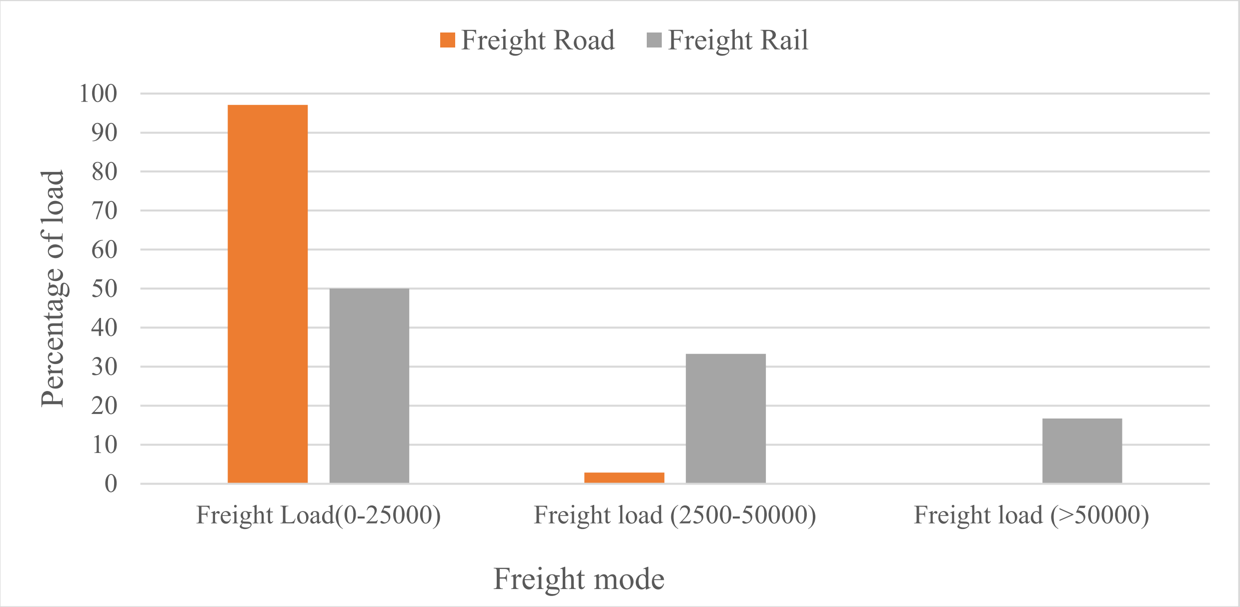


Figure 5.3 The load percentages for both freight rail and road transportation modes

5.2.3. Freight demand

Freight demand involves the assessment of the demand of freight by clients from suppliers for market disposal in the freight and logistics industry. Consequently, this consist of the determination of load that needs to be transported by both freight modes considering the distance covered. In this section, weight in tonnage per kilometre is used as the unit of measurement during freight movement as load is being determined. The importance of freight demand contributes to the assessment of current scenarios of freight in the central regions of South Africa and identifies the mode that has high demand of freight between freight road and rail as projected by stakeholders involved. Therefore, aspects such as commodity type and freight load cost were analysed to establish the freight demand within and outside the central regions of South Africa. Table 5.3 provides an assessment of the demand for freight within the central regions and other parts of South Africa in terms of commodity preference. This is to identify which freight transportation mode between road and rail accommodates commodity types that are in high demand. The obtained results show that freight road carries 50% of food for a load of 32 933 ton/km and 37%

of clothes for a load of 2 511 tons/km, whereas freight rail carries 27% of minerals for a load of 3 952 340 tons/m and 24% of both food and clothes for the same load of 350 000 tons/km. Therefore, this implies that for food and clothes, there is higher demand for freight movement by road as compared to freight rail. However, there is a gap in terms of demand of goods and materials by freight rail as it is used to carry commodities that are transported in massive quantities. Subsequently, there is a higher demand for various commodities by freight road as compared to freight rail irrespective of the capacity magnitude. Further, this proves that freight rail is more important for the supply element whilst freight road is more concerned with the demand element.

Table 5.3 The freight load of commodity types for freight road and rail

	Road		**Rail**	
Commodity types	**Weight (ton/km)**	**% of weight**	**Weight (ton/km)**	**% of weight**
Food	32 933	50	3 500 000	24
Clothes	24 874	37	3 500 000	24
Furniture & Appliances	2 511	4	0	0
Materials	3 571	5	0	0
Mineral	1 775	3	3 952 340	27
Machinery	795	1	6 000	1
Others	0	0	3 502 400	24

5.2.4. Freight load movement costs

For a freight and logistic company to make profits and remain sustainable, there must be less freight costs as compared to income generated by the companies during the movement of cargo to various locations. The production can be at an optimal level only when the freight load costs are reduced, irrespective of the impact that the transportation modes pose on the environment. Therefore, freight load cost contributes to the production and the assessment was made to investigate which freight transportation has lower costs but with greater freight movement. Figure 5.4 shows the assessment of freight load cost by clients in the central regions and other parts of South Africa. This is important in finding the current trend that is associated with freight load costs based on freight movement within the central and other parts of South Africa. The findings show that there is 100% more freight movement by road than rail for freight costs between R0-50 000/load; there is 46% more freight movement by rail than road for freight costs between R50

000-100 000/load and for freight cost over R100 000/load, there is 80% more freight movement by rail than road (refer to Appendix A, Table B which shows the freight cost per load for road and rail). This suggests that freight road can create high movement of freight at lower costs as compared to freight rail and thus proves to be economically efficient.

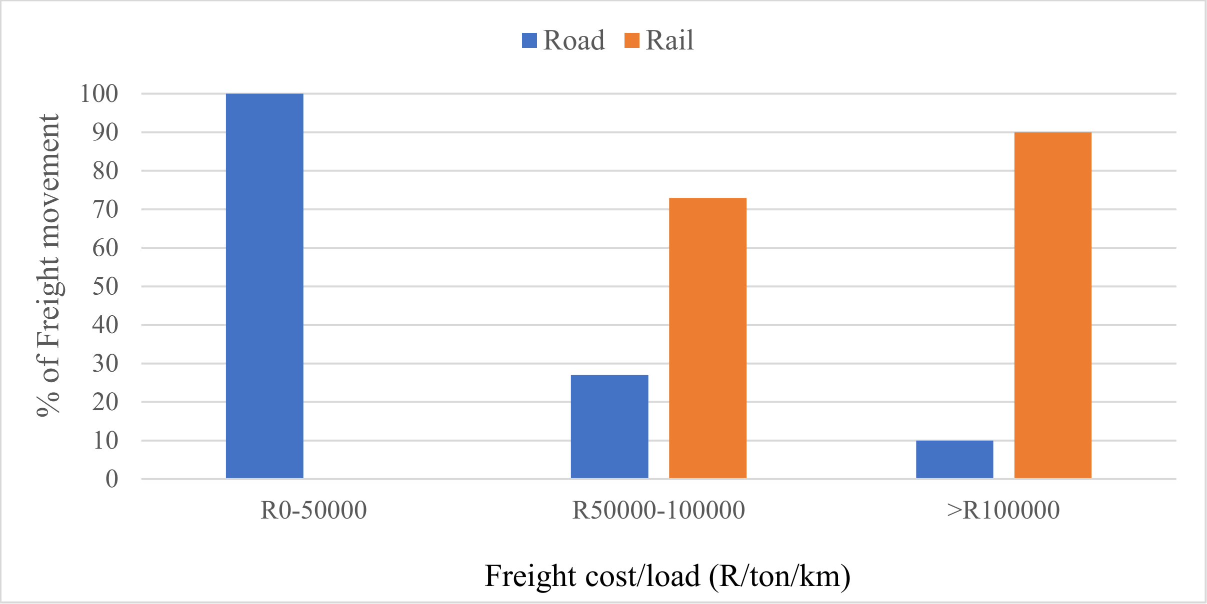


Figure 5.4 The percentage level of freight load cost demand for freight rail and road

5.2.5. Freight origin and destination matrix

The freight origin and destination matrix involve the assessment of movement of freight between different locations within and even outside of the central regions of South Africa. It identifies the freight movement by indicating the origin-destination points that are more active than others and improving the decision-making process of involved stakeholders in the freight and logistics industry with regard to route selections.

Table 5.4 shows the daily number of trips by freight rail and road transportation modes moving along the listed origin and destination matrices from the 41 samples of data collected by the author in the central regions of South Africa. According to the table, the three major origin and destination locations are Johannesburg (Gauteng) – Bloemfontein (Free State) with 5 trips per day by road; Johannesburg (Gauteng) – Kimberley (Northern Cape) with 5 trips per day by road, and Durban (KwaZulu-Natal) – QwaQwa (Free State) with 4 trips per day by road. It is evident that freight road has more origin and destination locations as compared to freight rail as it has a total number of 34 trips per day whilst freight rail has a total number of only 7 trips per day. Therefore, it proves to be operationally efficient with Gauteng being the centre of freight movement producing 37% of the total number of trips per day for both freight road and rail. Furthermore, rail has significantly less network coverage than road in terms of origin-to-destination trips. It is also worth noting that the dashes ("-") in Table 5.4 indicate that no data were received from respondents during data collection for trips in these corridors.

Figure 5.5 illustrates the direction of the origin and destination points as listed in Table 5.4. This is important in showing the location of origin and destination during freight movement. From Figure 5.5, there are more origin and destination points within the Free State producing 44% of the total number of trips per day by freight road only as compared to other regions in South Africa. This may be due to the number of freight companies located in this area and the demand of freight supply. However, Gauteng still creates more origin points than any other regions with a total of 35% of trips per day by road and 57% total trips per day by rail, thus making it the origin centre for freight movement within the central and other parts of South Africa.

Table 5.4 The various origin and destination locations for road and rail

Origin	**Destination**	**Freight movement pattern**	**Freight road route names**	**Freight rail corridor names**	**Number of trips per day by Freight Rail**	**Number of trips per day by Freight Road**
Johannesburg (Gauteng)	Bloemfontein (Free State)	Two-way	N1	Gauteng – Free State	-	6
Cape Town (Western Cape)	Johannesburg (Gauteng)	Two-way	N1	Gauteng – Cape Town	-	2
Johannesburg (Gauteng)	Kimberly (Northern Cape)	Two-way	N1	Gauteng – Northern Cape	-	5
Kimberly (Northern Cape)	Kathu (Northern Cape)	One-way	R31	Northern Cape	-	1
Kimberly (Northern Cape)	Hartswater (Northern Cape)	One-way	N12& N18	Northern Cape	-	2
Cape Town (Western Cape)	Bloemfontein (Free State)	Two-way	N1	Free State –	-	3

				Cape Town		
Durban (KwaZulu-Natal)	Bloemfontein (Free State)	Two-way	N3 &N5	Free State – Durban	-	2
Durban (KwaZulu-Natal)	QwaQwa (Free State)	One-way	N3&R74	Free State – Durban	-	4
Bloemfontein (Free State)	Maseru (Lesotho)	One-way	N8	Free State – Lesotho	-	1
Bultfontein (Free State)	Bloemfontein (Free State)	One-way	R700	Free State	-	3
Harrismith (Free State)	Bloemfontein (Free State)	One-way	N5 & N1	Free State	-	3
Theunissen (Free State)	Bloemfontein (Free State)	One-way	R30	Free State	-	1
Wesselsbron (Free State)	Bloemfontein (Free State)	One-way	R719 &R700	Free State	-	1
Johannesburg (Gauteng)	Port Elizabeth (Eastern Cape)	Two-way	N1	Gauteng – Eastern Cape	2	-
Johannesburg (Gauteng)	East London (Eastern Cape)	Two-way	N1&N6	Gauteng – Eastern Cape	2	-
Nelspruit (Mpumalanga)	Maputo (Mozambique)	Two-way	N4	Mpumalanga – Maputo	1	-
Bloemfontein (Free State)	East London (Free State)	Two-way	N6	Free State – Eastern Cape	2	-

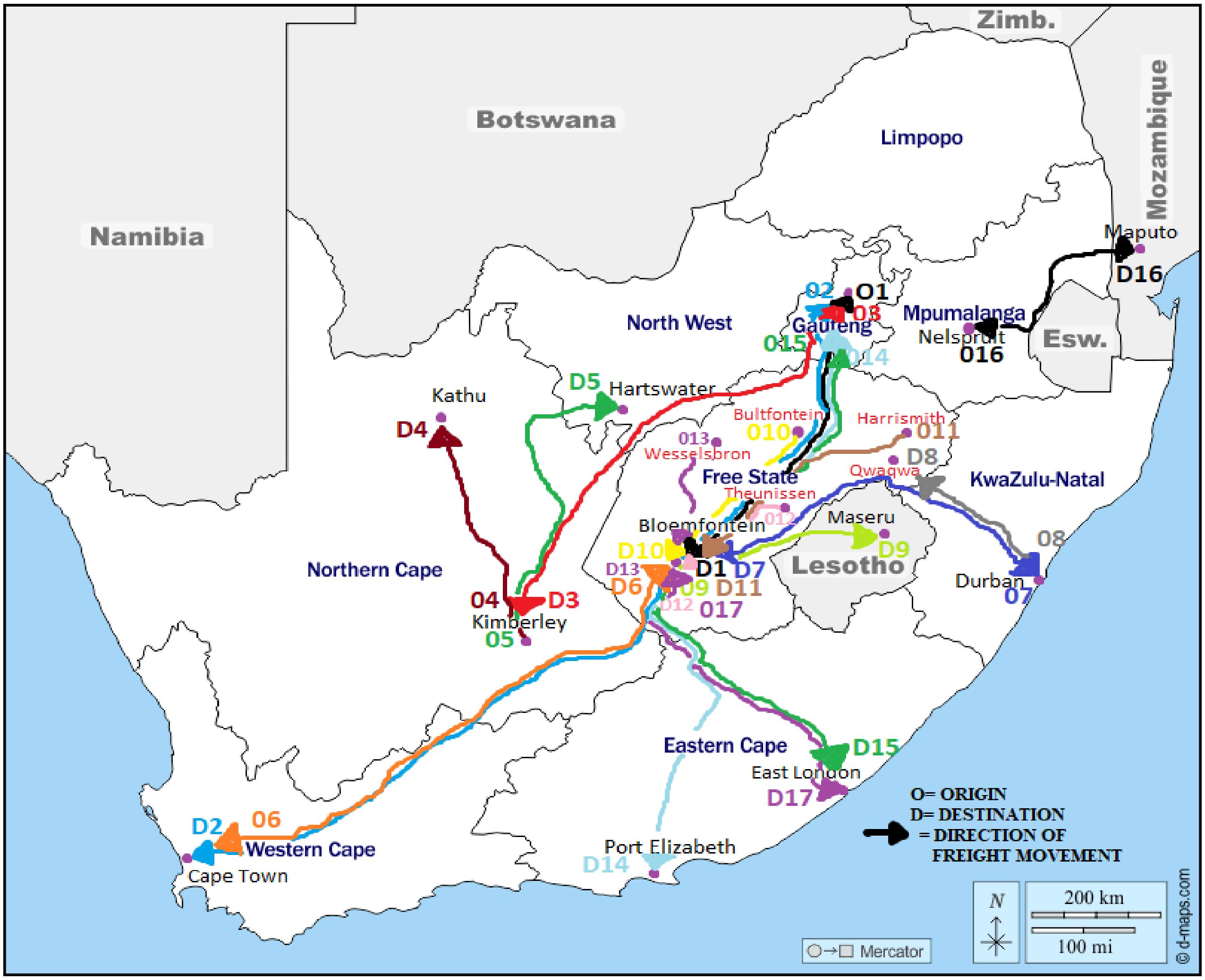


Figure 5.5 The origin and destination matrix of freight movement within the central regions and other parts of the country (Base map source: Google Maps, 2017b).

5.3. The Current Economic and Operational Efficiency of Freight Transportation by Rail and Road

As mentioned in Chapter 1, there are considerable opportunities to improve the efficiency of freight transportation globally and even locally, especially in urban areas. However, there are relatively limited chances to shift volumes of longer-haul freight from one mode to another without imposing additional costs on businesses and consumers involved (Brogan *et al.*, 2013). It is important to examine the current economic and operational efficiency of freight transportation to be able to provide guidelines for a balanced freight transportation system in the central regions of South Africa. It is imperative to also understand how freight transportation affects the current economy in terms of its operational or productivity levels, hence, the assessment of the current impact that freight rail and road has on the economic status had to be performed. The following aspects were assessed to establish the current economic and operational efficiency of freight transportation by rail and road:

- Operational efficiency between freight road and rail.
- The economic efficiency of freight road and rail.
- The performance of service delivery between road and rail.
- The perception of suppliers for the effects of freight road and rail on the environment, infrastructure, and service delivery.

5.3.1 Operational efficiency between freight road and rail

Operational efficiency entails the measure of efficiency for freight transportation modes based on the performance in service delivery and operational costs. In other words, it measures the efficiency of load being transported by both freight transportation modes as a function of either operating cost or service delivery. It is usually based on monetary terms, but provision was also made on the performance scale based on the transit time and freight load movement to account for the operational efficiency of these modes. This is essential as it allows one to establish the current operational deficiencies that exist between freight rail and road transportation modes, so that more sustainable and efficient measures could be put in place to improve the operational elements for future freight transportation systems. The data of freight load movement between the two modes over a period of ten years and an average total transit time of freight rail and road was assessed (refer to Appendix A, Table C which shows the freight load in ton/km for road and rail).

Figure 5.6 shows the freight load movement by road and rail modes over a period of 10 years. This is to determine the freight mode that is suitable for carrying more load/mass in tons per kilometre over the past ten years and to establish the economic and operational efficiency within this period. Between the years 2011 and 2016, the freight load movement was greater by 30-40% for rail than road and between 2017 and 2020, freight load movement was greater by 60-78% for rail than road. This implies that freight rail has greater carrying capacity over freight road, which makes it a suitable mode to carry large quantities of cargo and making it operationally efficient. The figure also shows a marginal increase in freight road while increasing freight rail, with the exception of a decline in 2019 and 2020, which could be attributed to COVID-19.

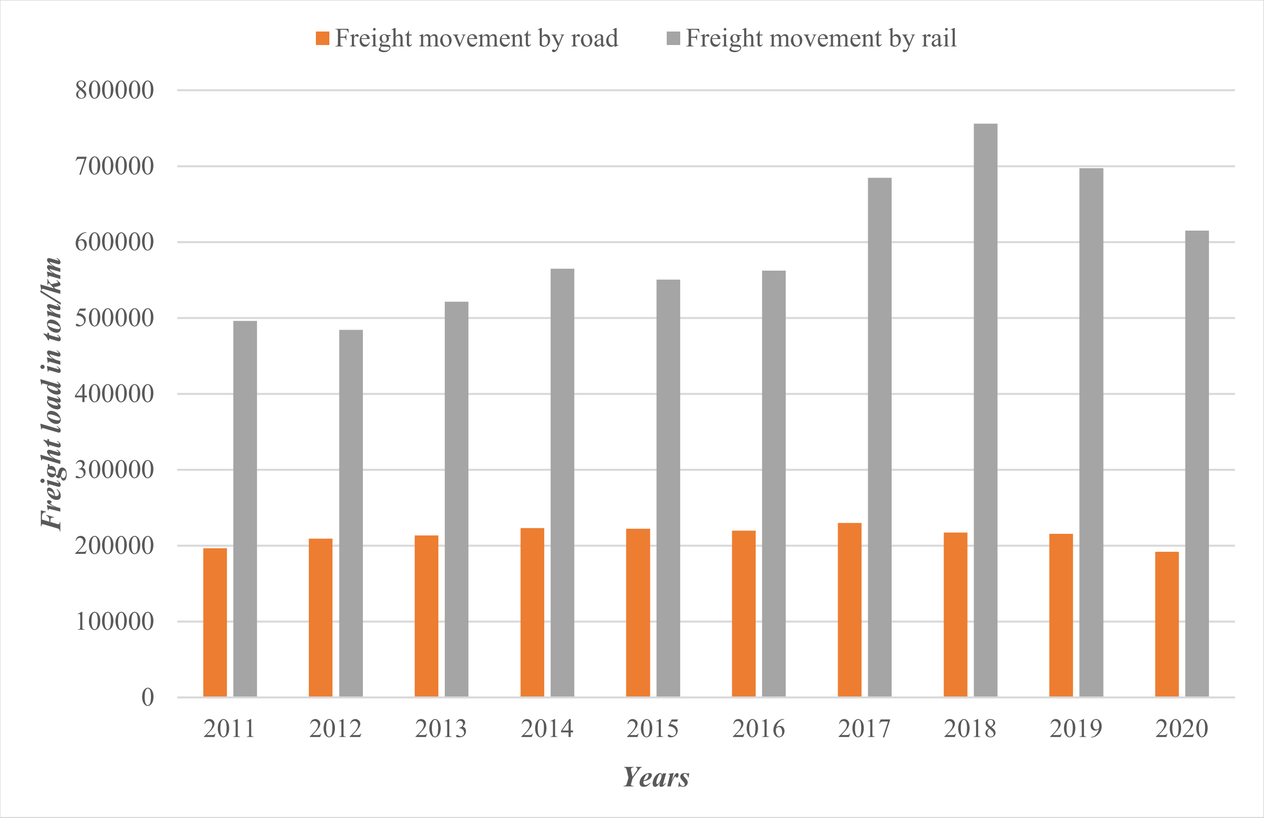


Figure 5.6 The freight load movement by road and rail from 2011 to 2020 (Source: Stats SA, 2011a-2020k)

Furthermore, operational performance of the freight rail and road was associated with transit time which is the total journey time comprising stops and loading and offloading times during freight movement. Hence, Table 5.5 represents the average total transit time for the freight movement between rail and road including factors such as average stoppage time, average offloading/loading times that are all represented in hours. This is to examine efficiency in terms of time variable between the two freight transportation modes under investigation and Free State to Western Cape was selected as the common route due to its high volume of freight movement. The obtained results reveal that the average total transit time for freight rail (25.7 hrs) is significantly greater than that of freight road (12.31 hrs) for the same distance. This means that freight rail takes 67.66% more total average transit time than freight road. In other words, freight rail takes 8.76 hrs more transit time, 0.06 hrs more stoppage time, and even 4.59 hrs more loading and offloading time than freight road. This suggests that freight road is more operationally efficient than freight rail as it takes less total average transit time as compared to freight rail and the current desired average total transit time for this distance is approximately 13 hours.

Table 5.5 The average total transit time for Freight Rail and Road

Freight modes	Average Transit time (hrs)	Average Stoppage time (hrs)	Average Loading and offloading time (hrs)	Average Total Transit Time (hrs)
Truck	6.74	2.16	3.41	12.31
Train	15.5	2.22	8	25.72

5.3.2. The economic efficiency of freight road and rail

Economic efficiency involves the assessment of freight transportation modes' factors such as fuel cost, cost of time, and travel cost to achieve an optimum economic growth of the country. Freight transportation is important as it forms the cornerstone of the economy, so there needs to be continuous assessment of freight transportation mode factors towards achieving a sustainable and efficient economic status. Freight fuel cost, average relative travel cost (which excludes stops, tolls and offloading and loading costs) and the relative cost of time for movement of cargo between the two freight transportation modes were assessed to determine which freight mode is contributing fairly to the economic growth of South Africa.

Figure 5.7 shows the average fuel consumption between the freight road and rail transportation modes during the movement of cargo within the central regions and other parts of the country. This is important in establishing which freight transportation mode between freight road and rail consumes less fuel and proves to be more economically efficient from respondents. According to the data, the assessment was also made for the same route (Gauteng to Eastern Cape) because it is one of the major routes for freight movement within the central regions and other parts of South Africa. According to the fuel consumption results, freight road consumes 466 litres more fuel per ton per kilometre than freight rail for the same major routes, making rail more economically efficient than road (refer Appendix A, Table D which shows the fuel consumption in litres per ton per kilometre for road and rail). This means that freight rail providers will spend less money on fuel while still being unable to provide fast delivery service due to differences in load per tonnage and distance between the two modes of transportation.

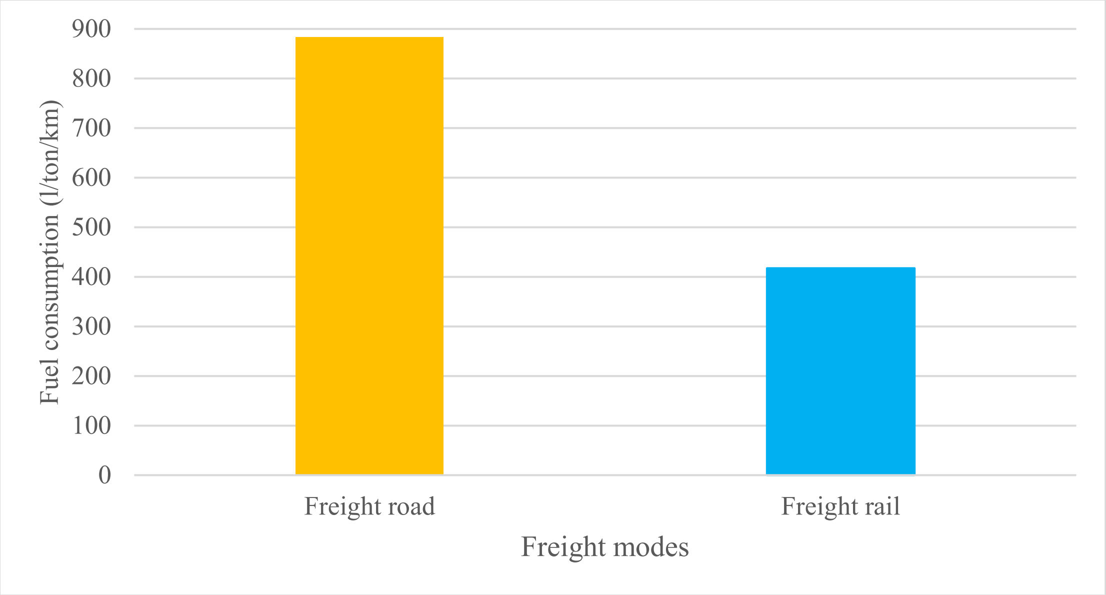


Figure 5.7 The average fuel consumption of freight rail and road

Furthermore, assessment was made to determine the economic and operational efficiency between freight rail and road based on the empirical models for average relative travel time and travel cost as mentioned in Chapter 4, section 4.4.3. Also, the assessment was carried out on the same route as in Figure 5.7, however, it was based on average trips based on ton per kilometre made by each transportation mode from the primary data obtained. Table 5.6 shows the results obtained from the empirical models used to determine the current economic and operational efficiency based on the average relative travel time (inclusive of the entire journey time with walking from station or warehouse to the warehouse or during exchange of operator particularly in rail, which differs from the 'time' in section 5.3.1) and relative travel cost for both freight modes under investigation. Despite the fact that these equations (refer to Eq. 5.3 & 5.4) are commonly used for passenger transportation, they covered the 'travel time' and 'travel distance' included from walking to and from warehouses and stations prior to initial freight movement by operators in this context. This is vital in establishing which freight mode is more economical and operationally efficient in terms of cost and travel time that may add in providing guidelines for a more optimal and balanced freight transportation system in the central regions of South Africa. As indicated on Table 5.6, freight road travels for an average of 29.9 hrs less than freight rail with an average freight travel cost of R17.41 per ton/km/hr more than freight rail and thus making it economically inefficient in terms of cost, but operationally efficient in terms of overall travel time. This proves that freight road takes less average relative time but more average relative travel cost on the same major routes for freight movement (refer to Appendix C which shows the calculation for average travel time and travel cost for movement of cargo).

Table 5.6 The average relative trave time and travel cost between freight road and rail

Freight modes	Average relative travel time for movement of cargo (hr)	Average relative travel cost for movement of cargo (R/ton/km/hr)
Road	32.4	28.23
Rail	62.3	10.82

5.3.3. The performance of service delivery between road and rail

Service delivery constitutes the interaction between suppliers and clients where the supplier provides service and the clients either gain value or lose value as a result. This assessment was made on the service delivery attributes such as average number of trips and average distance based on tonnage per day per kilometre made by freight rail and road on major routes within the central and other parts of South Africa.

Figure 5.8 shows the freight rail and road service delivery factors within the central regions and other parts of South Africa. This information contributes to the assessment of the current economic and operational efficiency by identifying which freight mode between road and rail has great service delivery attributes that clients value the most. As indicated on the graph, freight road has an average of 217 more trips (having variations in tonnage per day per kilometre) with an average of 911 km less distance than freight rail for a normal day based on the data collected from involved stakeholders in the freight and logistics industry (refer to Appendix A, Table E which shows the average number of trips and travel distance between road and rail). This suggests that freight road makes more trips for shorter travel distances than freight rail and thus results in being more economical and operationally efficient. Hence, clients prefer using freight road over freight rail due to its reliability in service delivery, irrespective of the travel distance.

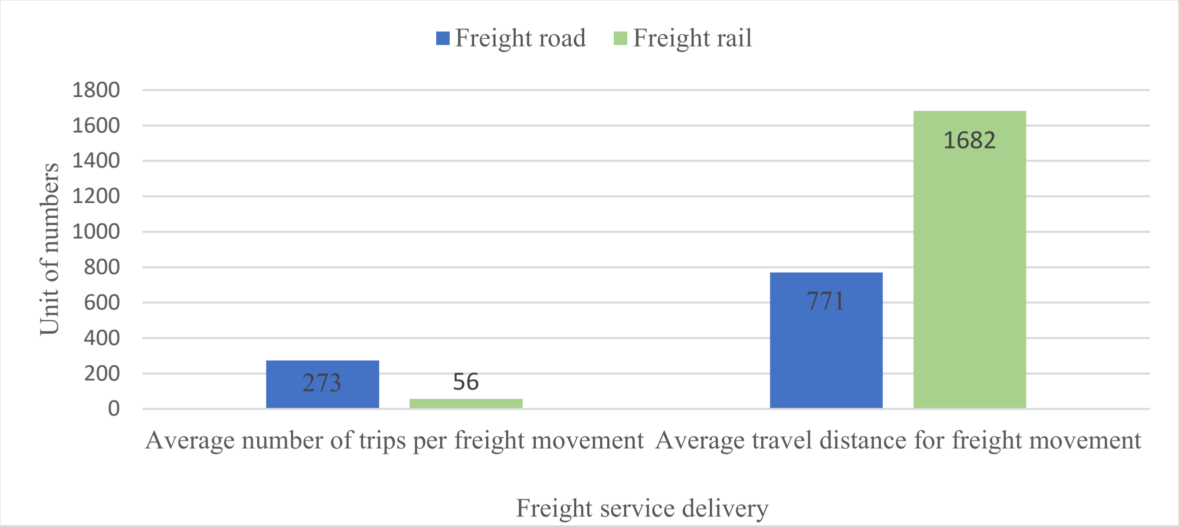


Figure 5.8 The service delivery attributes for freight road and rail

5.3.4. The perception of suppliers for the effects of both modes on freight aspects

To further understand and assess the efficiency of freight transportation, the views and perceptions of suppliers were collected in this study. This perception provided the effect that freight road and rail transportation modes have on the environment, infrastructure, and service delivery. This information assisted in identifying which freight transportation mode between road and rail has manageable effects on the environment, infrastructure, and service delivery performance in achieving efficient operation.

Figure 5.9 provides the perception of freight suppliers in terms of the effect that freight rail and road have on the environment, road or rail infrastructure and service delivery. These parameters are presented in percentages and categorised according to their level of effect (good, fair, and bad) from the feedback received from freight suppliers. The importance of this assessment is to study the effect that these freight transportation modes have on the environment, infrastructure, and even the delivery of service for better improvements in future freight transportation systems. Therefore, the "good" in this context describes positive effect, "fair" moderate effect, and "bad" negative effect on the various aspects listed in the figure below. According to the perception received from stakeholders, the freight road has a good effect of 50% on both the environment and the quality of road infrastructure, with 33% being on the performance of service delivery (refer to Appendix A, Table F which shows the freight aspect as perceived by freight stakeholders). Additionally, for “bad” effect on infrastructure and service delivery reliability, freight road also showed a 0% effect for both these aspects. Thus, freight road proves to have a total good effect on all identified factors as compared to freight rail, making it an operationally efficient mode of freight transportation as perceived by freight suppliers.

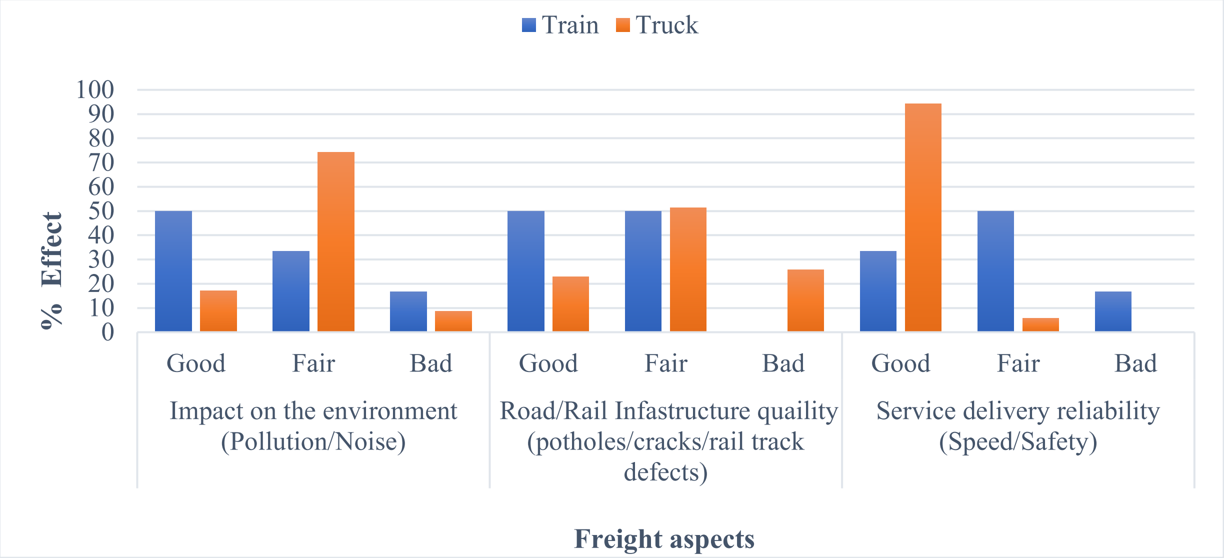


Figure 5.9 Freight suppliers’ perception on road and rail’s effect on the environment, road and rail infrastructure condition, and service delivery performance.

5.4. Findings of Primary and Secondary Data Analyses

The following results were obtained during the analysis of the primary and secondary data:

- The scenarios of the freight transportation system revealed that the freight movement road route network is much more operative than the freight movement rail route network and forms greater volumes of freight movement within the central regions and other parts of South Africa.
- The major regions with higher movement of freight for both freight transportation modes are Gauteng, Free State, Northern Cape, and Eastern Cape.
- Free State and Gauteng are the busiest regions with the highest volume of freight movement, and this is because most freight clients are based in the Gauteng region and run through the Free State region to reach their desired destinations during freight movement.

- There is high demand of freight road as transportation mode as it consists of fast travel time, provides diverse commodities, and carries less tonnage per kilometre as compared to freight rail.
- Freight by road is currently the most preferred transportation mode within the central regions and other parts of South Africa due to an overall good performance on the environment, road infrastructure and quality of service delivery.
- Freight by road proved to be efficient at service delivery which is one of the most important elements in the freight and logistics industry.
- Freight by road has less relative travel time and relative travel cost (an entire journey cost inclusive of walking to and from the warehouse and station based on cost of time) which are attributes contributing to operational and economic efficiency of freight transportation modes.
- There is an imbalance in the current freight transportation system within the central regions and other parts of South Africa with an unequal share of freight between road and rail as freight road is being utilised more for freight movement than freight rail (refer to section 5.2 and 5.3.3).
- There is a discrepancy between freight rail and road that exists due to freight road being more related to the demand aspect whilst freight rail is related to the supply aspect of freight movement.
- Therefore, there is a need to provide some balanced freight transportation system guidelines to have a more efficient and operational transportation system in South Africa which will be addressed in Chapter 6. Additionally, the impact of the freight transportation system is higher in urban areas as compared to rural areas due to the large scale of industrialism.
- As a result, these findings address the objectives in this study and corroborate the need to have a balanced modal split between road and rail in the central regions of South Africa.

CHAPTER 6: MODELLING AND SIMULATION FOR RAIL AND ROAD TRANSPORTATION

6.1. Introduction

The purpose of the model estimation was to develop a multiple linear regression model for the overall cost of the freight movement, which was also taken as the disutility function. By using the developed model, the overall cost of freight movement (disutility function) was estimated under the base case scenario and different simulated scenarios. Further, the Binary Logit model was used to observe the probability (market share) of the use of two models from freight movement under different scenarios.

For the empirical model of the disutility function to be developed, there must be some inferential statistical analysis conducted to identify which parameters influence the freight road and rail transportation system. For this purpose, correlation was performed to assess the degree of association between movement of freight (both by road and rail) and various independent variables, which are likely to influence freight movement. In this context, the overall cost of the disutility function was considered as the dependent variable and various parameters such as load cost, waiting time, travel time, parking cost, loading and unloading cost, and fuel cost, were considered as the independent variables. The consistency, reliability and normality of the data were conducted using kurtosis and skewness, standard deviation, and Cronbach's Alpha test. Therefore, standard deviation provided consistency, skewness and kurtosis provided normality, and Cronbach's Alpha test provided reliability of the data set for this study. Co-linearity between various independent variables was assessed by using the VIF test. The significance test (t-test) was conducted to observe the statistical significance between the dependent variables and independent variables. Therefore, the independent variables which significantly influenced the dependent variable were chosen based on the above-mentioned analyses.

6.2. The Determination of Disutility Functions for Generalised Cost

In this section, one of the factors that are known to influence the trip distribution was determined by considering the relative travel costs between two zones during freight movement. Furthermore, this theory explains that when people make decisions based on these attributes/parameters, such as travel time, travel cost, travel comfort, and so on, they perceive them indirectly as a measure of service rather than directly as attributes/parameters, so these attributes/parameters must be weighted identically across choices (Mathew & Rao, 2007). As a result, the set of parameters derived from primary data in this study had to be weighted across options (road and rail) using a weightage and ranking matrix in order to support the measure of service as perceived by stakeholders (no units as the matrix based on scaling of parameters). It was convenient to use this method of analysis to measure all parameters related to the disutility of a journey in freight movement and is referred to as the generalised cost. This was determined using the following matrix:

$$Cij = \left(\frac{W1*R1+W2*R2+W3*R3+\cdots.WniRni}{R1+R2+R3+\cdots Rni}\right) \tag{6.1}$$

where:

$W1$ = weightage ranking for parameter 1

$R1$ = rating score for parameter 1

$W2$ = weightage ranking for parameter 2

$R2$ = rating score for parameter 2

$W3$ = weightage ranking for parameter 3

$R3$ = rating score for parameter 3

Wni = weightage ranking for parameter continuous parameters

Rni = rating score for parameter continuous parameters

Since the disutility function represents the generalised costs of each choice, the matrix was adopted by assigning weights and ranks to the influential parameters. Therefore, based on the generalised cost matrix, W1 is the weight assigned to parking cost (R0-2=1; R2-4=2; >R4=3) with ranking (R1) for the same parameter (R0-4= 1; >R4=2). This procedure was also adopted for W2 (load cost); W3 (fuel cost); W4 (loading and offloading time); W5 (waiting time) and W6 (travel time) with corresponding rankings (R2, R3, R4, R5 & R6) for each parameter, all based on the data obtained in Table 6.1. Some parameters were assigned with the same weights or ranks as they ranged within the same scales. Additionally, the weights and rankings were assigned because of independent parameters having different contributions or influences on the dependent parameter under investigation. Once all the parameters were provided with weights and rankings, the input results were used on the Cij matrix (refer to Appendix D). Therefore, these weights and rankings were necessary in having a common unit of measurement for parameters and to obtain the generalised costs as shown in Table 6.1.

Table 6.1 shows the influential parameters of freight road and rail within the central regions and other parts of South Africa. These influential parameters were used to determine the disutility functions in Table 6.2 and for inferential statistical analysis to assess the relationship that exists between dependent variable (Cij) and independent variables (direct cost and travel factors) using IBM SPSS, version 2.7, 2020 software. This is important in identifying the degree of influence that these influential parameters contribute to the generalised freight costs and for model estimates.

Table 6.1 The disutility functions of parameters for generalised cost of freight road and rail

Cij	**(W1)**	**(R1)**	**(W2)**	**(R2)**	**(W3)**	**(R3)**	**(W4)**	**(R4)**	**(W5)**	**(R5)**	**(W6)**	**(R6)**
11	1	2	2	1	2	1	1	1	1	1	3	1
9	1	1	2	1	2	1	1	1	1	1	2	1
9	1	2	2	1	2	1	1	1	1	1	1	1
9	1	1	2	1	2	1	1	1	1	1	2	1
11	1	1	3	1	2	1	1	1	1	1	3	1
12	1	1	3	1	2	2	1	1	1	1	2	1
7	1	1	1	1	2	1	1	1	1	1	1	1
15	3	2	1	1	2	2	1	1	1	1	2	1
14	3	2	2	1	2	1	2	1	1	1	1	1
8	1	1	2	1	2	1	1	1	1	1	1	1
10	2	1	2	1	2	1	1	1	1	1	2	1
11	2	1	3	1	2	1	1	1	1	1	2	1
11	1	1	4	1	2	1	1	1	1	1	2	1
14	3	2	2	1	2	1	1	1	1	1	2	1
13	2	2	3	1	2	1	1	1	1	1	2	1
7	1	1	1	1	2	1	1	1	1	1	1	1
8	1	2	1	1	2	1	1	1	1	1	1	1
9	1	1	3	1	2	1	1	1	1	1	1	1
15	3	2	1	1	2	2	1	1	1	1	2	1
13	2	1	3	1	2	2	1	1	1	1	2	1

11	2	1	2	1	2	2	1	1	1	1	1	1
11	2	2	2	1	1	1	1	1	1	1	2	1
15	3	2	1	1	2	2	1	1	1	1	2	1
10	1	1	1	1	2	1	2	1	1	1	3	1
7	1	1	1	1	2	1	1	1	1	1	1	1
11	1	1	2	1	2	2	2	1	1	1	1	1
9	1	1	3	1	2	1	1	1	1	1	1	1
9	1	2	2	1	1	1	1	1	1	1	2	1
11	1	1	2	1	2	2	2	1	1	1	1	1
10	1	1	1	1	2	2	1	1	1	1	2	1
9	1	2	1	1	2	1	2	1	1	1	1	1
7	1	1	1	1	1	1	2	1	1	1	1	1
10	1	2	2	1	2	1	2	1	1	1	1	1
9	1	1	1	1	2	2	1	1	1	1	1	1
11	1	1	1	1	2	1	2	2	1	1	2	1
22	3	2	5	1	3	2	2	1	1	1	2	1
15	1	1	4	1	3	2	1	1	1	1	2	1
17	1	1	5	1	3	2	2	1	1	1	2	1
18	1	2	4	1	3	2	2	1	1	1	3	1
17	1	1	4	1	3	2	2	2	1	1	1	1
20	1	1	5	1	3	2	2	2	1	1	3	1

Furthermore, Table 6.2 shows the disutility functions of influential parameters for generalised cost of freight road and rail. These generalised cost results were obtained from assigning weights and ranking using the disutility function and the independent parameters were obtained from the primary data which will further be used for running inferential statistical tests. The importance of this matrix was to achieve common disutility functions based on influential parameters of freight road and rail. However, other parameters were not included as their weights and rankings were not within acceptable scales (exceeding 1-5), thus leading to irrational Cij values. Because the parking cost parameter is commonly associated with the road mode, the parking cost for rail was indicated by zero, as shown in Table 6.2 (Columns 2 and 7 rows at the bottom). Furthermore, some of these parameters were more related to socioeconomic factors such as comfort, dependability, safety, and so on, which had no significant impact on determining the overall freight cost.

Table 6.2 The generalised cost based on disutility functions and related independent parameters

Cij	Parking Cost (R/hr)	Load Cost (R/ton/km)	Fuel Cost (l/ton/km)	Loading and offloading (hr)	Waiting Time (hr)	Travel Time (hr)
11	0.00	5.31	10.58	2	0	14
9	0.00	3.43	14.87	3	1	7
9	0.00	4.75	14.44	1	1	4
9	1.70	3.06	10.48	3	1	8
11	0.00	7.72	12.34	2	4	15
12	0.00	7.85	16.96	2	1	6
7	0.00	2.17	11.65	1	2	5
15	8.17	0.07	18.82	1	4	8
14	6.25	3.06	12.64	6	2	5
8	1.17	5.04	15.80	0	1	5
10	3.08	5.70	11.57	3	3	7
11	3.83	6.49	11.59	4	4	7
11	0.00	10.14	10.98	2	4	10
14	5.00	4.72	10.49	3	2	9
13	3.67	6.49	10.01	4	1	8
7	0.00	3.07	14.69	4	1	3
8	0.00	1.61	12.87	0	0	3
9	0.00	6.67	10.80	2	1	4
15	5.83	0.66	16.12	1	1	6
13	2.50	8.90	17.35	2	4	6
11	3.00	3.35	17.56	1	1	2
11	6.67	5.13	4.31	2	4	8
15	5.00	1.63	15.17	1	1	9
10	0.00	1.51	10.72	8	3	13
7	1.67	2.07	13.88	1	3	5
11	0.00	3.66	15.20	8	0	3
9	0.00	6.16	15.06	2	8	3
9	0.00	3.46	6.22	4	1	9
11	0.00	6.37	17.64	8	0	3
10	0.00	1.20	17.42	4	2	10
9	0.00	2.71	10.27	8	0	2
7	0.00	3.00	8.64	8	3	3
10	6.33	5.00	10.55	8	6	4
9	0.00	2.76	17.18	2	4	5
11	0.00	0.74	14.41	9	4	8
22	0.00	13.76	23.65	7	1	10
15	0.00	8.02	18.28	1	0	10

17	0.00	13.50	21.86	8	0	6
18	0.00	10.02	21.19	8	1	12
17	0.00	11.13	14.75	8	4	4
20	0.00	14.20	26.98	12	8	16

6.3. The Normality, Reliability, and Consistency of the Influential Parameters

As mentioned in section 6.1, the standard deviation was used to provide consistency, skewness and kurtosis to provide normality, and Cronbach's Alpha test to provide reliability of the data set for this study. It is important to note that the data for freight road and rail were combined for this analysis in order to contribute to the development of a single model in this study.

Table 6.3 shows the standard deviation, kurtosis and skewness and Cronbach's Alpha for influential parameters of freight rail and road. The results obtained show that the standard deviations for all parameters were small values ranging from 2.05 to 5.04 and closer to their mean values, thus proving the consistency of the data set; kurtosis and skewness values obtained were from -0.376 to 1.339 which is between -3 and +3, thus proving the normality of this data set and the Cronbach's Alpha value obtained was 0.715, which proves the reliability of the data set. Thus, overall, this implies that the data set is consistent, has some normality, and is reliable.

Table 6.3 The calculated statistics parameters of freight road and rail

Parameters	**Mean**	**Standard Deviation**	**Skewness**	**Kurtosis**	**Cronbach's Alpha**
Generalised freight cost	11.585	3.598	1.053	0.797	0.716
Parkin cost	1.558	2.423	1.339	0.490	
Load cost	5.444	3.563	0.920	0.304	
Fuel cost	14.683	5.040	0.648	0.554	
Loading and offloading	4.098	3.308	0.834	-0.376	
Waiting time	2.244	2.047	1.161	1.218	
Travel time	7.073	3.308	0.941	0.423	

6.4. Major Parameters Influencing Mode Choice for Freight Movement

From the influential parameters obtained in Table 6.2, the inferential statistical analysis such as correlation, VIF, t-test and multiple regression analysis were conducted in this section. These inferential statistical tests are essential in providing parameters that are more significant to the model and determine coefficients needed for the model estimate.

6.4.1. Correlation analysis for influential parameters of freight road and rail

The correlation analysis is intended to study the relationship that exists between the dependent variable, which in this case is the generalised freight costs (Cij), and the independent variable such as parking cost, fuel cost, load cost, and so forth. This is important in identifying the correlation relationship that exists between the variables and whether it is negative or positive, so that certain independent variables may be omitted from the desired model. The correlation relationships are based on a scale between -1 and 1; where 1 indicates a strong positive relationship; -1 indicates a strong negative relationship, and a zero indicates no relationship at all.

Table 6.4 shows the Pearson correlation coefficients of influential parameters for both freight road and rail transportation modes. The Pearson coefficients (r=>0.5) obtained show that load cost (r=0.696) and fuel cost (r=0.682) have a strong positive relationship to generalised freight cost, but parking cost (r=0.395), loading and offloading time (r=0.400), and travel time (r=0.480) can also be identified as having an acceptable positive relationship (r closer to 0.5) to generalised freight cost with waiting time (r=0.068) having a negligible positive relationship to generalised freight cost. This means that the parking cost, load cost, fuel cost, loading and offloading time, and travel time are correlated more positively to generalised travel cost than waiting time. In other words, these independent variables have a major influence on the general freight cost for both freight rail and road.

Table 6.4 The Pearson correlation coefficients of freight rail and road parameters

	Generalised Freight Cost	Parking Cost	Load Cost	Fuel Cost	Loading and offloading Time	Waiting Time	Travel Time
Generalised freight cost	1.000	0.395	0.696	0.682	0.400	0.068	0.480
Parking cost	0.395	1.000	-0.004	-0.065	-0.245	0.024	0.035
Load cost	0.696	-0.004	1.000	0.564	0.342	0.221	0.350
Fuel cost	0.682	-0.065	0.564	1.000	0.278	0.021	0.257
Loading and offloading time	0.400	-0.245	0.342	0.278	1.000	0.207	0.126
Waiting time	0.068	0.024	0.221	0.021	0.207	1.000	0.157
Travel time	0.480	0.035	0.330	0.257	0.126	0.157	1.000

Note: Pearson correlation = r; r =-1 (negatively correlated); r = +1 (positively correlated); r = 0 (no correlation)

6.4.2. The significance test and variance inflation factor of influential parameters

To further understand the relationship that exists between the dependent and independent variables, significance test and variance inflation factor of influential parameters had to be conducted. The significance level for any given hypothesis is a test of the p-value that is expected to be equal or less than 0.05 resulting in the variable being statistically significant. In other words, if the p-value for a variable under test may be greater than 0.05, then that variable is insignificant to this hypothesis. The VIF was used to determine the co-linearity relationship that exists between the influential independent variables. This is imperative in identifying which parameters are significant to the model and whether they have co-linear relationships or not. As indicated in Table 6.5, parking cost (p=0.005), load cost (p=0.000), fuel cost (p=0.000), loading and offloading time (p=0.005) and travel time (p=0.001) are significant as the p-value is less than 0.05 and VIF for all parameters is below 10, thus there are no co-linear relationships. Additionally, the waiting time is not significant as it produced a low Pearson correlation coefficient value (refer to 5.5.3.1) and the p-value is bigger than 0.05, as shown in Table 6.5. This implies that these significant independent variables must be selected to be used in model estimation, excluding waiting time as the p-value is greater than 0.05 with no co-linear relationships amongst them.

Table 6.5 The significance test (p-value) between Cij and independent variables

Variables	p-value	VIF	Remark
Parking cost	0.005	1.080	
Load cost	0.000	1.274	
Fuel cost	0.000	1.533	
Loading and offloading time	0.005	1.261	
Waiting time	0.335	1.111	Not significant
Travel time	0.001	1.160	

VIF>10 = Co-linear relationship; p-value= 0.05 Significant

Therefore, from the significant test results in Table 6.5, the selected independent variables are parking cost (X_1), load cost (X_2), fuel cost (X_3), loading and offloading time (X_4) and travel time (X_6).

6.4.3. Multiple regression model estimation

Multiple regression model estimation is basically the explanation of the relationship between multiple independent variables with one dependent or criterion variable. This dependent variable or parameter is modelled as a function of several independent variables with corresponding coefficients (*B*) along with the constant term.

Table 6.6 is the model summary of influential parameters for freight rail and road transportation modes. In this table, the assessment is made on the R-squared which is called the *coefficient of determination*. This is important as it determines the percentage of the dependent variable variation that a linear model explains. From Table 6.6, the obtained R-squared for the influential parameters of freight road and rail is 0.907. Furthermore, the adjusted R-squared for the same parameters is 0.894 which entails that there is low variation of the dependent variable that is explained by independent variables in this regression analysis. The R-squared obtained is 0.890 which is closer to 1, indicating that the model is valid and the variables that are being tested are being explained fairly by this model. Additionally, the p-values obtained in section 6.4.2 are mostly significant as their p-values are less than 0.05 and representing sufficient evidence of the output variables provided by the model. Therefore, these significant variables are kept for supporting the model's precision or validity (they also provide realistic freight travel attributes to the model such as load cost, travel times and loading and offloading times, etc.).

Table 6.6 The model summary for freight road and rail

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	F Change	df1	df2	Sig. F Change
1	.952[a]	0.907	0.890	1.193	55.020	6	34	0.000

Dependent Variable: Cij; Predictors: (Constant), Travel Time, Parking Cost, Waiting Time, Fuel Cost, Loading and offloading, Load Cost

Subsequently, Table 6.7 represents the multiple regression results of freight road and rail for major influential parameters. Therefore, according to multiple regression model estimation, the coefficients obtained are as follows: constant variable (B_1=2.177), parking cost (B_2=0.727), load cost (B_3=0.323), fuel cost (B_4=0.281), loading and offloading time (B_5=0.323) and travel time (B_7=0.217). Furthermore, the chosen parameters contribute to model estimation by providing acceptable test conditions. Also, freight road and rail have the same regression model because they are compared based on similar freight parameters, which will aid in probability selection to identify the freight model split that exists between them.

Table 6.7 The regression analysis of major influential parameters for freight road and rail

Coefficients[a]											
Model		Unstandardised Coefficients		Standardised Coefficients	t	Sig.	Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	2.177	0.676		3.221	0.003					
	Parking cost	0.727	0.081	0.489	8.986	0.000	0.395	0.839	0.471	0.926	1.081
	Load cost	0.323	0.069	0.320	4.648	0.000	0.696	0.623	0.244	0.580	1.588
	Fuel cost	0.281	0.046	-0.394	6.075	0.000	0.682	0.721	0.318	0.653	1.404
	Loading and offloading	0.323	0.064	0.297	5.046	0.000	0.400	0.654	0.264	0.793	1.278
	Travel time	0.217	0.053	0.231	4.100	0.000	0.480	0.575	0.215	0.862	1.159

*Note: a. Dependent Variable: Generalised Freight Cost; *- Not significant so not included in the model development*

Thus, from the results obtained in Table 6.7, the selected independent variables are parking cost (X_1), load cost (X_2), fuel cost (X_3), loading and offloading time (X_4) and travel time (X_6) with the model being developed as follows:

$$\begin{aligned}\mathrm{Cij} &= 2.177 + B_2X_1 + B_3X_2 + B_4X_3 + B_5X_4 + B_7X_6 \\ &= 2.177 + 0.727\mathrm{X}_1 + 0.323\mathrm{X}_2 + 0.281\mathrm{X}_3 + +0.323\mathrm{X}_4 + 0.217\mathrm{X}_6 \qquad (6.2)\end{aligned}$$

where:

X_1 = Parking cost (R/hr)

X_2 = Load cost (R/ton/km/hr)

X_3 = Fuel cost (R/ton/km)

X_4 = Loading and offloading Time (hr)

X_6 = Travel time (hr); B_2, B_4, B_6 = Beta coefficients

6.5. Validation of the Developed Model

In this section, assessment was made of how well the model fits based on the correlation coefficient (R), coefficient of determination (R^2), adjusted coefficient of determination (Adj. R^2), and validation analysis between the actual and estimated freight costs per trip. Consequently, R is used to measure the quality of prediction of the dependent variable, R^2 is the proportion of variance in the dependent variable that can be explained by the independent variables, and Adj. R^2 interprets the accuracy in the determination of coefficients. From Table 6.6, the R-value is 0.952 which indicates a satisfactory level of prediction and R^2 is 0.906 which describes that the independent variables explain 91% of the variability of the dependent variable (generalised cost). The discrepancy between the values of R-squared and Adjusted R-square is 1.7% (very low), which entails a good fit of the model. From the significance tests conducted, 5 out of 6 (83%) variables are significant as the p-value is less than 0.05. This means that most independent variables contributed highly on the model estimation and thus sustain the validity of this model. Additionally, these significant independent variables provided coefficients to the developed model to validate its robustness.

Furthermore, validation encompasses the process of checking the accuracy and performance-based outputs of the data obtained from the developed model and comparing it to the actual data of the current market-related rates. This is important as it confirms the reliability of the model being developed as it validates the strength of its existence. The model prediction results should have tolerable percentage variance between 5-10% from the actual value to be accepted.

Data was gathered from stakeholders involved in the freight and logistics industry for the actual overall freight cost on one of the major routes within the central regions and other parts of South Africa. The N6 was the selected major route for the movement of freight between the Free State and Eastern Cape regions. A freight rail company provided the cost to be R20.19/ton/km/hr and for freight road to be R13.78/ton/km/hr for the same route (Transnet Freight Rail, 2021b; Digistics, 2021). This is important as it was used to validate the model by comparing this actual data with the output obtained from the developed model (see 6.4.3). The inputs used for the model were from Table 6.8 for both freight transportation modes (Free State – Eastern Cape: 652 km). The comparison is made for the generalised freight cost per trip results obtained from the model versus the overall cost per trip provided by stakeholders involved in the freight and logistics industry.

Table 6.8 shows the model estimates and actual freight cost for rail and road on the same major route of freight movement. The results show that the cost variance tolerance for both modes of transportation (road and rail) is less than ten, with the negative sign indicating a higher estimated output than the actual one (refer to Appendix E). This implies that the freight cost for the estimated model is valid in comparison to the actual freight cost for both transportation modes.

Table 6.8 The freight costs' validation comparison for road and rail transportation modes

Freight modes	Actual Freight Cost per trip (R/km/ton/hr)	Estimate Freight Cost per trip (R/km/ton/hr)	Freight Cost Variation (R/km/ton/hr)	Variance Tolerance (%)	Remark
Road	13.78	11.99	1.79	6.95	Acceptable and Valid
Rail	20.19	22.30	-2.11	-4.97	Acceptable and Valid

6.6. Simulation of the Model

Simulation involves the process of taking a sample of data under study and using it for current and real-world conditions to predict future scenarios. This is vital in providing future forecasts about the developed model and for the purpose of this study, to add to guidelines for developing an optimal and balanced freight transportation system in South Africa. Based on the model developed in 6.4, simulations were conducted using the data obtained in Table 6.2. The scenarios were constructed by changing the independent parameters for the movement of freight for both freight road and rail under varying scenarios.

This was executed by changing the values of parameters from the usual case to predicted estimations to enable the study of their real-world implications such as adding or subtracting a certain percentage from the base case scenario (see Table 6.9). From Table 6.9, the simulation conditions are stipulated in terms of how much percentages were increased or decreased from the parameters. These simulation conditions were applied to both freight transportation modes (rail and road) and on the same major routes (Bloemfontein to Johannesburg; Bloemfontein to Cape Town, and Bloemfontein to Eastern Cape). Additionally, several simulations were made on replicated scenarios, but only important simulation results were presented in Table 6.10. The rest of the simulation scenarios are presented in the Appendices section of this study for adequate reference.

Table 6.9 Condition identification for simulation of freight road and rail major parameters

Conditions	Simulation condition
Condition 1	An increase of 10 – 100% on parking cost by an increment of 10%
Condition 2	A decrease of 10 – 100% on parking cost by an increment of 10%
Condition 3	An increase of 10 – 100% on load cost by an increment of 10%
Condition 4	A decrease of 10 – 100% on load cost by an increment of 10%
Condition 5	An increase of 10 – 100% on fuel cost by an increment of 10%
Condition 6	A decrease of 10 – 100% on fuel cost by an increment of 10%
Condition 7	An increase of 10 – 100% on loading and offloading time by an increment of 10%
Condition 8	A decrease of 10 – 100% on loading and offloading time by an increment of 10%
Condition 9	An increase of 10 – 100% on travel time by an increment of 10%

Condition 10	A decrease of 10 – 100% on travel time by an increment of 10%
Condition 11	An increase of 10 – 100% on all parameters by an increment of 10%
Condition 12	A decrease of 10 – 100% on all parameters by an increment of 10%

Table 6.10 shows the generalised cost under important varying scenarios. This is based on the simulation scenarios conducted in Table 6.9 on influential parameters of freight road and rail. It is important in determining freight generalised cost variances between road and rail based on influential parameters when they are either increased or decreased by a certain percentage.

From Table 6.10, the following results were obtained:

- Scenario 2 (Bloemfontein to Johannesburg) when parking cost is increased by 10%, generalised cost for rail is greater than road by R0.91 km/kg/hr.
- Scenario 44 (Bloemfontein to Johannesburg) when fuel cost is increased by 30%, generalised cost for rail is greater than road by R1.08 km/kg/hr.
- Scenario 65 (Bloemfontein to Johannesburg) when loading and offloading time is decreased by 40%, generalised cost for rail is greater than road by R0.84 km/kg/hr.
- Scenario 107 (Bloemfontein to Johannesburg) when all parameters are increased by 60%, generalised cost for rail is greater than road by R1.55 km/kg/hr.
- Scenario 148 (Bloemfontein to Cape Town) when load cost is increased by 80%, generalised cost for rail is greater than road by R2.27 km/kg/hr.
- Scenario 190 (Bloemfontein to Cape Town) when loading and offloading time is increased by 100%, generalised cost for rail is greater than road by R3.95 km/kg/hr.
- Scenario 211 (Bloemfontein to Cape Town) when travel time is decreased by 10%, generalised cost for rail is greater than road by R1.82 km/kg/hr.
- Scenario 253 (Bloemfontein to Eastern Cape) when parking cost is decreased by 30%, generalised cost for rail is greater than road by R3.41 km/kg/hr.
- Scenario 275 (Bloemfontein to Eastern Cape) when load cost is decreased by 40%, generalised cost for rail is greater than road by R4.54 km/kg/hr.
- Scenario 317 (Bloemfontein to Eastern Cape) when loading and offloading time is decreased by 60%, generalised cost for rail is greater than road by R3.51 km/kg/hr.

- Scenario 359 (Bloemfontein to Eastern Cape) when travel time is decreased by 80%, generalised cost for rail is greater than road by R0.57 km/kg/hr.
- Scenario 41 (Bloemfontein to Johannesburg) when load cost is decreased by 100%, generalised cost for rail is greater than road by R0.92 km/kg/hr.

Table 6.10 Generalised costs (Cij) under important varying simulation scenarios

Scenarios	**Base case**	**Cijroad (R/km/kg/hr)**	**Cijrail (R/km/kg/hr)**
SC2 (BFN – JHB)	10% increase on Parking cost	11.43	12.34
SC44 (BFN – JHB)	30% increase on Fuel cost	12.86	13.94
SC65 (BFN – JHB)	40% decrease on Loading and offloading time	11.69	12.53
SC107 (BFN – JHB)	60% increase on all 5 parameters	16.98	18.53
SC148 (BFN – CPT)	80% increase on Load cost	13.97	16.24
SC190 (BFN – CPT)	100% increase on Loading and offloading time	12.00	15.95
SC211 (BFN – CPT)	10% decrease on Travel time	11.14	12.96
SC253 (BFN – EC)	30% decrease on Parking cost	13.15	16.56
SC275 (BFN – EC)	40% decrease on Load cost	12.54	17.08
SC317 (BFN – EC)	60% decrease on Loading and offloading time	13.31	16.82
SC359 (BFN – EC)	80% decrease on all 5 parameters	4.48	5.05
SC41 (BFN – JHB)	100% decrease on Load cost	8.89	9.81

6.6.1. The observed freight shares based on simulation scenarios

From the simulation scenarios developed, there had to be some share of freight between road and rail assessed. Consequently, a Binary Logit model was used for determining the freight share between road and rail by determining the probability of mode choice selection based on major influential parameters such as load cost, travel time, and so forth, and is as follows (see the results on columns 3 & 4 on Table 6.11):

$$\boldsymbol{p}_{\boldsymbol{ij}}^{\boldsymbol{mode}} = \frac{e^{-\mathbf{Cijt_1}}}{e^{-\mathbf{Cijt_2}} + e^{-\mathbf{Cijt_1}}} \tag{6.3}$$

Table 6.11 shows the freight share results for road and rail based on simulation scenarios performed for major routes in South Africa. From Table 6.11, the results obtained show the following:

- Scenario 4 (Bloemfontein to Johannesburg) when load cost is increased by 20%, freight share is 72.5% for road and 27.5% for rail.
- Scenario 25 (Bloemfontein to Johannesburg) when load cost is increased by 10%, freight share is 73% for road and 27% for rail.
- Scenario 33 (Bloemfontein to Johannesburg) when fuel cost is decreased by 20%, freight share is 72.3% for road and 27.7% for rail.
- Scenario 45 (Bloemfontein to Johannesburg) when fuel cost is increased by 10%, freight share is 75.4% for road and 24.6% for rail.
- Scenario 55 (Bloemfontein to Johannesburg) when loading and offloading is decreased by 30%, freight share is 69.5% for road and 30.5% for rail.
- Scenario 62 (Bloemfontein to Johannesburg) when loading and offloading is increased by 10%, freight share is 71.9% for road and 28.1% for rail.
- Scenario 83 (Bloemfontein to Johannesburg) when travel time is increased by 20%, freight share is 75.8% for road and 24.2% for rail.
- Scenario 112 (Bloemfontein to Johannesburg) when all parameters are decreased by 10%, freight share is 70.6% for road and 29.4% for rail.
- Scenario 93 (Bloemfontein to Johannesburg) when travel time is decreased by 20%, freight share is 68.9% for road and 31.1% for rail.
- Scenario 198 (Bloemfontein to Cape Town) when loading and offloading is decreased by 40%, freight share is 61.4% for road and 38.6% for rail.

Table 6.11 The freight share between freight road and rail based on varying scenarios

Scenarios	Base case	Freight share by Road	Freight share by Rail
SC 4 (BFN – JHB)	20% increase on Load cost	0.725	0.275
SC 25 (BFN – JHB)	10% increase on Load cost	0.730	0.270
SC 33 (BFN – JHB)	20% decrease on Fuel cost	0.723	0.277
SC 45 (BFN – JHB)	10% increase on Fuel cost	0.754	0.246
SC 55 (BFN – JHB)	30% decrease on Loading and offloading time	0.695	0.305
SC 62 (BFN – JHB)	10% increase on Loading and offloading time	0.719	0.281
SC 83 (BFN – JHB)	20% increase on all Travel time	0.758	0.242
SC 112 (BFN – JHB)	10% decrease on all parameters	0.706	0.294
SC 93 (BFN – JHB)	20% decrease on Travel time	0.689	0.311
SC 198 (BFN – CPT)	40% decrease on Loading and offloading time	0.614	0.386

From Table 6.10 and Table 6.11, five feasible scenarios were highlighted as follows:

- When load cost is increased by 10-20%, the freight share will be 72.5% for road and 27.5% for rail with generalised cost of rail being greater than road by approximately R0.91 km/kg/hr.
- When fuel cost is increased by 10-30%, the freight share will be 75.4% for road and 24.6% for rail with generalised cost for rail being greater than road by approximately R1.08 km/kg/hr.
- When loading and offloading is decreased by 30-40%, the freight share will be 69.5% for road and 30.5% for rail with generalised cost for rail being greater than road by R0.84 km/kg/hr.
- When travel time is decreased by 10-20%, the freight share will be 68.9% for road and 31.1% for rail with generalised cost for rail being greater than road by R1.82 km/kg/hr.
- When all parameters are decreased by 10-20%, the freight share will be 70.6% for road and 29.4% for rail with generalised cost for road being greater than rail by R0.20 km/kg/hr.

Therefore, the most feasible scenario will be the reduction of loading and offloading times by 30-40% (as loading and offloading times are more controllable than any other parameters), resulting in the freight share of 69.5% for road and 30.5% for rail with the generalised cost for rail being greater than road by R0.84 km/kg/hr. This will provide a balanced freight transportation system with an optimal modal split between freight road and rail within the central regions and other parts of South Africa.

6.7. Discussion

According to Havenga, Le Roux and Simpson (2018c), the annual tonnage handled by major freight transport infrastructures indicated that 1.53 billion tons of freight were transported by road, representing 76% of the total amount of freight transported in South Africa, with the balance being transported through maritime ports (13%), rail (10%), pipelines (1%), and airports (0,02%), demonstrating the operational and economic efficiency of freight road. According to the assessment of current economic and operational efficiency done in this chapter, the freight road still proves to be more economical and operationally efficient as it provides less travel time and has high demand of various commodities and thus corroborates the research done by Havenga, Le Roux and Simpson (2018c). This is imperative in the freight and logistics industry as stakeholders prefer transportation modes that are economical and operationally efficient by means of delivery of cargo in reasonable time periods and affordable generalised costs.

Furthermore, King and Ittman (2012) affirm that although the freight delivery has significant advantages, the great number of freight vehicles on the road contributes to overloading, subsequent road network deterioration and traffic congestion. However, this study provides different findings from King and Ittman's (2012) research as the perception received from stakeholders revealed freight road having a good effect on both the environment and the quality of road infrastructure. Therefore, this further shows that once there is an equal share of freight between road and rail, there could be a better impact on both the environment and infrastructure within the central regions of South Africa.

Additionally, Mesenbourg (2011) stated that an efficient movement of freight is vital for growth of the economy and there should be proper planning which must be based on regional commodity-level to try to inform the demand for regional transportation facilities and services. Based on the analysis of freight demand in this chapter, there is indeed a high demand for various commodities by both freight road and rail which contributes significantly to the economy of the country, and this proves Mesenbourg's (2011) research as valid. This is due to an increased number of agricultural and industrial activities within the urban areas of South Africa which have led to the inevitable demand of freight transportation. However, Kaack *et al.* (2018) highlighted the importance of modal shift, which is the transition from road-dominated freight transportation to rail-dominated freight transportation, as to elucidate the potential of modal shift to attain sustainability in the freight transport sector. Although Kaack *et al.*'s (2018) findings could lead to sustainability in the freight transportation industry, findings from this study reveal that an optimal modal split between freight road and rail having almost equal share of freight can be used as an alternative method in achieving a balanced and sustainable freight transportation system. Additionally, this will allow for at least a 70/30 utilisation of both freight transportation modes under study without an imbalance of freight share, as suggested by Kaack *et al.* (2018).

Conversely, Gardenete *et al.* (2018) observed that in freight transportation, rail has better performance than road transport, except in terms of employment multipliers, because transport by road is more labour intensive. From this study, Gradenete *et al.*'s (2018) research was substantiated as freight rail has greater carrying capacity over freight road which makes it a suitable mode to carry massive quantities of cargo and can be used for long-haul freight movement. This can further be affirmed by clients in this research who revealed the preference of freight rail over freight road due to its ability to carry commodities that are more economically beneficial, such as minerals, in the central regions and other parts of South Africa (see 5.2.3). However, the freight road showed good performance related to the demand aspect as perceived by involved stakeholders with freight rail showing good performance related to the supply aspect of freight movement. Hence, intermodal freight transportation is necessary in finding a balance of freight share between road and rail, leading to an equalised demand and supply level of the two transportation modes.

6.8. Summary

In this chapter, the findings revealed that Gauteng and the Free State are the major centres of freight movement between road and rail transportation modes, forming more routes and corridors. Also, freight road shows to have more demand in terms of supply in the central and other parts of

South Africa as it forms more origin and destination routes as compared to freight rail. Subsequently, freight road proves to be more economical and operationally efficient as it provides less travel time with higher demand for various commodities than freight rail. However, freight rail has greater carrying capacity over freight road which makes it a suitable mode to carry large quantities of cargo and can be used for long-haul freight movement. Additionally, freight road proved to have a moderate effect on the environment, road infrastructure quality, and service delivery performance based on the perception of involved stakeholders. Furthermore, there is an imbalance in the freight transportation system within the central and other parts of South Africa with freight road having a larger share of freight movement than freight rail. Hence, a model estimation was made to observe the overall cost of freight movement and examine the efficiency of road and rail transportation modes. The probability (share) of freight movement by the two modes was assessed under varying scenarios, which offered scenarios which could enable a balanced freight movement in the central regions of the country. The results revealed that there must be a reduction of 30-40% in loading and offloading times during freight movement which will provide a 69.5% freight share by road and 30.5% freight share by rail with the generalised cost for rail being greater than that of road by approximately R0.84 km/kg/hr. Although this modal split ratio is not 50:50, it will ensure a sustainable freight transportation system that can accommodate the use of both road and rail in freight movement within the central and other parts of South Africa.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1. Introduction

This chapter discusses the conclusion and recommendations of the study. The research objectives identified in section 1.3.2 are first briefly discussed. Concluding remarks on the results addressing these objectives, together with recommendations on reaching a sustainable freight transportation system within the central regions of South Africa, and future research that can contribute to an optimal and balanced freight transportation system are then identified.

The objectives of this research were to assess the scenarios of freight transportation system and challenges encountered in the central regions of South Africa; examine the current economic and operational efficiency of freight transportation by rail and road (trucks); develop an empirical model(s) for balanced and optimal freight transportation by rail and road in the central regions of South Africa, and develop guidelines for the balanced and optimal freight transportation by using both rail and road transportation modes. Additionally, the results addressing the objectives used in this study are discussed in the next sections.

7.2. Conclusions

The scenarios and challenges encountered in the central regions of South Africa revealed that there is an imbalance of freight transportation modes with an unequal share of freight between road and rail as freight road is being utilised more for freight movement than freight rail. Further, the freight movement route network is much more operative than the freight movement railway network due to the high demand (more routes with high volume of freight traffic) of freight movement by road than rail. Consequent to the current economic and operational efficiency in the central regions and other parts of South Africa, freight road showed to be the most preferred freight transportation mode due to an overall good performance on the environment, road infrastructure, and quality of service delivery. Subsequently, freight road demonstrated significance in providing diverse commodities ranging from clothing to minerals, being able to offer reasonable freight load costs, and carrying less freight load than freight rail. Furthermore, due to the high demand for freight movement by road rather than rail in the central regions and other parts of South Africa, freight road proved to be more efficient based on the freight movement network. As a result, the findings of this study suggest that freight road has a lower environmental impact and provides convenient and dependable service delivery in South Africa's central and other regions. Furthermore, infrastructural barriers, congestion, and increased costs are frequently the result of system distance capacity, which increases travel costs further; thus, this study contributed theoretically by identifying the economic and operational efficiency factors of using both freight road and rail to avoid congestion and increased travel costs.

Even though freight road is significantly more advantageous than freight rail, freight rail has proven to be operationally efficient due to its large carrying capacity. As a result, because current freight transportation scenarios in South Africa's central regions revealed an imbalance in freight share due to freight road being used more for freight movement than freight rail, the same estimated model demonstrated that the probability (share) of freight movement by the two modes under varying scenarios can lead to a sustainable freight transportation system. This will encourage the stakeholders involved to use freight transportation rather than their own personal mode of transportation. In general, because the freight transportation industry faces cost, capacity, transit speed, and equipment availability challenges, this estimated model can be used by freight and logistics stakeholders to balance freight shares between freight road and freight rail to overcome such challenges. This implies that they will be able to determine which parameters are more important than others in different scenarios.

Also, since the emergence of the freight and logistics industries is quite recent in the African continent, a model for disutility function was developed in this study which could assist in examining the overall freight cost by different transportation modes and simulating Binary Logit model to find balanced regional freight movement. Furthermore, theoretically, this study will contribute in terms of optimal split of freight by allowing an almost equal freight share between road and rail which will lead to a sustainable freight movement within the central regions and other parts of South Africa and thus overcoming the imbalance of freight shares between road and rail that currently exists in South Africa as a whole. Concurrently, loading and offloading times at ports or hubs should be reduced by 30-40% according to this study's simulation scenarios to achieve a freight share of 69.5% by road and 30.5% by rail. Furthermore, because there was a lack of intermodal connection flow across modes while considering factors such as social, economic, environmental, and land-use, the implementation of an internodal freight transportation system would allow for an engaged community partnership through job opportunities and the development of new infrastructure (road and rail) across different regions in South Africa.

7.3. Recommendations for a Sustainable Freight Transportation System

In the preceding section 7.2, it was concluded that an optimal and balanced freight transportation system with a modal split between freight road and rail is achievable in the central regions of South Africa. However, this is possible through adopting the following guidelines, based on the findings of this study:

- An intermodal freight transportation system may be implemented in all routes/corridors of freight movement using both road and rail in South Africa, with Gauteng being the major distribution centre.
- There should be a reduction of loading and offloading times by at least 30-40% at ports or hubs during freight movement.
- A modal split of 69.5% freight share by road and 30.5% freight share by rail can be adopted by freight and logistics stakeholders in freight movement. For example, if a client requests that a freight load be transported from one origin to a destination (say, Gauteng to Durban), road (truck) can take 69.5% of that freight load, with rail (train) taking the remaining 30.5% for the same route/corridor.
- Once the modal split is applied, the standard generalised freight costs will at least be reduced to R11.69 km/kg/hr for road and R12.53 km/kg/hr for rail.
- Freight rail should be used more for large quantities of freight load as it has large carrying capacity, and freight road for lower to moderate quantities of freight loads.

7.4. Future Research

The research that has been undertaken for this dissertation has highlighted a few topics of which future research would be beneficial.

Several areas where information is lacking were highlighted in the literature review. Allen *et al.* (2012) affirmed that there is limited understanding when it comes to the spatial and temporal nature of movement of goods within urban and rural areas (Allen *et al.*, 2012a). Hence, the freight and logistics industry has recently and slowly been gaining its recognition in South Africa. Therefore, future studies should aim at exploring the recent impacts of the freight transportation system on the economic growth of the country, particularly in the African continent.

Furthermore, there are other additional areas which were discovered in this study such as the limitation of load capacity between freight road and rail during freight movement. This has led to freight rail being the only favoured mode in transporting large quantities of cargo which still adds to an unequal share of freight between road and rail. Therefore, there should be investigations into increasing the load capacity of freight road in freight movement, but without negatively affecting the road infrastructure quality. This could be done by the design of freight vehicles that can accommodate large quantities of cargo in South Africa but considering factors such as cost, infrastructure, environment, and societal setting. Therefore, further research could be done to determine the travel modelling techniques based on large capacity and user-friendly freight vehicles.

Consequently, there are some infrastructural constraints in the freight transportation industry as freight rail is not in high demand due to poor maintenance of railway infrastructure in South Africa. As King and Ittman (2021) mentioned, although freight road delivery has significant advantages over freight rail, the great number of freight vehicles on the road contributes to overloading, subsequent road network deterioration and traffic congestion on urban and rural areas. This further proves that freight has shifted more to road due to deteriorated and poorly maintained rail infrastructures in South Africa. However, even though in this study, the perception of stakeholders involved in the freight and logistics industry revealed freight road to have an overall better performance on the environment and road infrastructure, based on suppliers' perspective it can change over a large population group or from the clients' perspective. Therefore, the degree of the infrastructural deterioration between the road surface and railway should be examined to reach an optimum structural operational capacity of the two transportation modes.

Moreover, this study investigated the economic and operational efficiency of freight road and rail in terms of travel factors, direct costs, and socioeconomic factors. This was important in establishing that the freight transportation system is not only based on monetary terms (profits) but involves other factors which all aim in contributing significantly to the transportation system and the economic growth of the country. However, during model estimation, most parameters that are related to socioeconomic factors such as safety, reliability, speed, and so forth, were not considered because of data limitations. These parameters are not essential in freight movement as opposed to the passenger movement system but are necessary as there is supposed to be an intermodal freight transportation system which ensures the neutrality across transportation modes by taking account of all relevant social, environmental, economic, and land-use factors. Therefore, future research should be performed by incorporating such parameters involved in the movement of freight. This could further assist the involved stakeholders in identifying which socioeconomic factors are more significant than others during the choice of transportation modes for freight movement.

7.5. References

Agamez-Arias, A. & Mayano-Fuentes, J. (2017). Intermodal transport in freight distribution: a literature review. Routledge, Taylor & Francis Group, *Transport review*. 37(6), pp. 782-807. https://doi.org/10.1080/01441647.2017.1297868

Aggarwal, V. K., & Newland, S.A., (2015). Responding to China's rise, US and UE Strategies, Springerlink e-book publications, The political economy of the Asia Republic, Chapter 2, pp. 23-34.

Allen, S., Seneviratne, S.I & Nicholls, N., (2012a). Changes in Climate Extremes and their impacts on the Natural Physical Environment, Columbia University academic commons, Colombia, Chapter 3, pp. 117-122.

Allen, J. & Browne, M. (2008). Review of survey techniques used in Freight Studies, Transport Studies Group University of Westminster London, Green Logistics Project: Work Module 9, pp. 4-55.

Allen, J., Browne, M. & Cherrett, T. (2012b). Investigating relationship between rod freight transport, facility location, logistic management and urban form. *J. Transport George*. Pp. 45-57.

Antonowicz, M. (2011). Regulation and logistics in rail freight transport. *The Archives of Transport XXIII* (3), pp. 275-284.

Archetti, C.M. & Sperenza, M. (2014). A survey on matheuristics for routing problems. *EURO J. Comput, Optim*. 2(4), pp. 223-246.

Basuroy, S. & Nguyen, D. (1998). Multinomial Logit market share models; Equilibrium characteristics and strategic implications. Management Science, 44(10), pp. 1396-1408.

Bektas, T. & Crainic. T.G. (2007). A brief overview of intermodal transportation. In Taylor GF (ed) *Logistics Engineering Handbook*, CRC Press, Boca Raton.

Bickman, L. & Rog, D. (2009). Applied research design: A practical approach. *Handbook of applied social research methods* (2nd Ed), pp. 3-43. Thousand Oaks, CA: Sage.

Bohlman, H., & Crompton, R., (2020). “The impact on the South African Economy of Alternative Regulatory Arrangements in the Petroleum Sector.” WIDER working paper 2020/153. https://doi.org/1035188/UNU-WIDER/2020/010-5.

Brogan, J.J., Aeppli, A.E., Beagn, D.F., Brown, A., Fischer, M.J., Grezenback, L.R., Mckenzie, E., Vimmerstedt, L., Vyas. A.D. & Witzke, E. (2013). Freight Transportation Modal Shares: Scenarios for a Low-Carbon Future. Transportation Energy Future Series. Cambridge Systematics, In (Cambridge, MA, Washington DC), pp. 20-40.

Chan, X., Lau, Y. & Ng, J.M.J. (2012). Critical evaluation of ERP implementation on firm performance: A case study of AT&T. *International Journal of Logistics Systems and Management*, Vol 12 No.1, pp. 52-69.

Council for Scientific and Industrial Research. (2011). Annual State of Logistics, Imperil Logistics, CSIR and Stellenbosch University 9th State of Logistics Survey, South Africa.

Crainic, T.G. (2004). Long haul freight transportation. In: Hall, R.W. (Ed), *Handbook of Transportation Sciences*, second edition. Norwell, MA. Pp. 451-516.

Crainic, T.G., Perboli, G., Rosano, M., (2019). Simulation of intermodal freight transportation systems: a taxonomy, ICT for City Logistics and Enterprises Center, Turin, Italy, pp. 4-15.

Colembska, E., (2008). A new Logistic Model of market information asymmetry reduction in Poland, Logistics, MDPI, Basel, Switzerland, pp. 4-19.

Dagsvik, J. (2000). Probabilistic Models for qualitative choice behavior: An introduction. Statistics Norway, Research Department, Norway, Documentation 2000/1, pp 30-60.

De Jong, P.T., McCarthy, C., Tomay, S.C. & Munoz., B., (2004). Prevalence of age-related macular degeneration in the United States, Arch Ophthalmol, Unites States, pp. 5-11.

De Jong, P.T & Berg, I.K., (2012). Interviewing for solutions, Freight and Logistics, United Stated, Fourth Edition, Chapter 3, pp17-44.

Demarcation, (2010). The vision, mission, values, mandate, functions, stakeholders & review of 2010/2011 performance, Municipal demarcation board strategic plan, Chapter 1, pp. 8-39.

Department of National Treasury, 2022. Medium term budget policy statement, NDP 2030, Republic of South Africa, ISBN:978-0-621-50536-8. (Accessed on 20 January 2023)

Department of Transport. (2011a). *Road Freight Strategy for South Africa*. Available from: http://www.transport.gov.za/LinkClick.aspx?fileticket=xCBSZLz9nfo%3D&tabid=113 (Accessed 02 July 2012).

Department of Transport. (2015b). *The National Development Plan*, The overview on Freight Transportation and Logistics Management, Chapter 1, pp. 1-5.

Digistics, (2021). Logitics trucking distributors, Operations past record, Bloemfontein.

Diziain, D., Gardrat, M. & Routgier, J.L. (2013). Far from the Capitals: what is the relevant city logistics public policies, 13th World Conference on Transport Research, Brazil, pp. 16.

Dollery, B.E. & Wallis, J.L. (1985). Conflict resolution and the deregulation of the South African transport sector, *Development of Southern Africa* 2(4), pp. 522-536.

Dube, M.S. (2014). Shared-Use of Railway Infrastructure in South Africa: The Case of Coal and Citrus Production in Mpumalanga, Master of Commerce, University of the Witwatersrand. Pp. 2-34.

Ellison, R.B., Teye, C. & Hensher, D.A. (2017). Modelling Sydney's light commercial service vehicles. Transport, Res, Poland publication, pp. 79-89.

EPA, (2018). Sources of Greenhouse Gas Emissions, https;//www.epa.gov/ghgemissions/sources-gas-emmissions (Accessed 2 January 2018).

EThekwini Municipality Plan. (2018). Preparation of the Mpumalanga northern functional area plan and draft scheme, including the MR385 East Corridor Precinct Plan: Wards 4, 5, 7 and 91, Corridor Plan and Urban design guidelines for MR385 East Corridor 1N-30465. South Africa, pp. 10-57.

European Conference of Ministers of Transport, (2001). ECM, Catalogue of publications 1963-2001, OECD, North America, pp. 30-42.

Faber, P.R., (1998). Airpower: Theory and Practice, Sage journals, pp45-60, retrieved from https://doi.org/10.1177/096834459800500209, (Accessed on 11 January 2020).

Facanha, C. & Horvath, A. (2005). Environmental Assessment of Freight Transportation in the U.S. *The International Journal of Life-Cycle Assessment* 11(4). Pp. 229-239.

First State of Logistics for South Africa, (2004). CSIR Centre of Logistics and Decision Support, Pretoria.

Free State Development Corporation, (2018). Agriculture and Agro-processing, Free State Economic Sector, South Africa, https://www.fdc.co.za/index.php/addons/fs-economic-sectors/agriculture-agro-processing, (Accessed 17 June 2020)

Gardenete, M.A. & Lopez-Cabaco, R. (2018). How modes of transport perform differently in the economy of Andalusia, Department of Economics, University of Layola de Andalucía, Seville. Transport policy 66, pp. 1-8.

Garret, M. (2014). *Encyclopedia of Transportation, Social Science and Policy*. Sage publishing, Los Angeles.

Ghisolfi, V., Ribeiro, G.M., Chaves, G.L., Filho. D.O.R., Hoffmann. I.C.S. & Perim. L.R. (2019). Evaluating Impact of Overweight in Road Freight Transportation: A Case study in Brazil with system dynamics, Transportation Engineering program, Federal University of Rio de Janeiro. Rio de Janeiro article, pp. 1-35.

Giuliano, G., Kang, S. & Yuan, Q. (2017) Spatial planning models of airport-driven urban development. Johannesburg planning, Lit, pp. 263-279.

Grainic, T.G., Ricciardi, N., Storchi, G. (2004). Advanced freight transportation systems for congested urban areas, *Transportation Research Par C* 12, pp. 119-1137.

Google Maps, (2022a). Interesting 10 Facts about South Africa, South Africa., Online publishing, available on:https://www.google.com/url?sa=i&url=https%3A%2F%2Fshowme.co.za%2Ffacts-about-south-africa (Accessed 03 January 2021).

Google Maps, (2017b). Map of South Africa English labels, wikimidea commons, retrieved from https://commons.wikimedia.org/wiki/File:Map_of _South_Africa_with_English_labelsvg (Accessed 18 February 2020)

Hall, R. (2003). *Handbook of Transportation Science*, Springer Verlag.

Havenga, J.H., Bod, D., A, Simpson, Z. P., Viljoen, N., (2016a). A logistics barometer for South Africa: towards sustainable freight mobility, Transport and Supply Chain Management, 10(1), a228, doi:10.4102/jtscm. v10i1.228.

Havenga, J.H., Le Roux, P.P.T. & Simpson, Z.P., (2013b). The importance of disaggregated freight flow forecasts to inform transport infrastructure investments, Journal of Transport and supply chain management, 7(1), pp.1-4. Retrieved on htpps://doi.org/10.4102/jtscm.v7i1.106.

Havenga J.H., le Roux, P.P.T. & Simpson, Z.P. (2018c). A heavy goods vehicle fleet forecast for South Africa. *Journal of Transport and Supply Chain Management*, 12(0), a342. https://doi.org/ 10.4102/jtscm. y12i0.342

Havenga, J., King, D.J., Bean, W., Steyn, W.J. vdM., (2010d). The state of logistics in South Africa: The effect of road conditions on logistics, CSIR Built Environment. Pretoria, Gauteng, South Africa. CSM, Department of Logistics, Stellenbosch University, Western Cape. Pp. 1-8.

Havenga, J.H., Pienaar, W.J. & Simpson, Z. (2011e). A case for measuring logistics costs on a national level: South African Application, Corporate Ownership and Control 8(3). Pp. 622-631.

Hawker, J.S., Falzarano, A. & Ketha, S. (2007). Intermodal Transportation Network Custom Evaluators for Environmental Policy Analysis. ESRI International User Conference, San Diego, CA.

Helms, R.V. & Jacobs, J.A. (1999). Method and apparatus for freight transportation using satellite navigation system, Qualcomm Incorporated, San Diego California, pp. 1-26.

Hensher, D. & Figliozzi, M.A. (2015). Behavioral insights into Modelling of freight transportation and distribution systems, Institute of Transport and Logistics studies. The University of Sydney. Pp. 1-4.

Hence, H., (2012). The Integrated Climate Protection Programme Hesse 2012 (INKLM 2012), The Hession Ministry of Environment, Rural Development and Consumer Protection, Climate adapt, Ed.4, pp. 30-40.

Hitchcock, G. & Carslaw, D. (2016). Road transport and air pollution – Where are we now? *Energy and Environment*, London, p. 10.

Holguin-Veras, J., Jallerr, M. Sanchez-Diaz, L., Wojtowicz, J., Lawson, C., Levinson, J., Campbel, L.S. & Shin, H.S. (2013). Transferability of freight trip generation models. Johannesburg transport, Res, Board 2379, pp. 1-8.

IBM Corp. (2020). IBM SPSS Statistics for Windows (Version 27.0), [Computer software], IBM Corp.

Integrated Development Plan (IDP) (2018 & 2019). Mangaung Metropolitan Municipality, draft integrated development plan, Bloemfontein, pp. 22-48.

Jin, J. & Rafferty, R. (2017). Does congestion negatively affect income growth and employment growth? Empirical evidence from US metropolitan regions. Trans Policy 55:1-8.

Kaack, L.H., Vaishnav, P., Morgan, M.G., Azevedo, I.I. & Rai, S. (2018). Decarbonizing Intraregional Freight Systems with a focus on Model shift. *Environ. Res. Lett*. 13(8), p. 083001.

Kendra, M., Kalina. T., Jurkovic, M., Votjek, M. & Synak, F. (2018). Environmental comparison of different transport mode, University of Zilina, Faculty of operation and Economics of Transport Communications, Department of Road, and Urban Transport Slovak Republic. Original scientific paper, 28.8.2018. Pp. 1-5.

King, D. & Ittman, H. (2012). *Statistic of Logistics Survey for South Africa*, Logistic Value, and cost drivers from macro and micro-economic perspective. CSIR. 5th annual state of logistics survey for South Africa.

Kothari, C.R. (2004). Research Methodology: Methods and Techniques. New Delhi: New Age International publishers.

Kutner, M.H., Nachtsheim, C.J. & Neter, J. (2004). *Applied Linear Regression Models*, 4th edition, Homewood, II: Irwin.

Lafkihi, M., Shenle, P. & Eric, B. (2019). Freight transportation service procurement: A literature review and future research opportunities in omnichannel E-commerce. *Transportation Research Part E: Logistics and Transportation Review*, 125, pp. 348-365.

Lane-Visser, E.L. & Vanderschuren, M. (2019). Towards Sustainable Freight Energy Management: Development of a Strategic Decision Support Tool. University of Cape Town, thesis publication, pp. 2-5.

Lee, H. (2014). Modeling carrier interactions in an International Freight Transport System, International Journal of information systems and supply chain management, Department of Civil and Environmental Engineer, Rutgers University 7(1). Pp. 15-39.

Luarance, W.F., Clements, G.R., Sloan. S., O'connell, C.S., Mueller, N.D., Goosem, M., Venter, O., Edwards, D.P., Phalan, B., Balmford, A.A., (2014). A global strategy for road building, Nature, pp. 229-232. Doi:10.1038/mature13717. (Accessed on 20 January 2023).

Levinson, D. (2003). Perspectives on efficiency in transportation," International Journal of Transport Management, pp. 145-155.

Litman, T., (2010). Current mobility trends- Implications for sustainability, Transportation Association publication, Chapter 2, pp 13-17.

Lindholm, M. (2012). How a Local Authority Decision Makers Address Freight Transport in the Urban Area, *Procedia – Social and Behavioral Sciences*, 39, pp. 134-145.

Lowe, D. (2005). *Intermodal Freight Transport*. Burlington, M.A, Elsevier.

Macario, R. (2013). Modeling for public policies inducement of urban freight business development, In Ben Akiva M, Meersman H, Van de Voorde E. (Eds). *Freight transport Modeling*, pp. 405-432.

Madubanya, J. (2016). *Evaluating the operational efficiency of Rail Freight Volumes*, MTech dissertation, Dept of Quality Operations Management, University of Johannesburg.

Mahnmassani, H.S. (2001). Freight and Commercial Vehicle Applications Workshop Report. In *Travel Behaviour Research: The leading edge*, Pergamon, London.

Martner, C. & Garcia, G. (2015). Performance measurement for intermodal corridors: A methodological approach. Logistics development strategies and performance measurement, Roundtable Report 158, International Transport Forum. Available from http://www.itfoecd.org/sites/default/files/docs/logisticsstrategy-performance-management.pdf (Accessed 15 July 2016).

Mathers, N., Fox, N. & Hunn, A. (2009). Surveys and Questionnaires, The NIHR Research Design Service Yorkshire & the Humber, National Institute for Health Research, pp. 8-22.

Mathew. T.V. & Rao. K.V.J. (2007). Introduction to Transportation Engineering, Modal Split, NPTEL. Chapter 9, pp. 9.3-9.7.

Matulin, M., Bosnjak, I. & Skorput, P. (2005). Development of project evaluation methodology for intelligent transport systems, Faculty of Transport and Traffic Sciences, ITS Croatia Association, Croatia, pp. 1-8.

Maurage, P., Heeren, A. & Presenti, M. (2013). The peripheral of over-interpreting correlations in health studies, *J Nuture*, 2013:143:931-3.retrieved from https://www.researchgate.net/publication/280141801_Relations_between_cognitive_abilities_drinking_characteristics_and_emotional_recognition_in_alcohol-dependence_A_preliminary_exploration. (Accessed 17 May 2019).

Mesenbourg, T. (2011). The role of commodity flow survey in understanding the U.S economy, Commodity flow Workshop. Transportation Research Circular Number E-C158. http://onlinepubs.trb.org (Accessed 18 April 2020).

Mezyk, K., & Zamkowska, TP., (2016). The impact of freight transport operations on the level of pollution in cities, Transport Research Procedia 39: 81-90, Crestochowa University of Technology, Poland, pp. 12-16.

Miller-Hooks, E., Zhang, X. & Faturechi, R. (2011). Measuring and maximizing resilience of Freight Transportation Networks, University of Maryland and College Park. Pp. 1-4.

Mindrila, D. & Balentyne, P. (2014). *The basic practice of statistic*, Chapter 15. 6th Edition, pp. 1-12.

Mostert, M. & Limbourg, S. (2016). External costs are competitiveness for freight transport - A state of the art. University of Liege (ULg), HEC Management School. Belgium. Pp. 1-23.

Murray, L., Nguyen, H., Yu-Feng, L., Remmenga, M.D. & Smith, D.W. (2012). Variance inflation factors in regression models with dummy variable, Conference on Applied Statistics in Agriculture. https://doi.org/10.4148/2475-7772.1034

Myburgh, P.A. (2018). A review of the South African rod network and its impact on the bituminous product industry, Roads Review. SABITA, Department of Trade, and Industry, Available from http://www.dti.gov.za/. Pp. 22-44.

National Cooperative freight Research Program (NCRP) (2011). *Impacts of Public Policy on the Freight Transportation System*, Transportation Research Board, Washington DC, NCFRP Report 6 (Revised), PP. 60-85.

National Cooperative Highway Research Program (NCHRP), (2011). *Freight transportation Surveys*: State of practice, National Academies press, Washington, Chapter 3, pp. 12-30.

NATMAP, (2019). Status quo of transport, Freight movement patterns and characteristics, Volume1, pp. 1-52.

Oudani, M., Alaoui, A.E.H., Boukachour, J., (2014). *An efficient genetic algorithm to solve the intermodal terminal location problem*. Int. J. Sup. Oper. Man, 1, 279–296.

Pauw, K. & van Schoor, P., (2005a). A profile of the Free State province: Demographics, poverty, inequality and unemployment. Background Paper 1:4, Provide project background paper series, pp. 12-25.

Pauw, K. & van Schoor, P., (2005b). A profile of Mpumalanga demographics, poverty, inequality and unemployment, Background paper 2005: 1(8), pp 8-12.

Petro, F. & Konećnȳ, V. (2017). Calculation of emissions from transport services and their use for the internalization of external costs in road transport. Transcom 2017: International scientific conference on sustainable, modern, and safe transport, University of Zilina, Department of Road and Urban Transport, pp. 668-682.

Pope, C. & Mays, N. (2000). *Qualitative Research in Health Care*. BMJ Books.

Porter, M. & Bhattacharya, S. (2005). Investigation of staff and patients' opinions of a proposed trial of elective single embryo transfer. *Hum Report*. 20: pp. 2523-2530.

Poverello Maps, 2014. Linear cascading effect on Southern African development, Journal of Transport and Supply Chain Management, Nabee, G., & Walters, J., (2018). AOSIS, pp.6.

Resnik, D.B. (1998). *The ethics of Science: An Introduction*, London: Routledge.

Reyneker & Drent (2012). SANEC Gauteng and Harrismith, Fact finding: Transport, Energy & Water, 2G@THERE publication, South Africa, pp. 15-30.

RFA. (2014). *Vehicle cost schedule*, Road Freight Association Pretoria, South Africa.

Rodriguez, D.A., Shay, E. & Winn, P. (2013). Comparative review of Portable Global Positioning System units, Department of City and Regional planning, University of North Carolina at Chapel Hill, US. Chapter 1, Nova Science Publishers Inc. Pp. 22-40.

Salonen, M. & Toivonen, T., (2013). Modelling travel time in urban networks: comparable measures for private car and public transport, Journal of Transport Geography, Department of Geosciences and Geogrpahy, University of Hlsiniki, Finland, p.p. 12-15.

Sànchez-Diaz, I., Georén, P. & Brolinson, M. (2017). Shifting urban freight deliveries to the off-peak hours: a review of the theory and practice, Technology Management and Economics, Chalmers University of Technology, Sweden. 47(4), pp. 521-543.

Savy, M. (2009). Freight transport modes: Competition, cooperation, or area of advantage? University of Paris East Director, Observatory of Transport Policies, and strategies in Europe, 14th ACEA Scientific Advisory Group Meeting. Pp. 5-20.

Skender, H.P., Host, A. & Nuhanovic, M. (2016). The role of logistics service providers in international trade, University of Rijeka, Croatia, Faculty of Economics. 16th international scientific conference Business Logistics in Modern Management, pp. 1-17.

Slack, B. (2001). Intermodal transportation, in Handbook of Logistics and Supply-chain Management Edition. Pergamon, Amsterdam, pp. 141-154.

Stander, H.J. & Pienaar, W.J. (2002). Perspective on Freight Movement by road and rail in South Africa. Department of Logistics, University of Stellenbosch, conference journal, pp. 1-12.

Statistics South Africa. (2011a). Provincial profile, Census 2011, report 03-01-733011, Pretoria, retrieved from https://www.statssa.gov.za/publications/P03014/P030142011.pdf (Accessed in July 2020).

Statistics South Africa, (2011b). Land transport (Preliminary), Statistical release P7162December, retrieved from https://www.statssa.gov.za/publications/P7162/P7162January2011.pdf. (Accessed 15 June 2020).

Statistics South Africa, (2012c). Land transport (Preliminary), Statistical release P7162December, retrieved from https://www.statssa.gov.za/publications/P7162/P7162Jane2012.pdf. (Accessed 15 June 2020).

Statistics South Africa, (2013d). Land transport (Preliminary), Statistical release P7162December, retrieved from https://www.statssa.gov.za/publications/P7162/P7162April2013.pdf. (Accessed 15 June 2020).

Statistics South Africa, (2014e). Land transport (Preliminary), Statistical release P7162December, retrieved from https://www.statssa.gov.za/publications/P7162/P7162October2014.pdf. (Accessed 15 June 2020).

Statistics South Africa, (2015f). Land transport (Preliminary), Statistical release P7162December, retrieved from https://www.statssa.gov.za/publications/P7162/P7162January2015.pdf. (Accessed 23 July 2020).

Statistics South Africa, (2016g). Land transport (Preliminary), Statistical release P7162December, retrieved from https://www.statssa.gov.za/publications/P7162/P7162March2016.pdf. (Accessed 23 July 2020).

Statistics South Africa, (2017h). Land transport (Preliminary), Statistical release P7162December, retrieved from https://www.statssa.gov.za/publications/P7162/P7162March2016.pdf. (Accessed 23 July 2020).

Statistics South Africa, (2018i). Land transport (Preliminary), Statistical release P7162December, retrieved from https://www.statssa.gov.za/publications/P7162/P7162May2018.pdf. (Accessed 23 July 2020).

Statistics South Africa, (2019j). Land transport (Preliminary), Statistical release P7162December, retrieved from https://www.statssa.gov.za/publications/P7162/P7162May2019.pdf. (Accessed 23 July 2020).

Statistics South Africa, (2020k). Land transport (Preliminary), Statistical release P7162December, retrieved from https://www.statssa.gov.za/publications/P7162/P7162May2019.pdf. (Accessed 17 March 2021).

Statistics South Africa, (2021*l*). Land transport (Preliminary), Statistical release P7162December, retrieved from https://www.statssa.gov.za/publications/P7162/P7162June2021.pdf. (Accessed 04 November 2021).

Stevenson, J. (2017). The New Freight Transportation Puzzle, controlling freight costs move, Material Handling & Logistics Penton publishing, mhlnews.com/transportation distribution., pp. 24-27.

Steyn, H., (2015a). Corporate strategy and projects- mind the gap, International Association for management of technology, IAMOT Conference proceedings, pp 12-23.

Steyn W.J., Nokes W.A., Monismith C.L., Harvey T.J., Holland T.J. & Burmas N. (2012b). Challenges confronting road transport and the use of vehicle-pavement interaction analysis in addressing these challenges, Journal of the South African Institution of Civil Engineering. 54(1), pp. 14-21.

Steyn, W.J., v.d.M. & Bean, W.L. (2010c). Cost of bad roads to the economy, The 6th annual state of Logistics Survey for South Africa: Logistic value and cost driving macro and micro-economic change towards global competitiveness and sustainability 2009, Kind, D. (ed), CSIR.

Sukamolson, S. (2007). Fundamentals of quantitative research. Language Institute Chulalongkon University. Pp. 1-20.

Tavasszy, L.A., Thissen, M.J.P.M. & Ooosterhaven, J., (2011). Challenges in the application of spatial general equilibrium models for transport appraisal, research in Transportation Economics, Elsevier, vol 31(1), pp. 12-18.

Tejaswi, G., Kumar, A., Aramesh, S. & Kumar, M. (2015). Development of mode choice models using multinomial logit approach in Hydrated City. International Journal, Resident Engineer Technologist, 04(13), pp. 311-314.

Thill, J. (2008). Intermodal freight transportation and regional accessibility in the United States, University of North Carolina, Charlotte, Sage journals, pp. 2-9.

Tob-Ogu, A., Kumar, N., Cullen, J. & Ballantyne, E.E. (2018). Sustainability intervention mechanism for managing road freight transport externalities; A systematic literature review, Faculty of Social Sciences, Sheffield, UK, pp. 1-18.

Transcom, (2017). The MOBNET system assumptions, the use of UAV's for search and reuse operations, Poland, retrieved from https://mobnet-h2020.eu/index.php/news/item/transcom-2017. (Accessed 28 August 2020).

Transnet Freight Rail, (2018). Transnet solutions delivered, annual report, Johannesburg, South Africa, pp. 7-17.

Transnet Freight Rail, (2021). Freight rail operations, historical statistical report, Bloemfontein.

Transport visuals. (2002). Modelling of intermodal freight transportation network, Department of Transportation Management, Vilnius Gediminas Technical University. XVII (3), pp. 117-121.

Transport Infrastructure. (2014). Chapter 6, Transport Infrastructure 2050 Spatial Vision Plan, Pretoria, pp. 8-18.

Tran, H., Chen, S., & Shumack, S., (2003). Epidemiology and aetiology of basal cell carcinoma, *British Journal of Dermatology,* Volume 149, Issue 66, pp. 50-52.

UNECE, (2009). Illustrated glossary for transport statistics, ISBN: 978-92-79-17082-9.

Vilko, J., Rumpu, A. & Koivuneimi, J. (2012). An information-exchange perspective on supply-chain risk management. Systematic organization motives and cognitive barriers. *International Journal of Logistics Systems and Management*, 12 (4), pp. 460-482.

Visser, J. & Hassall, K. (2010). What should be the balance between free markets and a not so invisible hand in urban freight regulation and land use. Dutch and Australian experience, 6th International Conference on City Logistics, Amsterdam.

Waters, C.D.J, (2003). Logistics: An introduction to supply chain, research-gate publication, United Kingdom, retrieved from httppss://www.reserahcgate.net/publication/47037506 (Accessed 16 July 2020).

World Bank. (2016). Logistic Performance Index (LPI), Global rankings, 2-16. Retrieved from http://lpi.worldbank.org/international/global (Accessed 12 July 2020).

Zeimpekis, V., Minis, I. & Pappa, V. (2010). Real-time logistics management of dried figs using RFID technology: Case study in a Greek cooperative company.' *International Journal of Logistics Systems and Management*, 7(3), pp. 265-285.

Zhang, M. & Pel, A. (2016). Synchromodal hinterland freight transport: Model study for the port Rotterdam. *J. Tramp, Geography*. 52, pp. 1-10.

Zhang, X., Li, Lin. & Zhang, J. (2019). An optimal service model for rail freight transportation; Pricing, planning, and emission reducing, *Journal of cleaner production*.

APPENDIX A: Primary and secondary data

- **Freight supply**

Table A The freight load percentages between road and rail (Source: Self-administered questionnaires, 2020-2021)

	% Of freight loads		
Freight modes	0-25000 (ton/km)	25000-50000(ton/km)	>50000(ton/km)
Freight road	97.1	2.9	
Freight rail	50	33	16.7

- **Freight load movement costs** (Source: Self-administered questionnaires, 2020-2021)

Table B The freight cost between road and rail during movement of cargo.

	% of Freight movement		
Freight Modes	**R0-50000**	**R50000-100000**	**>R100000**
Road	100	27	10
Rail	0	73	90

- **Operational efficiency between freight road and rail** (Source: Stats SA, 2020a-2021*l*)

Table C The annual freight load(ton/km) movement for road and rail.

Years	**Freight movement by road**	**Freight movement by rail**	**Freight load differences annually**
2011	196561	496177	299616
2012	209416	484253	274837
2013	213584	521362	307778
2014	222934	564879	341945
2015	222221	550283	328062
2016	219732	562158	342426
2017	229843	684660	454817

2018	217401	756005	538604
2019	215745	697206	481461
2020	191847	614945	423098

- **The economic efficiency of freight road and rail** (Source: Self-administered questionnaires, 2020-2021)

Table D The average fuel consumption and fuel cost for road and rail based on primary data.

Freight modes	**Average Fuel Consumption(l/ton/km)**	**Average Fuel Cost (R/ton/km)**
Freight Road	883,4	1 708,96
Freight Rail	417,395	4 204,42

- **The service delivery performance between freight rail and road** (Source: Self-administered questionnaires, 2020-2021)

Table E The average number of trips for road and rail within the central regions of South Africa

Freight modes	**Average number of trips per freight movement**	**Average travel distance for freight movement**
freight road	273	771
freight rail	56	1682

- **The perception of suppliers for the effects of freight road and rail on the environment, infrastructure, and service delivery** (Source: Self-administered questionnaires, 2020a-2021*l*)

Table F The freight aspect effects by road and rail as perceived by stakeholders.

	Freight aspects								
	Impact on the environment (Pollution/Noise)			**Road/Rail Infrastructure quality (potholes/cracks/rail track defects)**			**Service delivery reliability (Speed/Safety)**		
Freight mode	***Good***	***Fair***	***Bad***	***Good***	***Fair***	***Bad***	***Good***	***Fair***	***Bad***
Train	50	33.33	16.67	50	50		33.33	50	16.67
Truck	17.14	74.29	8.57	22.86	51.43	25.71	94.29	5.71	

APPENDIX B: Self-administered questionnaire

HERE ARE THE QUESTIONS WHICH ADDRESSES THE TOPIC UNDER INVESTIGATION (*please indicate by* **X** and kindly provide **averages** e.g., if it's between '**0-500tons'**, then the average maybe '**200tons'** depending on your records**)**:

Questions	Answers		
1. How much quantity is being transported per month per mode (truck/train)?	0-500tons **Ave:**	500-1000tons	1000-5000tons
2. How many trips are required per month per mode of transport (truck/train)?	5-20 **Ave:**	20-40	40-60
3. How many kilometres does it travel from one hub to the other?	100-300km **Ave:**	300-600km	600-900km
4. How many hours does it take during loading and offloading?	0-2hrs **Ave:**	2-4hrs	4-8hrs
5. How much does it cost per load?	0-R2000 **Ave:**	R2000-R5000	R5000-R20000
6. What is the fuel consumption with regards to the movement of goods per load?	0-300 litres **Ave:**	300-900 litres	900-1500 litres
7. How long does it take to travel from the origin to the destination?	0-3hrs **Ave:**	3-6hrs	6hrs-9hrs
8. How does it affect the road/railway infrastructure?	Good	Bad	Fair
9. What is the service range of this mode of freight transportation?	Food/ Clothes	Goods/ Materials	Machinery/plants
10. How flexible and accessible is this mode?	Very Flexible	Flexible	Inflexible
11. What impact does it have on the environment?	Good	Fair	Bad
12. How reliable it is in terms of service delivery?	Good	Fair	Bad
13. What are the common delays in service delivery?	Breakdown	Fuel shortage	Fatigue
14. How much stoppage/ resting time is allowed for drivers during transportation?	0-30min **Ave:**	30min-1hr	1hr-4hrs

15. What are the storage problems?	Less space	Safety	Hazardous
16. Employee (mode operators) age ranges	18-25yrs	25-35yrs	35-60yrs
17. Gender of employee dominance	Male	Female	Equal
18. Are there any parking problems experienced during offloading?	Yes	No	Sometimes
19. How much is the loading and offloading costs?	R200-400 **Ave:**	R400-600	R600-900
20. How much are the packing costs?	R0-150 **Ave:**	R150-300	R300-450

APPENDIX C: Relative travel time and cost calculations

1. $Relative\ Travel\ Time\ (RTT) = \frac{a+b+c+d+e}{f+g+h}$ (Salonen *et al*., 2013)

a = in-vehicle travel time

b = transfer time between transit vehicles

c = waiting time for transit service

d = walking time to transit service

e = walking time from transit service

f = personal vehicle driving time

g = parking delay

h = walk time from parking to destination

- It should be noted that the calculations were based on an average of the sample obtained from respondents (road and rail) in terms of the relative time spent at warehouses or stations prior to initial freight movement (example of calculation was made of one mode only).

- Therefore, for road freight a= 80,8 hr; b = 38 hr; c = 39 hr; d= 34 hr; e= 35 hr; f= 4 hr; g= 1; h= 2 hr

$$\text{Relative Travel Time(RTT)} = \frac{a+b+c+d+e}{f+g+h}$$

$$= \frac{80{,}8+38+39+34+35}{4+1+2}$$

$$= 32{,}4 \text{ hrs.}$$

2. $\text{Relative Travel Cost} = \frac{i}{(j+K+0.5P)1/m}$ (Salonen *et al.*, 2013):

where:

- i= Transit Fare
- j= Cost of Fuel
- K= Cost of lubricants
- P= Parking Cost at Destination
- m = Average Car Occupancy

- It should be noted that the calculations were based on an average of the sample obtained from respondents (in terms of the relative cost of movement at warehouses or stations prior to initial freight movement) (example of calculation was made of one mode only).

- Therefore, for road freight *i*= R15 008 km/t/hr; j = R1120 t/km; K =R12,4 t/km; P= R62,5/hr; m= 1

$$\text{Relative Travel Cost} = \frac{i}{(j+K+0.5P)1/m} = \frac{15\ 008}{(1120+12{,}4+0.5 * 625)1/1} = \text{R}28{,}23 \text{ t/km/hr}$$

APPENDIX D: Disutility functions for generalised cost and influential parameters

Since in this study the focus is made on two modes which are freight rail and freight road, the determination of generalised cost based on disutility functions was made up of the following matrix components: Cij= Generalized cost = f (Direct cost and Travel factors)

Direct cost = **(Xa)**

- Parking cost(X1)
- Load cost (X2)
- Fuel cost (X3)

Travel factors = **(Xb)**

- Loading and unloading time(X4)
- Waiting time (X5)
- Travel time (X6)

The weightages (W) and ratings (R) for the mode attributes (Xi) was made from the primary data to find the Cij (generalised costs) which will contribute to the development of the model. Table 5.7 is the matrix of the generalised costs (Cij) using disutility functions in the form of weightages and ratings. This is to determine the generalised costs which involves the direct cost and travel factors per trip of freight road and rail within the central regions and other parts of South Africa. To elaborate more on disutility function, it is based on the theory that attributes/parameters that are related to mode choice are nothing but model characteristics which are considered as casual variables in the mode choice process. Further, this means that when people make choices based on these set of attributes/parameters such as travel time, travel cost, travel comfort etc., they perceive them indirectly as a measure of service and not directly as attributes/parameters only, hence these set of attributes/parameters need to be weighted identically across choices (as shown in the example below) (Mathew & Rao, 2007).

As indicated on the table 5.7, the matrix for the trips made by freight road and rail in each row adopted this model; Cij=$\left(\frac{W1*R1+W2*R2+W3*R3+\cdots.WniRni}{R1+R2+R3+\cdots Rni}\right)$. An example was made for the first row in terms of the determination of the weightages and ratings as follows:

* **Step 1**: Determination of the weightage **(W1)** for Parking Cost (X1)

- R0-2 = 1; R2-4 = 2; >R4=3; (Select 1 option based on given data)

***Step 2:** Determination of the rating **(R1)**

- R0-4= 1; >R4=2; (Select 1 option based on given data)

***Step 3**: Determination of weightage **(W2)** for Load Cost (X2)

- R0-3= 1; R3-6= 2; R6-9=3; R9-12=4; >R12=5 (Select 1 option based on given data)

***Step 4:** Determination of rating **(R2)**

- R0-15= 1; >R15=2 (Select 1 option based on given data)

***Step 5:** Determination of weightage **(W3)** for Fuel Cost (X3)

- R0-10= 1; R10-20=2; >R20= 3 (Select 1 option based on given data)

***Step 6:** Determining the rating **(R3)**

- R0-15= 1; R15-30=2; >R30= 3 (Select 1 option based on given data)

***Step 7:** Determination of weightage **(W4)** for Loading and offloading time(X4)

- 0-4 hrs.= 1; >4 hrs. = 2 (Select 1 option based on given data)

***Step 8:** Determination of rating **(R4)**

- 0-8 hrs.= 1, 8-16 hrs.= 2, >16 hrs.= 3 (Select 1 option based on given data)

***Step 9**: Determination of weightage **(W5)** for Waiting Time t(X5)

- 0-10 hrs.= 1; >10 hrs.= 2 (Select 1 option based on given data)

***Step 10:** Determination of rating**(R5)**

- 0-8 hrs.= 1; 8-16 hrs.= 2; >16 hrs.= 3 (Select 1 option based on given data)

***Step 11:** Determination of weightage **(W6)** for Travel time (X6)

-0-5 hrs.= 1, 5-10hrs.= 2, >10hrs = 3 (Select 1 option based on given data)

***Step 12:** Determination of rating **(R6)**

- 0-20hrs= 1; 20hrs >= 2 (Select 1 option based on given data)

***Step 13:** Calculate Cij model from the obtained data (**Step 1-12**)

- Cij= $\left(\frac{W1*R1+W2*R2+W3*R3+\cdots .WniRni}{R1+R2+R3+\cdots Rni}\right) = \left[\frac{(1x2)+(2x1)+(2x1)+(1x1)+(1x1)+(3x1)}{2+1+1+1+1+1}\right]$=11

APPENDIX E: Validation of model estimates

- *Freight Road Validation Process*

i. Overall Freight Cost per trip = R 6 613.61 ÷20 ton÷24 = **R13,78/ton/km/hr**

ii. Overall freight cost (model) = $2.177 + 0.727X_1 + 0.323\ X_2 + 0.218X_3 + 0{,}323X_4 + 0.217X_6$

$$= 2.177 + (0.727 * 3.08) + (0.323 * \ 5.7) + (0.218 * 11.57) + (0{,}323 * 3) + (0.217 * 7)$$

$$= \underline{\mathbf{R11.99/ton/km/hr}}$$

iii. % Variance Tolerance = $\frac{13{,}78-11{,}99}{13{,}78+11{,}99} * 100 =$ 6,95 < 10% (Therefore the model is valid).

- *Freight Rail Validation Process*

iv. Overall Freight Cost per trip = R 12 092.67 ÷25 ton÷24 = **R20,19/ton/km/hr**

v. Overall freight cost (model) = $2.177 + 0.727X_1 + 0.323\ X_2 + 0.218X_3 + 0{,}323X_4 + 0.217X_6$

$$= 2.177 + (0.727 * 6.33) + (0.323 * \ 13.67) + (0.218 * 23.65) + (0{,}323 * 7) + (0.217 * 10)$$

$$\underline{= \mathbf{R\,22.3/ton/km/hr}}$$

$v.i.$ % Variance Tolerance = $\frac{20{,}19-22{,}3}{20{,}19+22{,}3} * \ 100$ = -4.97 <10 % (Therefore the model is valid & negative shows that the developed model is higher than the actual cost)

APPENDIX F: Simulations of model estimates

Table G The simulations of freight road under varying scenarios.

Road Freight	Constant	B2	Parking cost(X1)	B3	Load cost(X2)	B4	Fuel cost(X3)	B5	Loading and Offloading(X4)	B7	Travel Time (X6)	Cij(R/km/t/hr)
Scenario1 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario2 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario2 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario3 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario4 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario5 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario6 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario7 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario8 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario10 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario11 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario12 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario13 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario14 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario15 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario16 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario17 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario18 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario19 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426

Scenario20 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario21 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.000	11.426
Scenario22 (BFN-JHB)	2.177	0.727	0.000	0.323	8.635	0.281	16.960	0.323	2.000	0.217	6.000	11.680
Scenario23 (BFN-JHB)	2.177	0.727	0.000	0.323	9.420	0.281	16.960	0.323	2.000	0.217	6.000	11.933
Scenario24 (BFN-JHB)	2.177	0.727	0.000	0.323	10.205	0.281	16.960	0.323	2.000	0.217	6.000	12.187
Scenario25 (BFN-JHB)	2.177	0.727	0.000	0.323	10.990	0.281	16.960	0.323	2.000	0.217	6.000	12.441
Scenario26 (BFN-JHB)	2.177	0.727	0.000	0.323	11.775	0.281	16.960	0.323	2.000	0.217	6.000	12.694
Scenario27 (BFN-JHB)	2.177	0.727	0.000	0.323	12.560	0.281	16.960	0.323	2.000	0.217	6.000	12.948
Scenario28 (BFN-JHB)	2.177	0.727	0.000	0.323	13.345	0.281	16.960	0.323	2.000	0.217	6.000	13.201
Scenario29 (BFN-JHB)	2.177	0.727	0.000	0.323	14.130	0.281	16.960	0.323	2.000	0.217	6.000	13.455
Scenario30 (BFN-JHB)	2.177	0.727	0.000	0.323	14.915	0.281	16.960	0.323	2.000	0.217	6.000	13.708
Scenario31 (BFN-JHB)	2.177	0.727	0.000	0.323	15.700	0.281	16.960	0.323	2.000	0.217	6.000	13.962
Scenario32 (BFN-JHB)	2.177	0.727	0.000	0.323	7.065	0.281	16.960	0.323	2.000	0.217	6.000	11.173
Scenario33 (BFN-JHB)	2.177	0.727	0.000	0.323	6.280	0.281	16.960	0.323	2.000	0.217	6.000	10.919
Scenario34 (BFN-JHB)	2.177	0.727	0.000	0.323	5.495	0.281	16.960	0.323	2.000	0.217	6.000	10.666
Scenario35 (BFN-JHB)	2.177	0.727	0.000	0.323	4.710	0.281	16.960	0.323	2.000	0.217	6.000	10.412
Scenario36 (BFN-JHB)	2.177	0.727	0.000	0.323	3.925	0.281	16.960	0.323	2.000	0.217	6.000	10.159
Scenario37 (BFN-JHB)	2.177	0.727	0.000	0.323	3.140	0.281	16.960	0.323	2.000	0.217	6.000	9.905
Scenario38 (BFN-JHB)	2.177	0.727	0.000	0.323	2.355	0.281	16.960	0.323	2.000	0.217	6.000	9.651
Scenario39 (BFN-JHB)	2.177	0.727	0.000	0.323	1.570	0.281	16.960	0.323	2.000	0.217	6.000	9.398
Scenario40 (BFN-JHB)	2.177	0.727	0.000	0.323	0.785	0.281	16.960	0.323	2.000	0.217	6.000	9.144
Scenario41 (BFN-JHB)	2.177	0.727	0.000	0.323	0.000	0.281	16.960	0.323	2.000	0.217	6.000	8.891
Scenario42 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	18.656	0.323	2.000	0.217	6.000	11.903
Scenario43 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	20.352	0.323	2.000	0.217	6.000	12.379
Scenario44 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	22.048	0.323	2.000	0.217	6.000	12.856
Scenario45 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	23.744	0.323	2.000	0.217	6.000	13.333

Scenario46 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	25.440	0.323	2.000	0.217	6.000	13.809
Scenario47 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	27.136	0.323	2.000	0.217	6.000	14.286
Scenario48(BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	28.832	0.323	2.000	0.217	6.000	14.762
Scenario49(BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	30.528	0.323	2.000	0.217	6.000	15.239
Scenario50 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	32.224	0.323	2.000	0.217	6.000	15.715
Scenario51 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	33.920	0.323	2.000	0.217	6.000	16.192
Scenario52 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	15.264	0.323	2.000	0.217	6.000	10.950
Scenario53 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	13.568	0.323	2.000	0.217	6.000	10.473
Scenario54 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	11.872	0.323	2.000	0.217	6.000	9.997
Scenario55 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	10.176	0.323	2.000	0.217	6.000	9.520
Scenario56 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	8.480	0.323	2.000	0.217	6.000	9.043
Scenario57 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	6.784	0.323	2.000	0.217	6.000	8.567
Scenario58 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	5.088	0.323	2.000	0.217	6.000	8.090
Scenario59 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	3.392	0.323	2.000	0.217	6.000	7.614
Scenario60 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	1.696	0.323	2.000	0.217	6.000	7.137
Scenario61 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	0.000	0.323	2.000	0.217	6.000	6.661
Scenario62 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.200	0.217	6.000	11.491
Scenario63 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.400	0.217	6.000	11.556
Scenario64 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.600	0.217	6.000	11.620
Scenario65 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.800	0.217	6.000	11.685
Scenario66 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	3.000	0.217	6.000	11.749
Scenario67 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	3.200	0.217	6.000	11.814
Scenario68 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	3.400	0.217	6.000	11.879
Scenario69 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	3.600	0.217	6.000	11.943
Scenario70 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	3.800	0.217	6.000	12.008
Scenario71 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	4.000	0.217	6.000	12.072

Scenario72 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	1.800	0.217	6.000	11.362
Scenario73 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	1.600	0.217	6.000	11.297
Scenario74 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	1.400	0.217	6.000	11.233
Scenario75 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	1.200	0.217	6.000	11.168
Scenario76 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	1.000	0.217	6.000	11.103
Scenario77 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	0.800	0.217	6.000	11.039
Scenario78 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	18.656	0.323	0.600	0.217	6.000	11.451
Scenario79 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	0.400	0.217	6.000	10.910
Scenario80 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	0.200	0.217	6.000	10.845
Scenario81 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	0.000	0.217	6.000	10.780
Scenario82 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	6.600	11.557
Scenario83 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	7.200	11.687
Scenario84 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	7.800	11.817
Scenario85 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	8.400	11.947
Scenario86 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	9.000	12.077
Scenario87 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	9.600	12.208
Scenario88 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	10.200	12.338
Scenario89 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	10.800	12.468
Scenario90 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	11.400	12.598
Scenario91 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	12.000	12.728
Scenario92 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	5.400	11.296
Scenario93 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	4.800	11.166
Scenario94 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	4.200	11.036
Scenario95 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	3.600	10.906
Scenario96 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	3.000	10.775
Scenario97(BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	2.400	10.645

Scenario98 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	1.800	10.515
Scenario99 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	1.200	10.385
Scenario100 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	0.600	10.255
Scenario101 (BFN-JHB)	2.177	0.727	0.000	0.323	7.850	0.281	16.960	0.323	2.000	0.217	0.000	10.124
Scenario102 (BFN-JHB)	2.177	0.727	0.000	0.323	8.635	0.281	18.656	0.323	2.200	0.217	6.600	12.351
Scenario103 (BFN-JHB)	2.177	0.727	0.000	0.323	9.420	0.281	20.352	0.323	2.400	0.217	7.200	13.276
Scenario104 (BFN-JHB)	2.177	0.727	0.000	0.323	10.205	0.281	22.048	0.323	2.600	0.217	7.800	14.201
Scenario105 (BFN-JHB)	2.177	0.727	0.000	0.323	10.990	0.281	23.744	0.323	2.800	0.217	8.400	15.126
Scenario106 (BFN-JHB)	2.177	0.727	0.000	0.323	11.775	0.281	25.440	0.323	3.000	0.217	9.000	16.051
Scenario107 (BFN-JHB)	2.177	0.727	0.000	0.323	12.560	0.281	27.136	0.323	3.200	0.217	9.600	16.976
Scenario108 (BFN-JHB)	2.177	0.727	0.000	0.323	13.345	0.281	28.832	0.323	3.400	0.217	10.200	17.901
Scenario109 (BFN-JHB)	2.177	0.727	0.000	0.323	14.130	0.281	30.528	0.323	3.600	0.217	10.800	18.826
Scenario110 (BFN-JHB)	2.177	0.727	0.000	0.323	14.915	0.281	32.224	0.323	3.800	0.217	11.400	19.751
Scenario111 (BFN-JHB)	2.177	0.727	0.000	0.323	15.700	0.281	33.920	0.323	4.000	0.217	12.000	20.676
Scenario112(BFN-JHB)	2.177	0.727	0.000	0.323	7.065	0.281	15.264	0.323	1.800	0.217	5.400	10.501
Scenario113 (BFN-JHB)	2.177	0.727	0.000	0.323	6.280	0.281	13.568	0.323	1.600	0.217	4.800	9.576
Scenario114 (BFN-JHB)	2.177	0.727	0.000	0.323	5.495	0.281	11.872	0.323	1.400	0.217	4.200	8.652
Scenario115 (BFN-JHB)	2.177	0.727	0.000	0.323	4.710	0.281	10.176	0.323	1.200	0.217	3.600	7.727
Scenario116 (BFN-JHB)	2.177	0.727	0.000	0.323	3.925	0.281	8.480	0.323	1.000	0.217	3.000	6.802
Scenario117 (BFN-JHB)	2.177	0.727	0.000	0.323	3.140	0.281	6.784	0.323	0.800	0.217	2.400	5.877
Scenario118 (BFN-JHB)	2.177	0.727	0.000	0.323	2.355	0.281	5.088	0.323	0.600	0.217	1.800	4.952
Scenario119 (BFN-JHB)	2.177	0.727	0.000	0.323	1.570	0.281	3.392	0.323	0.400	0.217	1.200	4.027
Scenario120 (BFN-JHB)	2.177	0.727	0.000	0.323	0.785	0.281	1.696	0.323	0.200	0.217	0.600	3.102
Scenario121 (BFN-JHB)	2.177	0.727	0.000	0.323	0.000	0.281	0.000	0.323	0.000	0.217	0.000	2.177
Scenario122 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario123 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354

Scenario124 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario124 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario125 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario126 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario127 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario128 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario129 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario130 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario131 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario132 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario133 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario134 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario135 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario136 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario137 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario138 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario139 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario140 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	10.000	11.354
Scenario141 (BFN-CPT)	2.177	0.727	0.000	0.323	11.154	0.281	10.980	0.323	2.000	0.217	10.000	11.681
Scenario142 (BFN-CPT)	2.177	0.727	0.000	0.323	12.168	0.281	10.980	0.323	2.000	0.217	10.000	12.009
Scenario143 (BFN-CPT)	2.177	0.727	0.000	0.323	13.182	0.281	10.980	0.323	2.000	0.217	10.000	12.336
Scenario144 (BFN-CPT)	2.177	0.727	0.000	0.323	14.196	0.281	10.980	0.323	2.000	0.217	10.000	12.664
Scenario145 (BFN-CPT)	2.177	0.727	0.000	0.323	15.210	0.281	10.980	0.323	2.000	0.217	10.000	12.991
Scenario146 (BFN-CPT)	2.177	0.727	0.000	0.323	16.224	0.281	10.980	0.323	2.000	0.217	10.000	13.319
Scenario147 (BFN-CPT)	2.177	0.727	0.000	0.323	17.238	0.281	10.980	0.323	2.000	0.217	10.000	13.646
Scenario148 (BFN-CPT)	2.177	0.727	0.000	0.323	18.252	0.281	10.980	0.323	2.000	0.217	10.000	13.974

Scenario150 (BFN-CPT)	2.177	0.727	0.000	0.323	20.031	0.281	10.980	0.323	2.000	0.217	10.000	14.548
Scenario151 (BFN-CPT)	2.177	0.727	0.000	0.323	20.280	0.281	10.980	0.323	2.000	0.217	10.000	14.629
Scenario152 (BFN-CPT)	2.177	0.727	0.000	0.323	9.126	0.281	10.980	0.323	2.000	0.217	10.000	11.026
Scenario153 (BFN-CPT)	2.177	0.727	0.000	0.323	8.112	0.281	10.980	0.323	2.000	0.217	10.000	10.699
Scenario154 (BFN-CPT)	2.177	0.727	0.000	0.323	7.098	0.281	10.980	0.323	2.000	0.217	10.000	10.371
Scenario155 (BFN-CPT)	2.177	0.727	0.000	0.323	6.084	0.281	10.980	0.323	2.000	0.217	10.000	10.044
Scenario156 (BFN-CPT)	2.177	0.727	0.000	0.323	5.070	0.281	10.980	0.323	2.000	0.217	10.000	9.716
Scenario157 (BFN-CPT)	2.177	0.727	0.000	0.323	4.056	0.281	10.980	0.323	2.000	0.217	10.000	9.388
Scenario158 (BFN-CPT)	2.177	0.727	0.000	0.323	3.042	0.281	10.980	0.323	2.000	0.217	10.000	9.061
Scenario159 (BFN-CPT)	2.177	0.727	0.000	0.323	2.028	0.281	10.980	0.323	2.000	0.217	10.000	8.733
Scenario160 (BFN-CPT)	2.177	0.727	0.000	0.323	1.014	0.281	10.980	0.323	2.000	0.217	10.000	8.406
Scenario161 (BFN-CPT)	2.177	0.727	0.000	0.323	0.000	0.281	10.980	0.323	2.000	0.217	10.000	
Scenario162 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	12.078	0.323	2.000	0.217	10.000	11.662
Scenario163 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	13.176	0.323	2.000	0.217	10.000	11.971
Scenario164 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.274	0.323	2.000	0.217	10.000	12.279
Scenario165 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	15.372	0.323	2.000	0.217	10.000	12.588
Scenario166 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	16.470	0.323	2.000	0.217	10.000	12.896
Scenario167 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	17.568	0.323	2.000	0.217	10.000	13.205
Scenario168 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	18.666	0.323	2.000	0.217	10.000	13.513
Scenario169 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	19.764	0.323	2.000	0.217	10.000	13.822
Scenario170 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	20.862	0.323	2.000	0.217	10.000	14.130
Scenario171 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	21.960	0.323	2.000	0.217	10.000	14.439
Scenario172 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	9.882	0.323	2.000	0.217	10.000	11.045
Scenario173 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	8.784	0.323	2.000	0.217	10.000	10.737
Scenario174 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	7.686	0.323	2.000	0.217	10.000	10.428
Scenario175 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	6.588	0.323	2.000	0.217	10.000	10.119

Scenario176 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	5.490	0.323	2.000	0.217	10.000	9.811
Scenario177 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	4.392	0.323	2.000	0.217	10.000	9.502
Scenario178 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	3.294	0.323	2.000	0.217	10.000	9.194
Scenario179 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	2.196	0.323	2.000	0.217	10.000	8.885
Scenario180 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	1.098	0.323	2.000	0.217	10.000	8.577
Scenario181 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	0.000	0.323	2.000	0.217	10.000	8.268
Scenario182 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.200	0.217	10.000	11.418
Scenario183 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.400	0.217	10.000	11.483
Scenario183 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.600	0.217	10.000	11.547
Scenario184 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.800	0.217	10.000	11.612
Scenario185 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	3.000	0.217	10.000	11.677
Scenario186 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	3.200	0.217	10.000	11.741
Scenario187 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	3.400	0.217	10.000	11.806
Scenario188 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	3.600	0.217	10.000	11.870
Scenario189 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	3.800	0.217	10.000	11.935
Scenario190 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	4.000	0.217	10.000	12.000
Scenario191 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	1.800	0.217	10.000	11.289
Scenario192 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	1.600	0.217	10.000	11.224
Scenario193 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	1.400	0.217	10.000	11.160
Scenario194 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	1.200	0.217	10.000	11.095
Scenario195 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	1.000	0.217	10.000	11.031
Scenario196 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	0.800	0.217	10.000	10.966
Scenario197 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	0.600	0.217	10.000	10.901
Scenario198 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	0.400	0.217	10.000	10.837
Scenario199 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	0.200	0.217	10.000	10.772
Scenario200 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	0.000	0.217	10.000	10.708

Scenario201 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	11.000	11.571
Scenario202 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	12.000	11.788
Scenario203 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	13.000	12.005
Scenario204 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	14.000	12.222
Scenario205 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	15.000	12.439
Scenario206 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	16.000	12.656
Scenario207 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	17.000	12.873
Scenario208 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	18.000	13.090
Scenario209 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	19.000	13.307
Scenario210 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	20.000	13.524
Scenario211 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	9.000	11.137
Scenario212 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	8.000	10.920
Scenario213 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	7.000	10.703
Scenario214 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	6.000	10.486
Scenario215 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	5.000	10.269
Scenario216 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	4.000	10.052
Scenario217 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	3.000	9.835
Scenario218 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	2.000	9.618
Scenario219 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	1.000	9.401
Scenario220 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	10.980	0.323	2.000	0.217	0.000	9.184
Scenario221 (BFN-CPT)	2.177	0.727	0.000	0.323	11.154	0.281	12.078	0.323	2.200	0.217	11.000	12.271
Scenario222(BFN-CPT)	2.177	0.727	0.000	0.323	12.168	0.281	13.176	0.323	2.400	0.217	12.000	13.189
Scenario223(BFN-CPT)	2.177	0.727	0.000	0.323	13.182	0.281	14.274	0.323	2.600	0.217	13.000	14.107
Scenario224 (BFN-CPT)	2.177	0.727	0.000	0.323	14.196	0.281	15.372	0.323	2.800	0.217	14.000	15.024
Scenario225 (BFN-CPT)	2.177	0.727	0.000	0.323	15.210	0.281	16.470	0.323	3.000	0.217	15.000	15.942
Scenario226 (BFN-CPT)	2.177	0.727	0.000	0.323	16.224	0.281	17.568	0.323	3.200	0.217	16.000	16.860

Scenario227 (BFN-CPT)	2.177	0.727	0.000	0.323	17.238	0.281	18.666	0.323	3.400	0.217	17.000	17.777
Scenario228 (BFN-CPT)	2.177	0.727	0.000	0.323	18.252	0.281	19.764	0.323	3.600	0.217	18.000	18.695
Scenario229 (BFN-CPT)	2.177	0.727	0.000	0.323	20.031	0.281	20.862	0.323	3.800	0.217	19.000	19.860
Scenario230 (BFN-CPT)	2.177	0.727	0.000	0.323	20.280	0.281	21.960	0.323	4.000	0.217	20.000	20.530
Scenario231 (BFN-CPT)	2.177	0.727	0.000	0.323	9.126	0.281	9.882	0.323	1.800	0.217	9.000	10.436
Scenario232 (BFN-CPT)	2.177	0.727	0.000	0.323	8.112	0.281	8.784	0.323	1.600	0.217	8.000	9.518
Scenario233 (BFN-CPT)	2.177	0.727	0.000	0.323	7.098	0.281	7.686	0.323	1.400	0.217	7.000	8.601
Scenario234 (BFN-CPT)	2.177	0.727	0.000	0.323	6.084	0.281	6.588	0.323	1.200	0.217	6.000	7.683
Scenario235 (BFN-CPT)	2.177	0.727	0.000	0.323	5.070	0.281	5.490	0.323	1.000	0.217	5.000	6.765
Scenario236 (BFN-CPT)	2.177	0.727	0.000	0.323	4.056	0.281	4.392	0.323	0.800	0.217	4.000	5.848
Scenario237 (BFN-CPT)	2.177	0.727	0.000	0.323	3.042	0.281	3.294	0.323	0.600	0.217	3.000	4.930
Scenario238 (BFN-CPT)	2.177	0.727	0.000	0.323	2.028	0.281	2.196	0.323	0.400	0.217	2.000	4.012
Scenario239 (BFN-CPT)	2.177	0.727	0.000	0.323	1.014	0.281	1.098	0.323	0.200	0.217	1.000	3.095
Scenario240 (BFN-CPT)	2.177	0.727	0.000	0.323	0.000	0.281	0.000	0.323	0.000	0.217	0.000	2.177
Scenario241 (BFN-EC)	2.177	0.727	2.750	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	13.874
Scenario242 (BFN-EC)	2.177	0.727	3.000	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	14.056
Scenario243 (BFN-EC)	2.177	0.727	3.250	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	14.238
Scenario244 (BFN-EC)	2.177	0.727	3.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	14.420
Scenario245 (BFN-EC)	2.177	0.727	3.750	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	14.601
Scenario246 (BFN-EC)	2.177	0.727	4.000	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	14.783
Scenario247 (BFN-EC)	2.177	0.727	4.250	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	14.965
Scenario248 (BFN-EC)	2.177	0.727	4.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	15.147
Scenario249 (BFN-EC)	2.177	0.727	4.750	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	15.328
Scenario250 (BFN-EC)	2.177	0.727	5.000	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	15.510
Scenario251 (BFN-EC)	2.177	0.727	2.250	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	13.511
Scenario252 (BFN-EC)	2.177	0.727	2.000	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	13.329

Scenario253 BFN-EC)	2.177	0.727	1.750	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	13.147
Scenario254 (BFN-EC)	2.177	0.727	1.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	12.966
Scenario256 (BFN-EC)	2.177	0.727	1.250	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	12.784
Scenario257 (BFN-EC)	2.177	0.727	1.000	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	12.602
Scenario258 (BFN-EC)	2.177	0.727	0.750	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	12.420
Scenario259 (BFN-EC)	2.177	0.727	0.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	12.239
Scenario260 (BFN-EC)	2.177	0.727	0.250	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	12.057
Scenario261 (BFN-EC)	2.177	0.727	0.000	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.000	11.875
Scenario262 BFN-EC)	2.177	0.727	2.500	0.323	9.790	0.281	17.350	0.323	2.000	0.217	6.000	13.980
Scenario263 (BFN-EC)	2.177	0.727	2.500	0.323	10.680	0.281	17.350	0.323	2.000	0.217	6.000	14.267
Scenario264 (BFN-EC)	2.177	0.727	2.500	0.323	11.570	0.281	17.350	0.323	2.000	0.217	6.000	14.555
Scenario265 (BFN-EC)	2.177	0.727	2.500	0.323	12.460	0.281	17.350	0.323	2.000	0.217	6.000	14.842
Scenario266 (BFN-EC)	2.177	0.727	2.500	0.323	13.350	0.281	17.350	0.323	2.000	0.217	6.000	15.130
Scenario267 (BFN-EC)	2.177	0.727	2.500	0.323	14.240	0.281	17.350	0.323	2.000	0.217	6.000	15.417
Scenario268 (BFN-EC)	2.177	0.727	2.500	0.323	15.130	0.281	17.350	0.323	2.000	0.217	6.000	15.705
Scenario269 (BFN-EC)	2.177	0.727	2.500	0.323	16.020	0.281	17.350	0.323	2.000	0.217	6.000	15.992
Scenario270 (BFN-EC)	2.177	0.727	2.500	0.323	16.910	0.281	17.350	0.323	2.000	0.217	6.000	16.280
Scenario271 (BFN-EC)	2.177	0.727	2.500	0.323	17.800	0.281	17.350	0.323	2.000	0.217	6.000	16.567
Scenario272 (BFN-EC)	2.177	0.727	2.500	0.323	8.010	0.281	17.350	0.323	2.000	0.217	6.000	13.405
Scenario273 (BFN-EC)	2.177	0.727	2.500	0.323	7.120	0.281	17.350	0.323	2.000	0.217	6.000	13.118
Scenario274 (BFN-EC)	2.177	0.727	2.500	0.323	6.230	0.281	17.350	0.323	2.000	0.217	6.000	12.830
Scenario275 (BFN-EC)	2.177	0.727	2.500	0.323	5.340	0.281	17.350	0.323	2.000	0.217	6.000	12.543
Scenario276 (BFN-EC)	2.177	0.727	2.500	0.323	4.450	0.281	17.350	0.323	2.000	0.217	6.000	12.255
Scenario277 (BFN-EC)	2.177	0.727	2.500	0.323	3.560	0.281	17.350	0.323	2.000	0.217	6.000	11.968
Scenario278 (BFN-EC)	2.177	0.727	2.500	0.323	2.670	0.281	17.350	0.323	2.000	0.217	6.000	11.680
Scenario279 (BFN-EC)	2.177	0.727	2.500	0.323	1.780	0.281	17.350	0.323	2.000	0.217	6.000	11.393

Scenario280 (BFN-EC)	2.177	0.727	2.500	0.323	0.890	0.281	17.350	0.323	2.000	0.217	6.000	11.105
Scenario281 (BFN-EC)	2.177	0.727	2.500	0.323	0.000	0.281	17.350	0.323	2.000	0.217	6.000	10.818
Scenario282 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	19.085	0.323	2.000	0.217	6.000	14.180
Scenario283 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	20.820	0.323	2.000	0.217	6.000	14.668
Scenario284 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	22.555	0.323	2.000	0.217	6.000	15.155
Scenario285 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	24.290	0.323	2.000	0.217	6.000	15.643
Scenario286 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	26.025	0.323	2.000	0.217	6.000	16.130
Scenario287 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	27.760	0.323	2.000	0.217	6.000	16.618
Scenario288 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	29.495	0.323	2.000	0.217	6.000	17.105
Scenario289 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	31.230	0.323	2.000	0.217	6.000	17.593
Scenario290 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	32.965	0.323	2.000	0.217	6.000	18.080
Scenario291 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	34.700	0.323	2.000	0.217	6.000	18.568
Scenario292 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	15.615	0.323	2.000	0.217	6.000	13.205
Scenario293 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	13.880	0.323	2.000	0.217	6.000	12.717
Scenario294 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	12.145	0.323	2.000	0.217	6.000	12.230
Scenario295 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	10.410	0.323	2.000	0.217	6.000	11.742
Scenario296 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	8.675	0.323	2.000	0.217	6.000	11.255
Scenario297 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	6.940	0.323	2.000	0.217	6.000	10.767
Scenario298 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	5.205	0.323	2.000	0.217	6.000	10.280
Scenario299 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	3.470	0.323	2.000	0.217	6.000	9.792
Scenario300(BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	1.735	0.323	2.000	0.217	6.000	9.305
Scenario301(BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	0.000	0.323	2.000	0.217	6.000	8.817
Scenario302 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.200	0.217	6.000	13.757
Scenario303 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.400	0.217	6.000	13.822
Scenario304 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.600	0.217	6.000	13.886
Scenario305 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.800	0.217	6.000	13.951

Scenario306 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	3.000	0.217	6.000	14.016
Scenario307 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	3.200	0.217	6.000	14.080
Scenario308 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	3.400	0.217	6.000	14.145
Scenario309 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	3.600	0.217	6.000	14.209
Scenario310 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	3.800	0.217	6.000	14.274
Scenario311 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	4.000	0.217	6.000	14.339
Scenario312 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	1.800	0.217	6.000	13.628
Scenario313 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	1.600	0.217	6.000	13.563
Scenario314 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	1.400	0.217	6.000	13.499
Scenario315 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	1.200	0.217	6.000	13.434
Scenario316 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	1.000	0.217	6.000	13.370
Scenario317 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	0.800	0.217	6.000	13.305
Scenario318 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	0.600	0.217	6.000	13.240
Scenario319 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	0.400	0.217	6.000	13.176
Scenario320 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	0.200	0.217	6.000	13.111
Scenario321 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	0.000	0.217	6.000	13.047
Scenario322 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	6.600	13.823
Scenario323 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	7.200	13.953
Scenario324 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	7.800	14.083
Scenario325 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	8.400	14.213
Scenario326 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	9.000	14.344
Scenario327 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	9.600	14.474
Scenario328 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	10.200	14.604
Scenario329 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	10.800	14.734
Scenario330 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	11.400	14.864
Scenario331 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	12.000	14.995

Scenario332 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	5.400	13.562
Scenario333 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	4.800	13.432
Scenario334 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	4.200	13.302
Scenario335 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	3.600	13.172
Scenario336 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	3.000	13.042
Scenario337 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	2.400	12.911
Scenario338 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	1.800	12.781
Scenario339 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	1.200	12.651
Scenario340 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	0.600	12.521
Scenario341 (BFN-EC)	2.177	0.727	2.500	0.323	8.900	0.281	17.350	0.323	2.000	0.217	0.000	12.391
Scenario342 (BFN-EC)	2.177	0.727	2.750	0.323	9.790	0.281	19.085	0.323	2.200	0.217	6.600	14.844
Scenario343 (BFN-EC)	2.177	0.727	3.000	0.323	10.680	0.281	20.820	0.323	2.400	0.217	7.200	15.996
Scenario344 (BFN-EC)	2.177	0.727	3.250	0.323	11.570	0.281	22.555	0.323	2.600	0.217	7.800	17.147
Scenario345 (BFN-EC)	2.177	0.727	3.500	0.323	12.460	0.281	24.290	0.323	2.800	0.217	8.400	18.299
Scenario346 (BFN-EC)	2.177	0.727	3.750	0.323	13.350	0.281	26.025	0.323	3.000	0.217	9.000	19.450
Scenario347 (BFN-EC)	2.177	0.727	4.000	0.323	14.240	0.281	27.760	0.323	3.200	0.217	9.600	20.602
Scenario348 (BFN-EC)	2.177	0.727	4.250	0.323	15.130	0.281	29.495	0.323	3.400	0.217	10.200	21.753
Scenario349 (BFN-EC)	2.177	0.727	4.500	0.323	16.020	0.281	31.230	0.323	3.600	0.217	10.800	22.905
Scenario350 (BFN-EC)	2.177	0.727	4.750	0.323	16.910	0.281	32.965	0.323	3.800	0.217	11.400	24.057
Scenario351 (BFN-EC)	2.177	0.727	5.000	0.323	17.800	0.281	34.700	0.323	4.000	0.217	12.000	25.208
Scenario352 (BFN-EC)	2.177	0.727	2.250	0.323	8.010	0.281	15.615	0.323	1.800	0.217	5.400	12.541
Scenario353 (BFN-EC)	2.177	0.727	2.000	0.323	7.120	0.281	13.880	0.323	1.600	0.217	4.800	11.389
Scenario354 (BFN-EC)	2.177	0.727	1.750	0.323	6.230	0.281	12.145	0.323	1.400	0.217	4.200	10.238
Scenario355 (BFN-EC)	2.177	0.727	1.500	0.323	5.340	0.281	10.410	0.323	1.200	0.217	3.600	9.086
Scenario356 (BFN-EC)	2.177	0.727	1.250	0.323	4.450	0.281	8.675	0.323	1.000	0.217	3.000	7.935
Scenario357 (BFN-EC)	2.177	0.727	1.000	0.323	3.560	0.281	6.940	0.323	0.800	0.217	2.400	6.783

Scenario358 (BFN-EC)	2.177	0.727	0.750	0.323	2.670	0.281	5.205	0.323	0.600	0.217	1.800	5.632
Scenario359 (BFN-EC)	2.177	0.727	0.500	0.323	1.780	0.281	3.470	0.323	0.400	0.217	1.200	4.480
Scenario360 (BFN-EC)	2.177	0.727	0.250	0.323	0.890	0.281	1.735	0.323	0.200	0.217	0.600	3.329
Scenario361 (BFN-EC)	2.177	0.727	0.000	0.323	0.000	0.281	0.000	0.323	0.000	0.217	0.000	2.177

Table H The simulations of freight rail under varying scenarios.

Rail Freight	**Constant**	**B2**	**Parking cost(X1)**	**B3**	**Load cost(X2)**	**B4**	**Fuel cost(X3)**	**B5**	**Loading and Offloading(X4)**	**B7**	**Travel Time**	**Cij(R/km/t/hr)**
Scenario1 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario2 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario2 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario3 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario4 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario5 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario6 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario7 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario8 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario10 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario11 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario12 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario13 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario14 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario15 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario16 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario17 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario18 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397

Scenario19 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario20 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario21 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	10.000	12.397
Scenario22 (BFN-JHB)	2.177	0.727	0.000	0.323	8.822	0.281	18.280	0.323	1.000	0.217	10.000	12.656
Scenario23 (BFN-JHB)	2.177	0.727	0.000	0.323	9.624	0.281	18.280	0.323	1.000	0.217	10.000	12.915
Scenario24 (BFN-JHB)	2.177	0.727	0.000	0.323	10.426	0.281	18.280	0.323	1.000	0.217	10.000	13.174
Scenario25 (BFN-JHB)	2.177	0.727	0.000	0.323	11.228	0.281	18.280	0.323	1.000	0.217	10.000	13.433
Scenario26 (BFN-JHB)	2.177	0.727	0.000	0.323	12.030	0.281	18.280	0.323	1.000	0.217	10.000	13.692
Scenario27 (BFN-JHB)	2.177	0.727	0.000	0.323	12.832	0.281	18.280	0.323	1.000	0.217	10.000	13.951
Scenario28 (BFN-JHB)	2.177	0.727	0.000	0.323	13.634	0.281	18.280	0.323	1.000	0.217	10.000	14.210
Scenario29 (BFN-JHB)	2.177	0.727	0.000	0.323	14.436	0.281	18.280	0.323	1.000	0.217	10.000	14.470
Scenario30 (BFN-JHB)	2.177	0.727	0.000	0.323	15.238	0.281	18.280	0.323	1.000	0.217	10.000	14.729
Scenario31 (BFN-JHB)	2.177	0.727	0.000	0.323	16.040	0.281	18.280	0.323	1.000	0.217	10.000	14.988
Scenario32 (BFN-JHB)	2.177	0.727	0.000	0.323	7.218	0.281	18.280	0.323	1.000	0.217	10.000	12.138
Scenario33 (BFN-JHB)	2.177	0.727	0.000	0.323	6.416	0.281	18.280	0.323	1.000	0.217	10.000	11.879
Scenario34 (BFN-JHB)	2.177	0.727	0.000	0.323	5.614	0.281	18.280	0.323	1.000	0.217	10.000	11.620
Scenario35 (BFN-JHB)	2.177	0.727	0.000	0.323	4.812	0.281	18.280	0.323	1.000	0.217	10.000	11.361
Scenario36 (BFN-JHB)	2.177	0.727	0.000	0.323	4.010	0.281	18.280	0.323	1.000	0.217	10.000	11.102
Scenario37 (BFN-JHB)	2.177	0.727	0.000	0.323	3.208	0.281	18.280	0.323	1.000	0.217	10.000	10.843
Scenario38 (BFN-JHB)	2.177	0.727	0.000	0.323	2.406	0.281	18.280	0.323	1.000	0.217	10.000	10.584
Scenario39 (BFN-JHB)	2.177	0.727	0.000	0.323	1.604	0.281	18.280	0.323	1.000	0.217	10.000	10.325
Scenario40 (BFN-JHB)	2.177	0.727	0.000	0.323	0.802	0.281	18.280	0.323	1.000	0.217	10.000	10.066
Scenario41 (BFN-JHB)	2.177	0.727	0.000	0.323	0.000	0.281	18.280	0.323	1.000	0.217	10.000	9.807
Scenario42 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	20.108	0.323	1.000	0.217	10.000	12.911
Scenario43 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	21.936	0.323	1.000	0.217	10.000	13.424
Scenario44 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	23.764	0.323	1.000	0.217	10.000	13.938
Scenario45 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	25.592	0.323	1.000	0.217	10.000	14.452

Scenario46 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	27.420	0.323	1.000	0.217	10.000	14.965
Scenario47 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	29.248	0.323	1.000	0.217	10.000	15.479
Scenario48(BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	31.076	0.323	1.000	0.217	10.000	15.993
Scenario49(BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	32.904	0.323	1.000	0.217	10.000	16.506
Scenario50 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	34.732	0.323	1.000	0.217	10.000	17.020
Scenario51 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	36.560	0.323	1.000	0.217	10.000	17.534
Scenario52 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	16.452	0.323	1.000	0.217	10.000	11.883
Scenario53 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	14.624	0.323	1.000	0.217	10.000	11.370
Scenario54 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	12.796	0.323	1.000	0.217	10.000	10.856
Scenario55 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	10.968	0.323	1.000	0.217	10.000	10.342
Scenario56 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	9.140	0.323	1.000	0.217	10.000	9.829
Scenario57 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	7.312	0.323	1.000	0.217	10.000	9.315
Scenario58 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	5.484	0.323	1.000	0.217	10.000	8.801
Scenario59 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	3.656	0.323	1.000	0.217	10.000	8.288
Scenario60 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	1.828	0.323	1.000	0.217	10.000	7.774
Scenario61 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	0.000	0.323	1.000	0.217	10.000	7.260
Scenario62 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.100	0.217	10.000	12.429
Scenario63 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.200	0.217	10.000	12.462
Scenario64 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.300	0.217	10.000	12.494
Scenario65 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.400	0.217	10.000	12.526
Scenario66 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.500	0.217	10.000	12.559
Scenario67 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.600	0.217	10.000	12.591
Scenario68 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.700	0.217	10.000	12.623
Scenario69 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.800	0.217	10.000	12.656
Scenario70 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.900	0.217	10.000	12.688
Scenario71 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	2.000	0.217	10.000	12.720
Scenario72 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	0.900	0.217	10.000	12.365

Scenario73 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	0.800	0.217	10.000	12.333
Scenario74 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	0.700	0.217	10.000	12.300
Scenario75 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	0.600	0.217	10.000	12.268
Scenario76 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	0.500	0.217	10.000	12.236
Scenario77 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	0.400	0.217	10.000	12.203
Scenario78 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	0.300	0.217	10.000	12.171
Scenario79 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	0.200	0.217	10.000	12.139
Scenario80 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	0.100	0.217	10.000	12.106
Scenario81 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	0.000	0.217	10.000	12.074
Scenario82 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	11.000	12.614
Scenario83 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	12.000	12.831
Scenario84 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	13.000	13.048
Scenario85 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	14.000	13.265
Scenario86 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	15.000	13.482
Scenario87 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	16.000	13.699
Scenario88 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	17.000	13.916
Scenario89 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	18.000	14.133
Scenario90 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	19.000	14.350
Scenario91 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	20.000	14.567
Scenario92 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	9.000	12.180
Scenario93 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	8.000	11.963
Scenario94 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	7.000	11.746
Scenario95 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	6.000	11.529
Scenario96 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	5.000	11.312
Scenario97(BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	4.000	11.095
Scenario98 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	3.000	10.878
Scenario99 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	2.000	10.661

Scenario100 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	1.000	10.444
Scenario101 (BFN-JHB)	2.177	0.727	0.000	0.323	8.020	0.281	18.280	0.323	1.000	0.217	0.000	10.227
Scenario102 (BFN-JHB)	2.177	0.727	0.000	0.323	8.822	0.281	20.108	0.323	1.100	0.217	11.000	13.419
Scenario103 (BFN-JHB)	2.177	0.727	0.000	0.323	9.624	0.281	21.936	0.323	1.200	0.217	12.000	14.441
Scenario104 (BFN-JHB)	2.177	0.727	0.000	0.323	10.426	0.281	23.764	0.323	1.300	0.217	13.000	15.463
Scenario105 (BFN-JHB)	2.177	0.727	0.000	0.323	11.228	0.281	25.592	0.323	1.400	0.217	14.000	16.485
Scenario106 (BFN-JHB)	2.177	0.727	0.000	0.323	12.030	0.281	27.420	0.323	1.500	0.217	15.000	17.507
Scenario107 (BFN-JHB)	2.177	0.727	0.000	0.323	12.832	0.281	29.248	0.323	1.600	0.217	16.000	18.529
Scenario108 (BFN-JHB)	2.177	0.727	0.000	0.323	13.634	0.281	31.076	0.323	1.700	0.217	17.000	19.551
Scenario109 (BFN-JHB)	2.177	0.727	0.000	0.323	14.436	0.281	32.904	0.323	1.800	0.217	18.000	20.573
Scenario110 (BFN-JHB)	2.177	0.727	0.000	0.323	15.238	0.281	34.732	0.323	1.900	0.217	19.000	21.595
Scenario111 (BFN-JHB)	2.177	0.727	0.000	0.323	16.040	0.281	36.560	0.323	2.000	0.217	20.000	22.617
Scenario112(BFN-JHB)	2.177	0.727	0.000	0.323	7.218	0.281	16.452	0.323	0.900	0.217	9.000	11.375
Scenario113 (BFN-JHB)	2.177	0.727	0.000	0.323	6.416	0.281	14.624	0.323	0.800	0.217	8.000	10.353
Scenario114 (BFN-JHB)	2.177	0.727	0.000	0.323	5.614	0.281	12.796	0.323	0.700	0.217	7.000	9.331
Scenario115 (BFN-JHB)	2.177	0.727	0.000	0.323	4.812	0.281	10.968	0.323	0.600	0.217	6.000	8.309
Scenario116 (BFN-JHB)	2.177	0.727	0.000	0.323	4.010	0.281	9.140	0.323	0.500	0.217	5.000	7.287
Scenario117 (BFN-JHB)	2.177	0.727	0.000	0.323	3.208	0.281	7.312	0.323	0.400	0.217	4.000	6.265
Scenario118 (BFN-JHB)	2.177	0.727	0.000	0.323	2.406	0.281	5.484	0.323	0.300	0.217	3.000	5.243
Scenario119 (BFN-JHB)	2.177	0.727	0.000	0.323	1.604	0.281	3.656	0.323	0.200	0.217	2.000	4.221
Scenario120 (BFN-JHB)	2.177	0.727	0.000	0.323	0.802	0.281	1.828	0.323	0.100	0.217	1.000	3.199
Scenario121 (BFN-JHB)	2.177	0.727	0.000	0.323	0.000	0.281	0.000	0.323	0.000	0.217	0.000	2.177
Scenario122 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario123 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario124 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario124 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario125 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369

Scenario126 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario127 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario128 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario129 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario130 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario131 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario132 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario133 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario134 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario135 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario136 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario137 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario138 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario139 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario140 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.000	0.217	4.000	13.369
Scenario141 (BFN-CPT)	2.177	0.727	0.000	0.323	12.243	0.281	14.750	0.323	8.000	0.217	4.000	13.728
Scenario142 (BFN-CPT)	2.177	0.727	0.000	0.323	13.356	0.281	14.750	0.323	8.000	0.217	4.000	14.088
Scenario143 (BFN-CPT)	2.177	0.727	0.000	0.323	14.469	0.281	14.750	0.323	8.000	0.217	4.000	14.447
Scenario144 (BFN-CPT)	2.177	0.727	0.000	0.323	15.582	0.281	14.750	0.323	8.000	0.217	4.000	14.807
Scenario145 (BFN-CPT)	2.177	0.727	0.000	0.323	16.695	0.281	14.750	0.323	8.000	0.217	4.000	15.166
Scenario146 (BFN-CPT)	2.177	0.727	0.000	0.323	17.808	0.281	14.750	0.323	8.000	0.217	4.000	15.526
Scenario147 (BFN-CPT)	2.177	0.727	0.000	0.323	18.921	0.281	14.750	0.323	8.000	0.217	4.000	15.885
Scenario148 (BFN-CPT)	2.177	0.727	0.000	0.323	20.034	0.281	14.750	0.323	8.000	0.217	4.000	16.245
Scenario150 (BFN-CPT)	2.177	0.727	0.000	0.323	21.235	0.281	14.750	0.323	8.000	0.217	4.000	16.633
Scenario151 (BFN-CPT)	2.177	0.727	0.000	0.323	22.260	0.281	14.750	0.323	8.000	0.217	4.000	16.964
Scenario152 (BFN-CPT)	2.177	0.727	0.000	0.323	10.017	0.281	14.750	0.323	8.000	0.217	4.000	13.009
Scenario153 (BFN-CPT)	2.177	0.727	0.000	0.323	8.904	0.281	14.750	0.323	8.000	0.217	4.000	12.650

Scenario154 (BFN-CPT)	2.177	0.727	0.000	0.323	7.791	0.281	14.750	0.323	8.000	0.217	4.000	12.290
Scenario155 (BFN-CPT)	2.177	0.727	0.000	0.323	6.678	0.281	14.750	0.323	8.000	0.217	4.000	11.931
Scenario156 (BFN-CPT)	2.177	0.727	0.000	0.323	5.565	0.281	14.750	0.323	8.000	0.217	4.000	11.571
Scenario157 (BFN-CPT)	2.177	0.727	0.000	0.323	4.452	0.281	14.750	0.323	8.000	0.217	4.000	11.212
Scenario158 (BFN-CPT)	2.177	0.727	0.000	0.323	3.339	0.281	14.750	0.323	8.000	0.217	4.000	10.852
Scenario159 (BFN-CPT)	2.177	0.727	0.000	0.323	2.226	0.281	14.750	0.323	8.000	0.217	4.000	10.493
Scenario160 (BFN-CPT)	2.177	0.727	0.000	0.323	1.113	0.281	14.750	0.323	8.000	0.217	4.000	10.133
Scenario161 (BFN-CPT)	2.177	0.727	0.000	0.323	0.000	0.281	14.750	0.323	8.000	0.217	4.000	9.774
Scenario162 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	16.225	0.323	8.000	0.217	4.000	13.783
Scenario163 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	17.700	0.323	8.000	0.217	4.000	14.198
Scenario164 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	19.175	0.323	8.000	0.217	4.000	14.612
Scenario165 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	20.650	0.323	8.000	0.217	4.000	15.027
Scenario166 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	22.125	0.323	8.000	0.217	4.000	15.441
Scenario167 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	23.600	0.323	8.000	0.217	4.000	15.856
Scenario168 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	25.075	0.323	8.000	0.217	4.000	16.270
Scenario169 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	26.550	0.323	8.000	0.217	4.000	16.685
Scenario170 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	28.025	0.323	8.000	0.217	4.000	17.099
Scenario171 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	29.500	0.323	8.000	0.217	4.000	17.513
Scenario172 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	13.275	0.323	8.000	0.217	4.000	12.954
Scenario173 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	11.800	0.323	8.000	0.217	4.000	12.540
Scenario174 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	10.325	0.323	8.000	0.217	4.000	12.125
Scenario175 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	8.850	0.323	8.000	0.217	4.000	11.711
Scenario176 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	7.375	0.323	8.000	0.217	4.000	11.296
Scenario177 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	5.900	0.323	8.000	0.217	4.000	10.882
Scenario178 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	4.425	0.323	8.000	0.217	4.000	10.467
Scenario179 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	2.950	0.323	8.000	0.217	4.000	10.053
Scenario180 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	1.475	0.323	8.000	0.217	4.000	9.638

Scenario181 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	0.000	0.323	8.000	0.217	4.000	9.224
Scenario182 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	8.800	0.217	4.000	13.627
Scenario183 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	9.600	0.217	4.000	13.886
Scenario183 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	10.400	0.217	4.000	14.144
Scenario184 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	11.200	0.217	4.000	14.402
Scenario185 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	12.000	0.217	4.000	14.661
Scenario186 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	12.800	0.217	4.000	14.919
Scenario187 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	13.600	0.217	4.000	15.178
Scenario188 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	14.400	0.217	4.000	15.436
Scenario189 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	15.200	0.217	4.000	15.694
Scenario190 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	16.000	0.217	4.000	15.953
Scenario191 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	7.200	0.217	4.000	13.110
Scenario192 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	6.400	0.217	4.000	12.852
Scenario193 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	5.600	0.217	4.000	12.594
Scenario194 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	4.800	0.217	4.000	12.335
Scenario195 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	4.000	0.217	4.000	12.077
Scenario196 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	3.200	0.217	4.000	11.818
Scenario197 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	2.400	0.217	4.000	11.560
Scenario198 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	1.600	0.217	4.000	11.302
Scenario199 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	0.800	0.217	4.000	11.043
Scenario200 (BFN-CPT)	2.177	0.727	0.000	0.323	11.130	0.281	14.750	0.323	0.000	0.217	4.000	10.785
Scenario201 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	4.400	13.136
Scenario202 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	4.800	13.223
Scenario203 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	5.200	13.309
Scenario204 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	5.600	13.396
Scenario205 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	6.000	13.483
Scenario206 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	6.400	13.570

Scenario207 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	6.800	13.657
Scenario208 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	7.200	13.743
Scenario209 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	7.600	13.830
Scenario210 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	8.000	13.917
Scenario211 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	3.600	12.962
Scenario212 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	3.200	12.875
Scenario213 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	2.800	12.789
Scenario214 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	2.400	12.702
Scenario215 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	2.000	12.615
Scenario216 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	1.600	12.528
Scenario217 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	1.200	12.441
Scenario218 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	0.800	12.355
Scenario219 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	0.400	12.268
Scenario220 (BFN-CPT)	2.177	0.727	0.000	0.323	10.140	0.281	14.750	0.323	8.000	0.217	0.000	12.181
Scenario221 (BFN-CPT)	2.177	0.727	0.000	0.323	12.243	0.281	16.225	0.323	1.100	0.217	4.400	12.001
Scenario222(BFN-CPT)	2.177	0.727	0.000	0.323	13.356	0.281	17.700	0.323	1.200	0.217	4.800	12.894
Scenario223(BFN-CPT)	2.177	0.727	0.000	0.323	14.469	0.281	19.175	0.323	1.300	0.217	5.200	13.787
Scenario224 (BFN-CPT)	2.177	0.727	0.000	0.323	15.582	0.281	20.650	0.323	1.400	0.217	5.600	14.680
Scenario225 (BFN-CPT)	2.177	0.727	0.000	0.323	16.695	0.281	22.125	0.323	1.500	0.217	6.000	15.573
Scenario226 (BFN-CPT)	2.177	0.727	0.000	0.323	17.808	0.281	23.600	0.323	1.600	0.217	6.400	16.466
Scenario227 (BFN-CPT)	2.177	0.727	0.000	0.323	18.921	0.281	25.075	0.323	1.700	0.217	6.800	17.359
Scenario228 (BFN-CPT)	2.177	0.727	0.000	0.323	20.034	0.281	26.550	0.323	1.800	0.217	7.200	18.252
Scenario229 (BFN-CPT)	2.177	0.727	0.000	0.323	21.235	0.281	28.025	0.323	1.900	0.217	7.600	19.174
Scenario230 (BFN-CPT)	2.177	0.727	0.000	0.323	22.260	0.281	29.500	0.323	2.000	0.217	8.000	20.038
Scenario231 (BFN-CPT)	2.177	0.727	0.000	0.323	10.017	0.281	13.275	0.323	0.900	0.217	3.600	10.215
Scenario232 (BFN-CPT)	2.177	0.727	0.000	0.323	8.904	0.281	11.800	0.323	0.800	0.217	3.200	9.322
Scenario233 (BFN-CPT)	2.177	0.727	0.000	0.323	7.791	0.281	10.325	0.323	0.700	0.217	2.800	8.429

Scenario234 (BFN-CPT)	2.177	0.727	0.000	0.323	6.678	0.281	8.850	0.323	0.600	0.217	2.400	7.535
Scenario235 (BFN-CPT)	2.177	0.727	0.000	0.323	5.565	0.281	7.375	0.323	0.500	0.217	2.000	6.642
Scenario236 (BFN-CPT)	2.177	0.727	0.000	0.323	4.452	0.281	5.900	0.323	0.400	0.217	1.600	5.749
Scenario237 (BFN-CPT)	2.177	0.727	0.000	0.323	3.339	0.281	4.425	0.323	0.300	0.217	1.200	4.856
Scenario238 (BFN-CPT)	2.177	0.727	0.000	0.323	2.226	0.281	2.950	0.323	0.200	0.217	0.800	3.963
Scenario239 (BFN-CPT)	2.177	0.727	0.000	0.323	1.113	0.281	1.475	0.323	0.100	0.217	0.400	3.070
Scenario240 (BFN-CPT)	2.177	0.727	0.000	0.323	0.000	0.281	0.000	0.323	0.000	0.217	0.000	2.177
Scenario241 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario242 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario243 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario244 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario245 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario246 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario247 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario248 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario249 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario250 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario251 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario252 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario253 BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario254 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario256 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario257 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario258 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario259 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario260 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556
Scenario261 (BFN-EC)	2.177	0.727	0.000	0.323	10.020	0.281	21.190	0.323	8.000	0.217	12.000	16.556

Scenario262 BFN-EC)	2.177	0.727	2.500	0.323	11.022	0.281	21.190	0.323	8.000	0.217	12.000	18.697
Scenario263 (BFN-EC)	2.177	0.727	2.500	0.323	12.024	0.281	21.190	0.323	8.000	0.217	12.000	19.021
Scenario264 (BFN-EC)	2.177	0.727	2.500	0.323	13.026	0.281	21.190	0.323	8.000	0.217	12.000	19.344
Scenario265 (BFN-EC)	2.177	0.727	2.500	0.323	14.028	0.281	21.190	0.323	8.000	0.217	12.000	19.668
Scenario266 (BFN-EC)	2.177	0.727	2.500	0.323	15.030	0.281	21.190	0.323	8.000	0.217	12.000	19.992
Scenario267 (BFN-EC)	2.177	0.727	2.500	0.323	16.032	0.281	21.190	0.323	8.000	0.217	12.000	20.315
Scenario268 (BFN-EC)	2.177	0.727	2.500	0.323	17.034	0.281	21.190	0.323	8.000	0.217	12.000	20.639
Scenario269 (BFN-EC)	2.177	0.727	2.500	0.323	18.036	0.281	21.190	0.323	8.000	0.217	12.000	20.963
Scenario270 (BFN-EC)	2.177	0.727	2.500	0.323	19.038	0.281	21.190	0.323	8.000	0.217	12.000	21.286
Scenario271 (BFN-EC)	2.177	0.727	2.500	0.323	20.040	0.281	21.190	0.323	8.000	0.217	12.000	21.610
Scenario272 (BFN-EC)	2.177	0.727	2.500	0.323	9.018	0.281	21.190	0.323	8.000	0.217	12.000	18.050
Scenario273 (BFN-EC)	2.177	0.727	2.500	0.323	8.016	0.281	21.190	0.323	8.000	0.217	12.000	17.726
Scenario274 (BFN-EC)	2.177	0.727	2.500	0.323	7.014	0.281	21.190	0.323	8.000	0.217	12.000	17.402
Scenario275 (BFN-EC)	2.177	0.727	2.500	0.323	6.012	0.281	21.190	0.323	8.000	0.217	12.000	17.079
Scenario276 (BFN-EC)	2.177	0.727	2.500	0.323	5.010	0.281	21.190	0.323	8.000	0.217	12.000	16.755
Scenario277 (BFN-EC)	2.177	0.727	2.500	0.323	4.008	0.281	21.190	0.323	8.000	0.217	12.000	16.431
Scenario278 (BFN-EC)	2.177	0.727	2.500	0.323	3.006	0.281	21.190	0.323	8.000	0.217	12.000	16.108
Scenario279 (BFN-EC)	2.177	0.727	2.500	0.323	2.004	0.281	21.190	0.323	8.000	0.217	12.000	15.784
Scenario280 (BFN-EC)	2.177	0.727	2.500	0.323	1.002	0.281	21.190	0.323	8.000	0.217	12.000	15.461
Scenario281 (BFN-EC)	2.177	0.727	2.500	0.323	0.000	0.281	21.190	0.323	8.000	0.217	12.000	15.137
Scenario282 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	23.309	0.323	8.000	0.217	12.000	18.969
Scenario283 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	25.428	0.323	8.000	0.217	12.000	19.564
Scenario284 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	27.547	0.323	8.000	0.217	12.000	20.160
Scenario285 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	29.666	0.323	8.000	0.217	12.000	20.755
Scenario286 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	31.785	0.323	8.000	0.217	12.000	21.351
Scenario287 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	33.904	0.323	8.000	0.217	12.000	21.946
Scenario288 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	36.023	0.323	8.000	0.217	12.000	22.541

Scenario289 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	38.142	0.323	8.000	0.217	12.000	23.137
Scenario290 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	40.261	0.323	8.000	0.217	12.000	23.732
Scenario291 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	42.380	0.323	8.000	0.217	12.000	24.328
Scenario292 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	19.071	0.323	8.000	0.217	12.000	17.778
Scenario293 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	16.952	0.323	8.000	0.217	12.000	17.182
Scenario294 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	14.833	0.323	8.000	0.217	12.000	16.587
Scenario295 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	12.714	0.323	8.000	0.217	12.000	15.992
Scenario296 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	10.595	0.323	8.000	0.217	12.000	15.396
Scenario297 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	8.476	0.323	8.000	0.217	12.000	14.801
Scenario298 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	6.357	0.323	8.000	0.217	12.000	14.205
Scenario299 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	4.238	0.323	8.000	0.217	12.000	13.610
Scenario300(BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	2.119	0.323	8.000	0.217	12.000	13.014
Scenario301(BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	0.000	0.323	8.000	0.217	12.000	12.419
Scenario302 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.800	0.217	12.000	18.632
Scenario303 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	9.600	0.217	12.000	18.890
Scenario304 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	10.400	0.217	12.000	19.149
Scenario305 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	11.200	0.217	12.000	19.407
Scenario306 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	12.000	0.217	12.000	19.665
Scenario307 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	12.800	0.217	12.000	19.924
Scenario308 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	13.600	0.217	12.000	20.182
Scenario309 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	14.400	0.217	12.000	20.441
Scenario310 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	15.200	0.217	12.000	20.699
Scenario311 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	16.000	0.217	12.000	20.957
Scenario312 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	7.200	0.217	12.000	18.115
Scenario313 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	6.400	0.217	12.000	17.857
Scenario314 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	5.600	0.217	12.000	17.598
Scenario315 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	4.800	0.217	12.000	17.340

Scenario316 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	4.000	0.217	12.000	17.081
Scenario317 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	3.200	0.217	12.000	16.823
Scenario318 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	2.400	0.217	12.000	16.565
Scenario319 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	1.600	0.217	12.000	16.306
Scenario320 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	0.800	0.217	12.000	16.048
Scenario321 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	0.000	0.217	12.000	15.789
Scenario322 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	13.200	18.634
Scenario323 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	14.400	18.894
Scenario324 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	15.600	19.155
Scenario325 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	16.800	19.415
Scenario326 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	18.000	19.675
Scenario327 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	19.200	19.936
Scenario328 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	20.400	20.196
Scenario329 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	21.600	20.457
Scenario330 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	22.800	20.717
Scenario331 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	24.000	20.977
Scenario332 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	10.800	18.113
Scenario333 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	9.600	17.853
Scenario334 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	8.400	17.592
Scenario335 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	7.200	17.332
Scenario336 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	6.000	17.071
Scenario337 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	4.800	16.811
Scenario338 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	3.600	16.551
Scenario339 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	2.400	16.290
Scenario340 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	1.200	16.030
Scenario341 (BFN-EC)	2.177	0.727	2.500	0.323	10.020	0.281	21.190	0.323	8.000	0.217	0.000	15.769
Scenario342 (BFN-EC)	2.177	0.727	0.000	0.323	11.022	0.281	23.309	0.323	8.800	0.217	13.200	17.994

Scenario343 (BFN-EC)	2.177	0.727	0.000	0.323	12.024	0.281	25.428	0.323	9.600	0.217	14.400	19.432
Scenario344 (BFN-EC)	2.177	0.727	0.000	0.323	13.026	0.281	27.547	0.323	10.400	0.217	15.600	20.870
Scenario345 (BFN-EC)	2.177	0.727	0.000	0.323	14.028	0.281	29.666	0.323	11.200	0.217	16.800	22.307
Scenario346 (BFN-EC)	2.177	0.727	0.000	0.323	15.030	0.281	31.785	0.323	12.000	0.217	18.000	23.745
Scenario347 (BFN-EC)	2.177	0.727	0.000	0.323	16.032	0.281	33.904	0.323	12.800	0.217	19.200	25.183
Scenario348 (BFN-EC)	2.177	0.727	0.000	0.323	17.034	0.281	36.023	0.323	13.600	0.217	20.400	26.621
Scenario349 (BFN-EC)	2.177	0.727	0.000	0.323	18.036	0.281	38.142	0.323	14.400	0.217	21.600	28.059
Scenario350 (BFN-EC)	2.177	0.727	0.000	0.323	19.038	0.281	40.261	0.323	15.200	0.217	22.800	29.497
Scenario351 (BFN-EC)	2.177	0.727	0.000	0.323	20.040	0.281	42.380	0.323	16.000	0.217	24.000	30.935
Scenario352 (BFN-EC)	2.177	0.727	0.000	0.323	9.018	0.281	19.071	0.323	7.200	0.217	10.800	15.118
Scenario353 (BFN-EC)	2.177	0.727	0.000	0.323	8.016	0.281	16.952	0.323	6.400	0.217	9.600	13.680
Scenario354 (BFN-EC)	2.177	0.727	0.000	0.323	7.014	0.281	14.833	0.323	5.600	0.217	8.400	12.242
Scenario355 (BFN-EC)	2.177	0.727	0.000	0.323	6.012	0.281	12.714	0.323	4.800	0.217	7.200	10.804
Scenario356 (BFN-EC)	2.177	0.727	0.000	0.323	5.010	0.281	10.595	0.323	4.000	0.217	6.000	9.366
Scenario357 (BFN-EC)	2.177	0.727	0.000	0.323	4.008	0.281	8.476	0.323	3.200	0.217	4.800	7.929
Scenario358 (BFN-EC)	2.177	0.727	0.000	0.323	3.006	0.281	6.357	0.323	2.400	0.217	3.600	6.491
Scenario359 (BFN-EC)	2.177	0.727	0.000	0.323	2.004	0.281	4.238	0.323	1.600	0.217	2.400	5.053
Scenario360 (BFN-EC)	2.177	0.727	0.000	0.323	1.002	0.281	2.119	0.323	0.800	0.217	1.200	3.615
Scenario361 (BFN-EC)	2.177	0.727	0.000	0.323	0.000	0.281	0.000	0.323	0.000	0.217	0.000	2.177

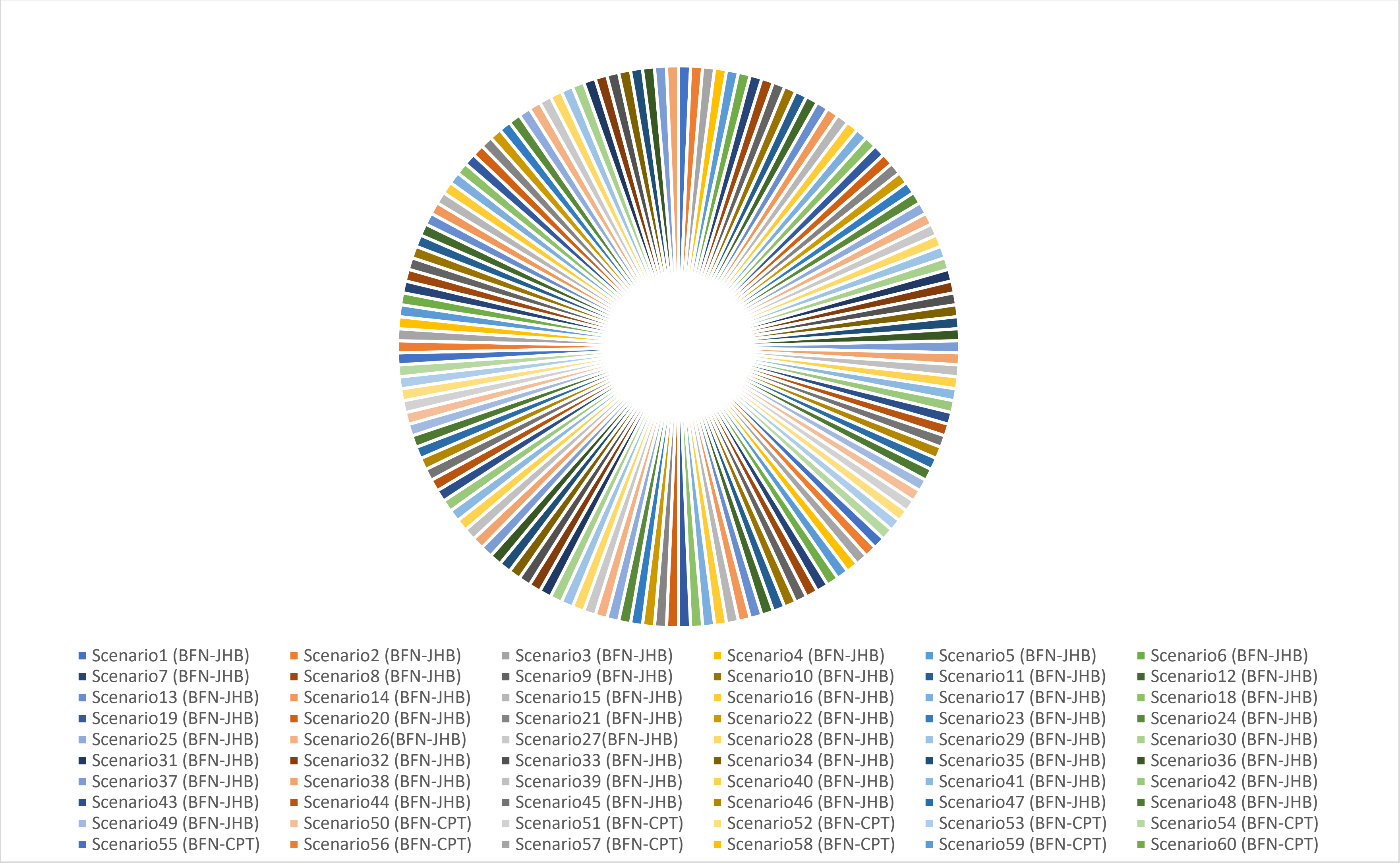


Figure A Bar chart representing the freight road simulations

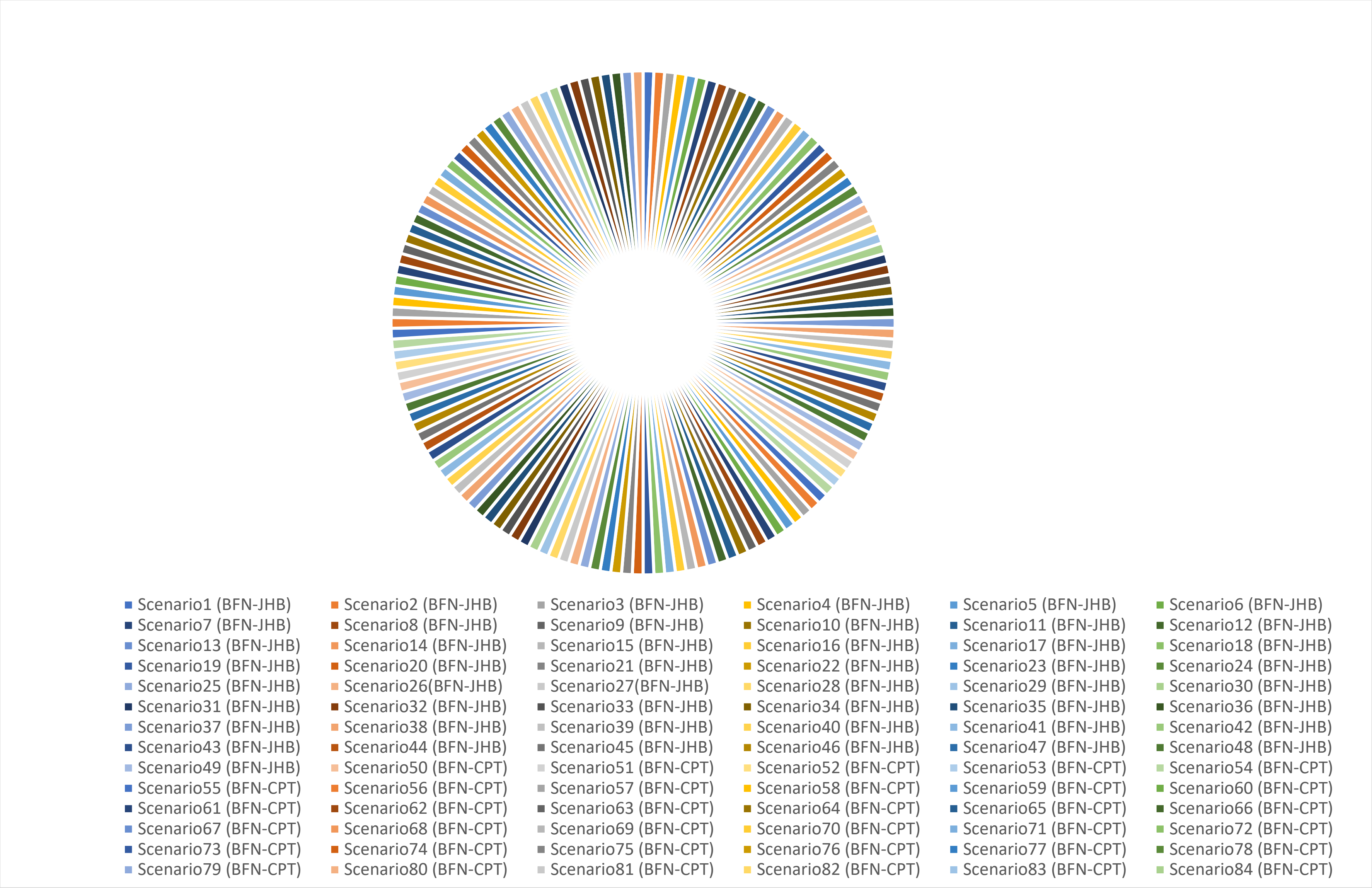


Figure B Bar chart representing the freight rail simulations