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Evaluating the Sustainability of Road Public Transport Systems in Johannesburg

Didintle Modisamongwe

Research report submitted to the Faculty of Engineering and Built Environment, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Urban Studies in the field of Sustainable and Energy Efficient Cities

Johannesburg, South Africa

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Declaration

I declare that this research report is my own unaided work. It is being submitted for the degree of Master of Urban Studies in Sustainable Energy Efficient Cities to the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

Didintle Oneilwe Modisamongwe

15 October 2021

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Abstract

The evolution of transport has primarily been driven by fossil fuel energy, resulting in multiple adverse impacts, including traffic congestion, urban sprawl, depletion of natural resources and air pollution. These negative externalities have necessitated a shift towards sustainable mobility, characterised by the use of energy efficient public transport that incorporates non-motorised transport and is supported by compact, decentralised and multi-functional urban layout.

The current study evaluated the sustainability of Johannesburg's road public transport, consisting of taxis, Metrobus, private buses, and the bus rapid transit system, Rea Vaya. The evaluation focused on public transport sustainability from a commuter perspective and thus assessed the efficiency of the service provided. To achieve this, four efficiency parameters were selected, they were accessibility, travel time, non-motorised transport, and reliability. The study utilised qualitative research data gathering tools in the form of questionnaires and interviews; and for rigour results were analysed using the thematic data analysis approach.

Study results revealed a deficiency in the availability of multiple modes throughout the study area, consequently the most accessible public transport option, taxis, had higher patronage and the least accessible mode, Rea Vaya had limited users. Furthermore, results indicated that urban residents walked long distances to access transport, and that local travel was easier than regional travel due to the dense urban form in townships. The incorporation of non-motorised transport lagged as Rea Vaya was the only mode with cycling infrastructure. However, walking was found to be inherent in the system due to commuters needs to travel rather than choice.

In assessing travel time, findings revealed that extended travel duration resulted from system inefficiencies such as waiting periods, multiple connections, winding routes, and vehicle mechanical failure. These inefficiencies were more pronounced in taxis and private buses, and further contributed to the energy inefficiency of the system by increasing vehicle kilometre travelled and fuel consumption. Additionally, commuters found public transport unreliable, especially taxis, as a consequence of extended waiting periods and unavailability during non-peak periods. Beyond system inefficiencies, commuters were concerned with public transport vehicle maintenance and infrastructure provision, such as adequate roads and traffic lights.

Overall, Johannesburg road public transport system comprises all four sustainability indicators; however, these are not integrated but rather spread across the different modes. Taxis are the most accessible transport mode, though not most sustainable. Inversely, Rea Vaya is the most sustainable mode, but it is inaccessible. In conclusion, the accessibility of a public transport system was valuable to commuters than overall sustainability.

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Dedication

Dedicated to my late grandfather, Moatlhodi Modisamongwe, Namane e tona ya tholo, Morolong o Nthuo, o dinaka di metshope.

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Chapter 1

1 Introduction

1.1 Overview

Road transportation has evolved over centuries, from wagons and carriages to the current internal combustible engine automobile, allowing people to live and travel further for employment, medical care, education, and other amenities. Cities have subsequently been designed and developed to be car-oriented to reap the benefits of faster travel. However, this mobility evolution, which has been primarily steered by fossil fuel technologies, brings unintended negative externalities including traffic congestion, air and noise pollution, safety concerns and urban sprawl (Schipper, 2002). According to Kennedy *et al.*, (2005) a way to mitigate against these impacts is through the provision of public transport that enables people' mobility while reducing over reliance on passenger vehicles and subsequently emissions and fosters compact urban form.

The provision of safe, accessible, and affordable public transport infrastructure is an essential step in the socio-economic advancement of South Africa; however, this realisation has not been followed by decisive and actionable policy (Thomas, 2016). Communities face the challenge of economic exclusion and inaccessibility to amenities due to a lack of public transport. In cases where transport is available, its layout and structure are often inefficient, thus increasing commuter travel time and cost (Chakwizira *et al.,*2011). Studies show a three-way relationship between land-use pattern, socio-economic status, and transportation needs (Stead, 2016). This relationship is exemplified by the apartheid planning system, which has resulted in long commutes from townships to the city centre as people search for employment opportunities.

Additionally, the transportation sector is emission and energy-intensive, contributing 70% to total energy use and 38% to total emissions in a typical South African metropolitan city (SACN, 2016); thus, energy efficiency and emission reduction are paramount to designing sustainable public transport systems. The sector also faces governance challenges, presented in the lack of coordination between multiple government structures (Thomas, 2016). Overall, "…designing sustainable transportation systems is considered one of the most pressing issues faced by modern cities (Hall, 1998 in Kennedy *et al.*, 2005:394).

1.2 Background and Context

There are various definitions of sustainable transport; however, the primary focus is satisfying society's social, economic and environmental needs. Santo and Ribeiro (2013) define sustainable transport as seeking a balance between current and future societal needs. A detailed definition drawing from the 1987 Brundtland Commission report's definition of sustainable development is that the concept entails the "… provision of accessibility and the generation of wealth by cost-effective and equitable means while safeguarding health and minimising the consumption of natural capital and emissions of pollutants." (Kennedy *et al.*, 2005:395). Stanley and Lucas (2014) expand the definition by adding mass travel, noting that sustainable public transport enables access to amenities that satisfy basic needs, is economically viable, socially inclusive, fairly distributed, safe, energy efficient and has reduced carbon emissions.

Institutional arrangement and governance are the pillars of the mentioned sustainability spheres, as they are vital in implementing and managing sustainable public transport systems (Stanley and Lucas, 2014). Thus, sustainable transport relies on effective and integrated transport planning, infrastructure investment, continual funding, and investment in local context design (Kennedy *et al.*, 2005). The

following subsections give details on the sustainability spheres, beginning with social, followed by economic and environmental sustainability. The section concludes with a write up on governance.

1.2.1 Social sustainability

The social aspects of transport mainly relate to the accessibility of public transport and the urban city form that facilitates it. Accessibility characterises the quality of a system from a user perspective and encompasses availability and proximity to a transport service (Vilakazi and Govender, 2014; Mokgukulushi *et al.*, 2018). Accessible transport systems allow citizens to access required goods and services, enable them to improve their social and economic situations (Litman, 2020; Sohail, 2005 in Vilakazi and Govender, 2014). Adversely, transport inaccessibility may result in physical isolation and economic exclusion as citizens have limited access to employment opportunities and other essential amenities (Chakwizira *et al.*, 2011).

Transport social impacts borne by urban form, are observed in where people reside and how they travel between amenities (Petersen, 2004). Non-compact or sprawled cities have long commutes, facilitating car dependence, increasing traffic congestion and energy consumption and discouraging public and non-motorised transport (NMT) usage (Sietchiping *et al.*, 2012; Petersen, 2004; Waters, 2016). Consequently, compact urban from provides a good foundation for the implementation of a sustainable transport system that is accessible and energy efficient, characterised by public transport and NMT usage.

1.2.2 Environmental Sustainability

The environmental sustainability of a transport system is mainly measured through its contribution to climate change and associated impacts. Literature (Schipper, 2002; Maure *et al.*, 2018; Ziervogel *et al.*, 2014) indicates that transport brings negative environmental impacts such as greenhouse gas emissions, degradation of water and air quality and noise. Impacts adversely affect humans, fauna, and flora through increased susceptibility to respiratory illness and altered weather patterns.

Generally, these impacts are managed through environmental taxation including, fuel levy, vehicle taxation and carbon tax (Schipper, 2002). In the South African context, examples are the fuel levy (DoT, 2019) and the recently promulgated carbon tax law. However, the challenge with these mitigation measures is the slow and ineffective implementation caused by politics. As a result, behaviour-based and technology measures are proposed as alternatives (Schipper, 2002). The former measure includes increased use of public transport, which would enable peoples' mobility while reducing environmental impacts (Stanley and Lucas, 2014). Technological advancements involve using alternative energy sources and propulsion technologies. Examples are hybrid engines, using a combination of the internal combustion engine and an electric engine (D'Agosto *et al.*, 2013), and using biodiesel, CNG and hybrid fuels (Stanley and Lucas, 2014). The above strategies intend to curb emissions and reduce reliance on fossil fuels, thus moving towards sustainable transport.

1.2.3 Economic Sustainability

The affordability of transport is one of the main priorities of sustainable transport, as affordable transport facilitates people’s mobility (Venter, 2011). This aspect is especially important for low-income groups who must decide between purchasing essential goods and travelling to work (Chakwizira *et al.*, 2011). According to Litman (2020), low-income earners spend more than the recommended 20% of their income on transportation. The cost is escalated for South Africans living on the periphery of the city, as they spend nearly 50% of their earnings on transport (Harrison *et al.*, 2003 in Kgatjepe and Ogra, 2016). It is thus vital for public transport to be affordable for all. Venter (2011) indicates that the cost of transport of transport may be reduced by improving urban form, where affordable housing is located along public

transport corridors. This measure would further reduce vehicle kilometre travelled, energy consumption and greenhouse gas emissions.

Sustainable transport includes ascertaining its continual and feasible funding, managed by dedicated ministries or departments (Kennedy *et al.*,2005). This aspect of sustainable transport is especially challenging in developing countries due to fiscal constraints (Stanley and Lucas, 2014).Two methods are suggested to improve this challenge, firstly implementing the polluter-pay principle, where citizens are responsible for the energy and environmental costs of using private cars. The second measure, value capture, is public-private partnerships, where private companies fund public transport projects around their area of business (Stanley and Lucas, 2014).

1.2.4 Governance

Effective governance is essential to urban transport, preceding finance, infrastructure, and land use planning, furthermore, it is a gateway to economic growth and development (Kennedy *et al.*, 2005 in Chakwizira and Mashiri, 2009). This is because the planning and implementation of sustainable transport projects requires political buy-in, together with multi-disciplinary and adequately resourced managing structures (Kennedy *et al.*, 2005). Effective transport governance requires a balance between economic growth and development, societal issues such as essential services delivery and environmental concerns, including climate change and cleaner fuels (Chakwizira and Mashiri, 2009). As such effective governance is required to ensure that sustainable transport is successfully implemented and managed.

1.2.5 Impact of Covid-19 on Public Transport

The current research project was conducted during the Covid-19 pandemic, which impacted how various industries, including transport function. The virus entered South Africa on the 5th of March 2020, subsequently the country entered a state of disaster and initiated lockdown a few days after as a measure to stop the spread of the virus. Lockdown brought multiple transport restrictions including the prohibition of cross-border and inter-provincial travel and the requirement to regularly disinfect public transport vehicles and enforce the wearing of masks (Pillay and Scheepers, 2021). The major restriction however was the limit in loading capacity, where taxis were only allowed to carry 70% of their vehicle capacity, buses 50% and train services were halted (Department of Transport, 2020).

The restrictions reduced the availability of public transport, which resulted in certain citizens being unable to access healthcare facilities for non-covid-19 medical care such as consultation, chronic diseases, antenatal care, etc (Pedem and Kobusingye, 2020). Additionally, the limit in loading capacity constricted public transport service providers profit margins due to reduced passenger fares. In the past, unprofitable routes have been closed or number of services reduced (Luke, 2020), impacting the commuter through reduced transport accessibility, increased crowding in available vehicles and longer waiting periods and travel times.

The Covid19 pandemic also brought critique to mass transportation as crowded spaces contributed heavily to the spread of the virus (Kakderi *et al*, 2021). This aspect is particularly relevant in the context of Johannesburg where crowded buses and taxis are a normal occurrence in the city. Additionally, the pandemic also pushed more persons to shift from public transport usage to private cars, as a way to minimise the risk of contracting the virus (Basu and Ferreira, 2021). This shift is likely to result in higher traffic congestion and increased energy consumption and pollution in cities. These statements highlight the need to improve on the conditions of mass travel. Overall, the Covid-19 pandemic amplified existing public transport challenges and highlighted the need to incorporate health aspects in sustainable public transport planning.

1.3 Study Rationale

The transportation sector is essential to people's daily lives; as such, its sustainability is vital. As noted earlier, sustainable transport needs to be accessible, cost-effective, carbon conscious, energy efficient, safe and well managed (Kennedy *et al.,* 2005, Schipper 2002). The research project focuses on evaluating the level of sustainability in Johannesburg road public transport system and identifying sustainability indicators that are most valued by commuters. This research is valuable as, generally, the focus is on the system's technical design or vehicle features such as propulsion technologies, with data considering how the commuter interacts with the system "…vaguely determined and, in fact... practically non-existent… "(Simona, 2010 in Vilakazi and Govender, 2014:259). Consequently, research that is commuter focused is essential in understanding the functional efficacy and user-friendliness of the transport system.

1.4 Research Aim

The overall aim of the study is to understand the extent of sustainability in Johannesburg's road public transport system. The aim will be achieved by firstly evaluating the concepts of sustainability and sustainable transport. The objective is to identify sustainability indicators to be utilised in assessing the level of sustainability in available road public transport. Ultimately, the study intends to present parameters that make road public transport in Johannesburg sustainable and identify the most sustainable road public transport type within the existing public transport system.

1.5 Research Questions

Research question and sub-questions are the building blocks of research, as they express what concerns the researcher(s). They are said to provide "a point of orientation for the investigation." and generally inform the research design and methodology (Bryman, 2007:5). Per Thabane *et al.* (2009:72), a research question is supposed to be "… appropriate, meaningful, and purposeful…feasible, interesting, novel, ethical, and relevant". A well-formulated research question stems from the research title and should be easily apparent and understood by the reader (Thabane *et al.*, 2009). These research questions characteristics are considered and applied in the study as presented below.

1.5.1 Main Research Question

To what extent is the current road public transport system in Johannesburg sustainable?

1.5.2 Research sub-questions

- What does the concept of sustainability in transport mean?
- What are sustainable mobility indicators?
- What is the stance of Johannesburg's commuters on the sustainability of current road public transport?
- How are sustainability indicators considered in road public transport planning?

1.6 Report Structure

The introductory chapter of the study provided an overview of sustainable transport, giving background and context to the research topic. The chapter further presented a synopsis of the three sustainability spheres and detailed the study's rationale and aim. The first chapter concluded by providing the study approach through the conceptual framework.

The rest of the report will include four more chapters, beginning with the Literature Review, exploring the research topic in detail. The third chapter, Research Methodology, notes the research process and procedures, whereas the fourth chapter gives the study Findings and Analysis. The report closes with Conclusions and Recommendations chapter.

Chapter 2

2 Literature Review

2.1 Introduction

Providing a good public transport system characterised by accessibility, reliability, affordability, safety, and energy efficiency is a challenge faced by multiple governments globally. In South Africa, improved public transport is key to social and economic advancement as the transport sector has the potential to provide direct employment and to facilitate job opportunities for other sectors that rely on its demand for their output (Thomas, 2016). As the transport sector is energy and emission intensive, shifting to low emissions public transport would assist in reducing the sector's contribution to overall greenhouses gases production.

The importance of good and functional public transport is evidenced by South Africans ranking transport as the third largest concern in the country, preceded by health and education (Heyns and Luke, 2016). The provision of transport services is difficult for the government amidst increasing urbanisation, inward migration and provision of other essential services (Walters, 2013). However, as transport facilitates the provision and access to health, education, housing, and employment it should be prioritised and recognised as a vital service.

Specifically in South Africa, the main concerns in public transport per commuters relate to the quality of the service provided, specifically accessibility, service frequency, travel duration, affordability, safety and the poor state of infrastructure (Heyns and Luke, 2016; StatsSA, 2014). According to Thomas (2016) the multiple transport challenges can be summarised into five categories. Firstly, accessibility, secondly, urban form, categorically the apartheid planning system legacy, followed by cost and affordability and over reliance on walking and exposure to risk; lastly, lack of coordination between government layers and structures. Transport challenges have previously been tackled through policies and regulations, including the White Paper on National Transport Policy, the National Development Plan, and the National Transport Masterplan (NATMAP). However, these plans are broad and unrealistic resulting in their slow implementation while transport challenges persist (Heyns and Luke, 2016). This demonstrates a need to improve public transport, albeit employing new methods such as sustainable transportation systems.

The literature review chapter explores the concept of sustainable public transport, beginning with a look into transport planning theory and its evolution. The third section focuses on the concept of sustainability and sustainable transport. The fourth section concludes the chapter by introducing the context of the study area.

2.2 Transport Planning Theory

People's mobility has evolved over centuries from walking, horse riding, use of carts, trams, trains and motorised transport such as buses and cars (**Figure 1**). This evolution has occurred as a need for people to travel further and faster and has consequently influenced how cities are designed, i.e., allowed for the expansion and growth of cities. The first form of cities was small, approximately two kilometres in radius, and designed for walking. These cities consisted of dense, mixed-use urban form and can still be seen in Barcelona, Mumbai and Hong Kong (Newman *et al*., 2016).

The walking cities evolved to be transit cities, characterised first by steam trains, then trams (Newman *et al*., 2016. The change to transit cities can still be seen in Paris, London and New York underground

railways, which are located less than 500 metres away from urban walking city form. The shift from walking as a mode of transport to transit, fostered the expansion from compact city form to star-shaped cities that follow transport routes (Knowles *et al*, 2020). This development-oriented city design enabled travel between work in the urban centres and homes located on the periphery of towns (Dittmar *et al,* 2004). According to urban historian Sam Bass Warner in Dittmar *et al* (2004), the design enabled the inception of the two-part cities, particularly in American cities including Boston, Cleveland, and Los Angeles (Dittmar *et al,* 2004; Jacobson and Forsyth, 2008).



Figure 1: The evolution of transport

2.2.1 Auto-Oriented Design of Cities

Development-oriented design was mainly destabilised by the introduction of the automobile with the internal combustion engine around the 1930s. Transit companies became unprofitable, with a shift from mass transit to personal mobility as residents now had multiple choices of travel; subsequently trams and rail transportation took the backseat (Knowles *et al.*, 2020). In some countries such as Britain, Australia and the United States of America(USA), the streetcars system was replaced by bus systems, however this was impermanent as cars gained more popularity and dominance due to their efficient speed and travel time (Dittmar *et al,* 2004; Knowles *et al.*, 2020). Consequently, new cities were now designed with motorised transport in mind (Johnston, 2004 in Koglin and Rye, 2014), and to transport masses of people and larger goods further and at greater speeds and efficiency (Knoflacher, 2009).

Auto-oriented city design promoted investment in and construction of infrastructure for motorised transport, including the building of new highways and widening existing roads (Koglin and Rye, 2014; Dittmar *et al.*, 2004). This benefitted the commuter by offering a faster, flexible and more convenient travel method, which mass transit lacked. The disadvantage was however that auto-oriented city design decentralised development, moving it to areas located close to highways and ring roads (Knowles *et al.*, 2020). Cities were dispersed through zoning of different areas and lacked urban form integration, which inadvertently perpetuated car usage as people needed to travel between the different zones.

Furthermore, the design showed little consideration for land use patterns, fostered urban sprawl, and reinforced reliance on cars as it had limited public transport provision to service the sprawling cities; where available mass transit was subpar and characterised by slow and infrequent services (Dittmar *et al.*, 2004; Newman *et al*., 2016). This scenario describes Johannesburg which is sprawling as evidenced by the increasing number of informal settlements on the periphery of the city, which have limited 'formal' public transport and have to rely on paratransit for travel.

Lastly and most importantly, as fossil energy technologies mainly drove this design, it further brought the negative impacts of increased fuel consumption and air pollution through greenhouse gas emissions (Schipper, 2002). Additionally, impacts were also indirect as increased popularity of motorised transport resulted in increased energy and resources demand, required to produce and transport fuel. The impacts of auto-oriented design worsened as time progressed and more people relied on cars for travel. There was more traffic congestion, longer travel times and more greenhouse gases emissions. The strategy employed by transport agencies and departments to expand and construct more roads did not assist as congestion on 30 to 80% of the new road capacity usually resurges after five years. This phenomenon is referred to as induced travel, meaning that people will travel further or more as travel conditions improve (Bohler-Baedeker and Huging, 2012).

The dominance of cars in cities around the world still persists, especially in the USA ,where resources and finances are prioritised for automobile infrastructure and the construction of new roads (Koglin and Rye, 2014). European cities have however promulgated policies and regulations that aim to curb this dominance and encourage public transport use (Koglin and Rye, 2014). The situation is however different in developing countries where dense corridor urban form dominates accompanied by inadequate formal public transport to support it. Subsequently, cars, motorcycles, and paratransit inundate these cities (Newman *et al*., 2016), and as a result the negative impacts of automobiles are likely to continue.

2.2.2 Transit-Related Development City Design

Auto-oriented design partially transformed into transit-related development, which entails increased development around transit points, creating pockets of dense and profitable developments (Table 1). These transit developments included the construction of rail systems and large real estates. This city design was driven by the need to reduce auto-oriented design negative externalities and for transport service providers and government's financial gain. Transit-related development is almost exclusive to USA and can be observed in cities like San Diego, Washington and Portland (Dittmar *et al.*, 2004).

Albeit the design focused primarily on financial gains from the land, with little consideration for the relationship between the development and the surrounding environment (Dittmar *et al.*, 2004), it prioritised mass transit, which has reduced energy consumption and carbon emission, in comparison to the automobile. Knoflacher (2009) notes that ideally public transport provision should focus on meeting the needs of the area; however, this is often not the case. Politicians and planners are often enthusiastic about big projects such as rail, which require high technology and financial investment, neglecting cost-efficient transport options with maximum reach (Mackett and Edwards,1998). This scenario aligns with Thomas (2016), referencing the Gautrain project in Gauteng, South Africa, where cheaper alternatives to the high-speed train, such as electronic trolleybuses and light rails, were not adequately considered.

The challenges associated with development-oriented, auto-oriented and transit related city designs indicated a need to shift to a design more integrated and inclusive of factors influencing and impacting transport, a people and urban form centric system. Knoflacher (2009:6) states that "in practice, it is … obvious that the urban system is the regulator and not the experts and the decision-makers". Black (2018) similarly states that urban planning involves a holistic approach where transport issues and solutions are conceptualised with social characteristics and community needs prioritised. A city is thus ideally "... the built expression of the social structure of the society that created it" (Knoflacher, 2009:1).

Overall, literature indicates that a way to reduce the negative externalities of the previous city designs is to prioritise public transport (Knoflacher, 2009; Newman *et al.*, 2016; Mackett and Edwards, 1998). The public transport type made available is however important, as it must be easily accessible, cost-effective in infrastructure development and management, provides high-quality service using multiple modes and displays consonance between urban land use policy and transport (Mackett and Edwards, 1998; McLeod *et al.*, 2017). These aspects characterise the building blocks of transit-oriented development (TOD) as explained in detail in the following subsection.

Table 1: City designs and characteristics

City Designs	Characteristics	Mode of travel
Development-oriented design	• Essential travel between work and home • Shift from compact cities to star shaped urban form	
Auto-oriented design	• Aim to transport more people and goods further • Investment in motorised transport • Dispersed city form (area zoning) • Inaccessible and inadequate public transit	
Transit-related development	• Development around public transit nodes - profit prioritised • No relation between development and urban form	
Transit-oriented development	• Mixed developments – cost, age & use • Compact urban form • NMT and public transit	

2.2.3 Transit-Oriented Development City Design

According to Knowles *et al.* (2020), the term TOD originates from the 1993 publication by Calthorpe. TOD refers to the development and growth of cities around public transport nodes, with housing, employment and other facilities located close to one another and to transport nodes. TOD describes a mutually beneficial relationship between land use development and transportation. It focuses on system speed, scale of operation and capacity, flexibility, and degree of spatial concentration of activities and amenities (Carey *et al.*, 2009). Mixed development in terms of density, type (residential, retail and office), and cost; promotion of non-motorised transportation (NMT) such as walking and cycling and maintaining green spaces in functional condition are also TOD characteristics (Dittmar *et al.*, 2004). TOD is beneficial to cities as it promises to increase accessibility to public transport, improve travel time by creating land-use patterns that prioritise transport, better manage demand, and increase public transport frequency.

As observed by Dittmar *et al.* (2004), three trends drive the concept of TOD; the first is urbanisation, as in 2030, 70% of the world's population is expected to be residing in cities. South Africa is predicted to be over 71% urbanised by 2030 and 80% by 2050 (COGTA-RSA, 2016). This rapid urbanisation requires cities to provided multiple infrastructures, including transport, in a smart and sustainable manner. The second trend is the revitalisation of the typical suburb, which now needs to cater for multigenerational and multicultural communities. The last trend is investment in travel, including rail and bus rapid transit (BRT). The convergence of these three trends makes for a "…new form of walkable, mixed-use urban development around new and existing rapid rail or bus stations" (Dittmar *et al.*, 2004:2).

Though multiple characteristics make for TOD projects, per literature (Knowles *et al.*, 2020; Dittmar *et al.*, 2004; Carey *et al.*, 2009), the major components include location efficiency, distinguished by high density, pedestrian friendliness, and access to public transit. The latter aspect is vital because of its potential to alleviate financial challenges for residents as the alternative method of travel, i.e., car, is often unaffordable (Dittmar *et al.*, 2004). This aspect is demonstrated by cities such as Singapore and Tokyo, which have implemented high density and compact urban form around rail transit enabling commuters to easily access public transport (Knowles, 2012).

The second component is a rich mix of housing types and accessing various amenities, including housing development catering for multigenerational and multicultural families; and the option to use different modes to gain access to amenities, whether walking, cycling or using public transit (Dittmar *et al.*, 2004). Placemaking is the third component, which relates to matching the functionality of a place to the desires and needs of its users. An example is the availability of schools and playing grounds near homes and workplaces, which foster the TOD ideology to "...achieve functional integration of transit and surrounding development, as well as synergy among all its uses." (Dittmar *et al.,* 2004:21).

Value capture is the fourth component, which prescribes that TOD projects must be beneficial to various stakeholders. To illustrate, TOD projects developers can get quick approval from authorities and have higher sales; occupants (renters or buyers) can benefit by being closer to work and being more productive and happier, directly benefiting businesses. The final component is tension resolution between node and place, which requires a balance between the two and a clear description of each (Dittmar *et al.,* 2004). Cao *et al.* (2020) state that a node is defined by its accessibility in a transport network, whereas a place refers to the land use around a transit point. Striking a balance between these variables will ensure that development is located appropriately in a city.

TOD is also synonymous with energy efficiency as it promotes less car trips and more public transport usage, essentially focusing on vehicle kilometre travelled reduction, which has a direct correlation to reduced energy consumption and greenhouse gas emissions (Cervero and Sullivan, 2011). Newman *et al* (2016) reiterates this statement by noting that cities dominated by mass transit and walking have reduced energy consumption per person, as on average private vehicles use two to three times more fuel per kilometre travelled than public transport.

Public transport options most utilised in TOD projects are rail and BRT system, their preference is due to their competitiveness to cars in speed, higher carrying capacity and reduced traffic congestion (Knowles *et al.*, 2020). These modes are often further made more energy efficient through improved engine design, use of alternative fuels and renewable energy. The latter may include using solar or wind energy to power light rail and using bus or rail stop canopies roofs to place photovoltaic panels to produce electricity for nearby communities (Cervero and Sullivan, 2011). The charging of electric buses through solar energy during off-peak travelling periods in Adelaide, Australia is an example of such a measure (Cervero and Sullivan, 2011). The Rea Vaya bus fleet provides another example of energy efficiency in transport, as it comprises Euro V[1] buses which utilise a combination of CNG and low-sulphur diesel as fuel sources. Overall, TOD is inherently energy efficient, however technological advancement and use of renewable energy sources greatly improve its efficiency.

The concept of TOD has been implemented successfully by various cities worldwide, notably Copenhagen with its Finger Plan, Stockholm through their General Plan and Oslo's using their Comprehensive plan. These cities TOD plans mainly involved the development of compact neighbourhoods or corridors around easily accessible, high frequency public transport (Knowles *et al*, 2020), thus reducing the need for private car usage and its associated energy inefficiency and adverse environmental impacts (see **Section 2.2.1**) . The City of Johannesburg (CoJ) is also in the implementation phase of a similar plan named the Corridors of Freedom, which aims to increase economic growth, improve urban form and use transport as a connecting spine (CoJ, undated).

It is evident that two significant characteristics underpin TOD, firstly the improvement of urban form to be more compact and secondly the betterment of public transit, inclusive of NMT. Improvement lies in making public transport attractive to commuters, which requires an understanding of the attractiveness and preference of cars, meaning focusing on the inefficiencies of public transport. Cars have the

[1] Euro V vehicles comply with the emission limits as defined in Directive 99/96/EC, which came into effect in 2009. It leads to further NOx reductions of 25% compared to Euro 4 and a PM mass emission limit for direct injection cars, like the diesel ones

advantage of flexibility, convenience, accessibility, and speed but lack capacity. Adversely public transport has speed and capacity but is deficient in flexibility, convenience, and accessibility, whereas NMT has the flexibility and speed but lacks capacity (Carey *et al.*, 2009; Knowles *et al.,* 2020). Liveability surveys reveal that people value access to services, modal choices, environmental quality, travel time, health, and safety in transport (Dittmar *et al.,* 2004). As such, the shift towards TOD requires improving public transport's weaknesses to make them more competitive and desirable than cars; however, this needs to be done in congruency with compact and mixed development neighbourhoods (Carey *et al.*, 2009).

The successful implementation of TOD relies heavily on policies and set frameworks, meaning cities have to formulate plans that define the density of areas, the type of mix in development envisaged and how that is to be supported by public transport and funded through sustainable mechanisms (Newman, 2009). Dittmar *et al.* (2004) note the lack of legislation and regulation to support TOD implementation as one of the constraints inhibiting TOD, together with the lack of consensus on the concept definition and collaboration of multiple disciplines required.

Overall, TOD is the most sustainable form of transport planning or, in the least, a vessel to reach the goal of sustainable transportation (Newman, 2009), as illustrated in Table 1. This conclusion stems from its characteristics and inherent benefits, including encouragement to use NMT, resource efficiency, reduced travel time and expense, mixed-income neighbourhoods, less traffic congestion and a reduction in cities' environmental impact or carbon footprint (Dittmar *et al.*, 2004; Carey *et al.*, 2009; Knowles *et al.*, 2020).

2.3 The Concept of Sustainability

Sustainability has been widely used since the late 1970s, gaining its popularity from the realisation by scientist and the global community that the earth has finite resources that need to be used at a pace that allows for their natural regeneration. The concept has evolved from being political to being present in every aspect of society (Newman and Kenworthy, 1999). The famous definition of sustainability per the 1987 Brundtland Commission report is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987: 39 in Harrison *et al.*, 2014:14). Other definitions of the concept are either derivative or extension of this definition. According to Dresner (2002), sustainability is about equity between and within generations. It is also a moral issue; relating to the use of resources to meet future generations' needs.

Corporations and businesses have appropriated sustainability to be more acceptable and seen as promoting 'green' concepts in the eyes of consumers and other businesses; there is thus a need to distinguish between strong and weak sustainability. Strong sustainability allows for the use, not depletion, of natural resources to find alternatives. An example is using coal-produced electricity profits to fund research or production of renewable energy (Dresner, 2002). Strong sustainability involves systemic and process changes such as "…development of accessible, reliable, and affordable integrated public transport services …" (Simon, 2016:72). Conversely, weak sustainability only conserves significant resources (Dresner, 2002), thus failing to understand the basic rules and functioning of nature, i.e., everything is connected and interdependent. Simon (2016) calls weak sustainability 'greenwash' approaches that do not address the root cause of unsustainability. Examples are switching to low energy light bulbs and recycling.

The above definitions culminate to three characteristics of sustainability, i.e., the development of economies, improved quality of life for citizens and the conservation and preservation of natural resources. For this reason, sustainability is often thought about in three spheres, economic, social, and environmental. The three spheres are interconnected and interdependent; an example is that citizens

are more likely to have access to better basic needs such as healthcare, education and transport, which improves their quality of life in a country with an excellent economic stance. Sustainability is applicable across various sectors; however, applied measures need to address root causes of unsustainability and not just focus on symptoms. An example is that the unsustainability of the transport sector should be addressed from a systems approach, meaning what causes the transport system not to function optimally.

2.4 Sustainable Transport

Sustainable transport stems from the concept of sustainable development, defined as "...users and beneficiaries paying their full costs, including those imposed on the future" (Schipper, 2002:2). The concept is inclusive of social (equity), economic, and environmental consideration. Per the WHO definition, a sustainable transport system must satisfy all three spheres of sustainability. Firstly, the social aspect, referring to poverty, unemployment, and essential services provision (e.g., education and healthcare). This aspect thus addresses how people use or access transport to improve or maintain their lives (*ibid*, 2002). The second sphere, economic, refers to transport's affordability whilst responding to changing demands (*ibid*, 2002). The third sphere is environmental consideration and has the ultimate goal to reduce carbon emissions through transport efficiency and use of alternative and/or renewable energy sources (*ibid*, 2002).

Picking up on the last sphere, Kennedy *et al.* (2005) states that typically transport planning would consider the provision of accessible, safe, and cost-effective transport, utilising available technology. However, this thinking has evolved to include environmental consciousness, mainly due to numerous concerns such as climate change, ecosystem damage and pollution, that arose from transport, specifically from the use of fossil fuel energy.

Schipper (2002), adds that sustainable transport mainly focuses on dealing with and minimising transport's negative externalities, including safety issues, congestion, noise, sprawl, and air emissions. On the latter, carbon dioxide is highlighted as it is the most significant contributor to climate change. Banister (2008), in McLeod *et al.*,(2017) reinforces that the goal of sustainable transportation is carbon reduction, which may be achieved through energy efficiency, multimodal systems, renewable energy use and car-pooling. However, these measures must be supported by good urban form as it is the cornerstone of any sound transport system.

Stanley and Lucas (2014) sum up the characteristics of sustainable transport in stating that it must enable people to access amenities that satisfy basic needs. It must further be economically and fiscally viable, socially inclusive, fairly distributed and not risk the safety and health of people. Consequently, a shift towards sustainable transportation, which entails "…the provision of accessibility and the generation of wealth by cost-effective and equitable means, while safeguarding health and minimising the consumption of natural capital and emissions of pollutants." is required (Kennedy *et al.*, 2005:395).

For the goal of sustainable transport to be realised, Kennedy *et al.* (2005) suggest focusing on four pillars, that is, "effective governance of land use and transportation; fair, efficient, stable funding; strategic infrastructure investments; and attention to neighbourhood design". The first pillar calls for improved governance of all sectors or disciplines involved in transport provision by establishing a transport body. Schipper (2002) agrees by indicating that for any significant move to be made, there have to be regulations, policies, and technologies to effectively develop, implement and manage sustainable transport. Efficient funding is the second pillar and focuses on finding alternative and long-lasting mechanisms to fund transportation as an infrastructure and as a service.

The third pillar refers to putting financial resources into future infrastructure and mobility concepts. In the short term, investments can be in car-transitional measures that still involve car usage but more

efficiently, such as park and ride, intelligent traffic system and car-pooling lanes (Schipper, 2002). Long term goals can include energy efficient measures such as use of renewable fuels and a shift from the internal combustion engine to new propulsion technologies (Kennedy *et al.*, 2005). The last pillar is local context, referring to the design of transport plans considering how neighbourhoods are, how they have or will evolve. This pillar aligns with TOD's 'place-making' component.

Overall, these definitions reveal that sustainability in transport needs to satisfy social, economic, and environmental agendas. However, the implementation of that requires a managing body comprised of professionals from multiple disciplines. Literature also reveals that sustainable transport's primary concern is managing transport's negative externalities. The following subsections explores the three sustainability spheres in the context of transport.

2.4.1 Social Sustainability in Transport

Cities worldwide struggle with transport issues. In South Africa, challenges faced include poor urban planning, resulting in sprawled cities and residential developments built away from economic and transport nodes, thereby creating an inaccessibility issue. The fragmentation of the public transport network, cost, long travel times and lack of integration within transport planning disciplines are also concerns (Mthimkulu, 2017). The status of transport in Johannesburg is reflected by commuter's dissatisfaction with transport accessibility, fares, long commutes, dispersed transport nodes, crime and violence (Kgatjepe and Ogra, 2016; Chakwizira *et al*, 2011)

2.4.1.1 Accessibility

Accessibility to transport is one of the most often discussed indicators in public transport provision as it characterizes the quality of a system from a user perspective (Vilakazi and Govender, 2014). Generally, people travel to reach a destination that offers personal or professional opportunities (Venter, 2016); thus, accessibility is key to trip generation and distance (Munier, 2007 in Kgatjepe and Ogra, 2016). The definition of accessibility varies depending on access to what (healthcare, school or work), by whom (settlement dwellers, disabled people or urbanites) and how referring to different transport modes; However, it is generally a measure of mobility quality, transport and opportunities access (Venter, 2016).

Venter *et al.* (2019) simplify the definition stating that accessibility refers to the ease with which a person can arrive at a particular opportunity using a specific transport mode. These definitions are also in line with Litman (2020:15), who defines the concept as "…people's ability to reach desired goods, services and activities". Vasconcellos (2001) in Kgatjepe and Ogra (2016) highlights that accessibility also means having options when selecting the mode of transport for a journey. Based on the above, accessibility is a critical aspect of a transport system, it moves beyond provision and enables improvement of citizen's economic and social situation (Sohail, 2005 in Vilakazi and Govender, 2014).

Adversely, transport inaccessibility results in social injustice and socio-spatial inequities, where citizens are unable to gain access to employment, education, and health services , thus denying citizens of the right to the city (Schipper, 2002, Boschmann and Kwan, 2008). Inaccessibility is more pronounced in poor communities living on the periphery of the city in informal settlements and needing to travel to the inner city where economic development is centralized (Kgatjepe and Ogra, 2016). Poor road infrastructure conditions in these communities further exacerbate the accessibility challenges, serving as a deterrent to increased frequency of transport services and inclusion in route planning by service providers (Venter *et al*, 2014).

Transport inaccessibility inhibits access to other essential amenities linked to improved quality of life (Lionjangaa and Venter, 2018). Venter *et al.* (2019) illustrate this by stating that 42% of Johannesburg urbanites are unable to reach job opportunities due to inadequate transport systems. According to Kennedy *et al.*, (2005) poor urban form and transport development characterized by urban sprawl and

a dependency on private cars with minimal public transport options are primary reasons for inaccessibility.

In improved situations where public transport is accessible, it is often insufficient and inefficient due to fragmentation, segmentation and numerous interchanges of the network (Todeschini, 2004 in Chakwizira *et al.*, 2011:57); requiring commuters to either walk or use a different connecting mode to complete a journey (Chakwizira *et al.*, 2011). On average, commuters are supposed to travel approximately 400m to reach public transport; however, in Johannesburg, the distance travelled averages 1 500m. Additionally, transferring from one mode to another adds 15 minutes to commuter journeys, thus showing the negative impact that public transport inefficiency has on commuter lives; as some have to wake up earlier, sometimes risking their safety to reach work or school (Mokgukulushi *et al.*, 2018).

2.4.1.2 Urban Form

The urban structure and layout are essential factors in a city as they largely determine where people reside, work, school, shop and the mode and distance used to travel between those areas (Petersen, 2004). City planning has evolved over the years from master planning, characterised by silo mentality, rigidity and non-consultation, to a more inclusive and flexible approach that includes other disciplines and departments, such as roads, transport systems and social infrastructure (Todes, 2012). Urban form influence on transport is seen in African cities like Johannesburg, Cairo, and Lagos, which are sprawled due to car-oriented design (Sietchiping *et al.*, 2012; Petersen, 2004).

Studies reveal a link between urban form and transport energy use and subsequently carbon emissions, where sprawled cities have ten times more energy usage and carbon emissions (Waters, 2016). Furthermore, sprawled cities are highly inefficient, impede the promotion of public and NMT, worsens congestion, and increases travel time (Bohler-Baedeker and Huging, 2012). Specific to Johannesburg is the legacy of the apartheid planning system, which created an environment for a sprawled city as it divided the city across racial lines(Todes, 2012). The system's spatial inequality and inefficiency resulted in what de Saint-Laurent (1998) in Thomas (2016:353) labels as "a geography of dual nature"; where the upper [white] class used cars and some public transport; and black commuters had to endure lengthy and costly journeys using available transport means.

Harrison *et al.* (2003) in Kgatjepe and Ogra (2016) states that commuters from the fringe of South African cities travel 20km on average compared to European and Asian countries commuters who travel 11km and 9km, respectively. The long commutes are due to poor urban form and transport routing, where public transport options cover a few residential areas in the city and have fewer stops (Kgatjepe and Ogra, 2016). These extended trips also have an energy implication as increased trip length results in higher energy consumption and emissions (**Section 2.2.3**). The Johannesburg Metrobus exemplifies poor routing with the use of traditional routes based on the radial system, which, do not service citizens adequately. Consequently, any energy efficiency measures (e.g., renewable fuel and hybrid propulsion technologies) implemented on the Metrobus system needs to be supported by efficient routing plans for the goal of sustainable mobility to be reached.

In the democratic era, the apartheid city planning, and infrastructure development have inadvertently led to increased transport constraints (Mthimkulu, 2017). One of the remedial measures utilised is the spatial development framework (SDF) which guides and prescribes how the city is to look in the future. Since the 2000s, Johannesburg's SDFs have focused on residential and economic development that is mobilised and supported by efficient public transport systems. However, the implementation of the SDFs failed around 2003 when there was an increase in upmarket property development in the northerly and westerly parts of the city (e.g., Midrand and Roodepoort), with no expansion and improvement of public transport (Todes, 2012). The impact of these developments is a rise in population (in-migration)

coupled with increased use of private vehicles due to the lack of alternative public transportation, culminating in high levels of traffic congestion, especially during peak travel time (Venter and Schnackenberg, 2001).

As a way forward, Curtis (2008) recommends planning for accessibility, where personal mobility is underrated, and land use policy and transport planning are integrated. Litman (2020) concurs, indicating that the focus should shift from mobility to accessibility, where transport systems are not car-centric but rather show consideration for mass transportation and NMT. Curtis (2008) further suggests the decentralisation of economic activities to an urban form of multiple nodes of activities. The solutions offered indicate that good urban form, i.e., compact and decentralised, can assist in increasing accessibility to transport and other amenities and result in a shift from cars to public transport, thereby reducing carbon emissions.

2.4.2 Economic Sustainability in Transport

Studies show that transport affordability is considered one of the pressing issues of sustainable transport in the global South (Venter, 2011). The economic aspects of transport are in two ways, commuter fares and infrastructure operating cost. Affordable transport thinking has shifted from focusing on transport provision cost reduction to affordable transport for the poor (Venter, 2011). The shift is significant as commuters in the low-income groups spend more than the recommended 20% of their income on transportation (Litman, 2020). In South Africa, cost was the second prioritised factor when selecting travel mode among 25,3% of Gauteng households, preceded only by travel time, and moving up from 2003 statistics where it was ranked third (StatsSA, 2014).

The percentage of salary spent on transport has increased over the years, per (Khosa 1995; Harrison *et al.,* 2003 in Kgatjepe and Ogra, 2016), as transport costs are regressive in poorer households. In some instances, transport costs exceed the income, thus indicating use of credit facilities and non-monetary income sources (Venter, 2011). In Johannesburg, commuters spend approximately R500 for subsidised bus travel and between R500 to R1 000 for taxis, where there are no funds, some commuters occasionally miss work (Chakwizira *et al.*, 2014). In areas where affordable public transport options are available, they are often inaccessible and their use results in increased travel time and cost as commuters have to walk or take a connecting mode (Kgatjepe and Ogra, 2016).

Transportation costs are influenced by rigid factors such as inflation and fuel prices (Kgatjepe and Ogra, 2016) and influenceable factors like spatial form, travel modes, and transport inefficiencies (Chakwizira *et al.*, 2014). Residents of dense and compact cities spend less on transport due to the short distance travelled. The variety of available modes also contributes to transport costs as the "…greater the quantity and quality of affordable modes (walking, cycling and public transit), the more affordable the transport system" (Litman, 2020:17).

Though commuters exhibit dissatisfaction with transport cost, transport inaccessibility and inefficiency force them to pay the fares (Heyns and Luke, 2016; Kgatjepe and Ogra, 2016). This scenario may signify a willingness to prioritise efficiency to price; adversely, it may also signify captivity by one mode. Commuter fare preference require evaluation and consideration in transport plans as they may assist in selecting the appropriate transport development for an area and facilitate a shift towards increased public transport use. The consideration may also assist in reaching one of National Transport Masterplan's objective of providing "a transport system that charges the traveller a fair reflection of the costs of making a journey or transporting a product, financially, socially and environmentally." (Heyns and Luke, 2016:5).

Sustainable transport requires fair and stable funding and investments in infrastructure, facilitated by dedicated governance bodies. However, obtaining financing from treasury can be challenging due to

budget constraints (Kennedy *et al.*, 2005). Prescriptive policy is one remedial measure to assist in subsidising public transport and making it affordable for the commuter (Venter, 2011). Public transport subsidisation in South Africa is a burning topic, especially in the taxi industry, which transports most commuters and is the only mode not subsidised. The lack of subsidisation contributes to bad driver behaviour brought on by the need to get more commuters and higher profit (Mthimkulu, 2017). This topic was also brought to the fore by the Covid-19 pandemic as the taxi industry failed to comply with the 70% loading capacity restrictions, citing financial constraints. Luke (2020) states that the taxi industry's defiance of Covid-19 transport regulations demonstrated its thin profit margins, informality and lawlessness nature.

To aid in making transport more affordable, Stanley and Lucas (2014) suggest alternative funding mechanisms. Mechanisms include polluter-pay and user-pay, where environmental costs are levied on travel choices and the funds are used to sustain public transport; and value-capture, where the beneficiary (mostly property developers) pay for transport projects around developments. This method has been used in Johannesburg with the refurbishment and expansion of Allandale Road by property developer Century Property Development (The Citizen, 2020).

Overall, transport affordability is generally a primary concern for commuters, especially those with limited income. Inefficiencies, such as connecting modes and inaccessibility, further exacerbate travel costs, coupled with poor urban form. The linkage of travel costs to urban form shows that transport sustainability is dependent on interconnected issues.

2.4.3 Environmental Sustainability in Transport

Transportation is good for countries' economic growth, enabling the movement of goods, services, and people. However, the sector carries significant environmental negative externalities, including traffic congestion and greenhouse gas emissions (Schipper, 2002). The World Bank, Cities on the Move 2002 report indicates that 500 000 people in developing countries die each year due to vehicle emissions; the same death toll is estimated for traffic accidents (Kennedy *et al.*, 2005). This impact is borne by all citizens, including cyclist and pedestrians (Schipper, 2002). In South Africa, the transportation sector is responsible for 70% of total energy use and 38% of total emissions in a typical metropolitan city (SACN, 2016).

The biggest concern with the increase of carbon emission is its contribution to climate change and its resultant impacts, which include altered rainfall patterns, extreme weather conditions, increased susceptibility to vector or/and waterborne diseases and loss of natural habitats or green spaces (Kiker, undated; Ziervogel *et al.*, 2014; Waters, 2016; Maure *et al.,* 2018). These impacts generally stem from the continuing over-reliance on cars. Therefore, a way to move towards sustainable mobility is to reduce transport-related emissions and provide car travel alternatives with low emissions.

One of the ways used by multiple countries including Brazil and India, to mitigate against these impacts and discourage car use is taxation favouring cleaner or renewable fuels and improved vehicle technology. Examples include fuel levy, vehicle taxation, and carbon tax (Schipper, 2002). South Africa has implemented such taxes in the form of fuel and carbon tax (DoT, 2019). Road transportation is exempt from direct carbon tax, though fuels (petrol and diesel) are taxed as part of the fuel levy (DoT, 2019). This hard approach is a good first step, however its implementation and success relies heavily on political will, as such alternative measures are required to propel transport stakeholders i.e., vehicle manufacturers, fuel companies and car users, towards improvement in technological advances and behavioural changes that can act as catalysts to sustainable transport implementation.

According to Bohler-Baedeker and Huging (2012) energy efficiency presents a great opportunity to make urban transport sustainable and provide the benefits of reduced greenhouse gas emissions and

traffic congestion, less noise pollution and fuel consumption, whilst also improving air quality. These benefits can be derived in three ways; firstly, through system efficiency, followed by travel efficiency and lastly, vehicle efficiency. System efficiency refers to transport design in relation to urban form, essentially optimising city form to reduce traffic congestion and travel time. As such, dense city form is ideal as it facilitates easy access to transport, reduces travel time and distance, whilst encouraging the use of NMT. System efficiency also includes the provision of road infrastructure such as synchronised traffic lights, which assists in traffic flow management, reducing congestion and vehicle energy consumption (Hemmerle *et al*, 2016). Travel efficiency comprises utilising energy-efficient modes, including public transport and NMT to curb energy consumed per trip (Bohler-Baedeker and Huging, 2012). The third measure, vehicle efficiency, involves technological advancements including use of alternative energy sources and propulsion technologies. The former includes using biodiesel, CNG, and hybrid fuels, on public transport to get the maximum carbon savings (Stanley and Lucas, 2014). Alternative propulsion technologies include using electric buses or vehicles with a combination of the internal combustion engine and an electric engine and hydrogen-powered fuel cell electric vehicles (Kühne, 2010).

The first measure of altering urban form is a long term goal requiring setting and implementing policies and regulation before bearing any sustainability fruits. The third measure, vehicle efficiency, has high operating and maintenance costs which is challenging for cities in developing countries with fiscal constraints (D'Agosto *et al.*, 2013); furthermore, the measure requires massive infrastructure development and stable power production, which is currently unsatisfactory in South Africa. Additionally, to derive maximum benefits from vehicle efficiency technological advancements, the measure must be preceded by travel efficiency. Resultantly, the second measure, travel efficiency provides a better chance of moving towards sustainable transport, as its focal point is environmental protection and is commuter-centred, tying in with Knoflacher (2009) idea that cities should be people-centric. It further requires less financial investment and time as it can be implemented on existing public transport infrastructure. This measure is explored in detail in the following subsection.

2.4.3.1 Travel Efficiency

Travel efficiency's primary objective is the use of public transport, with the incorporation of NMT, thus it is important to focus on ways to make public transport more attractive to commuters. The appeal of public transport, from a commuter's perspective, lies in its efficiency or competitiveness to cars reliability, time efficiency and flexibility (Hensher, 2006; Mugion *et al*, 2018). Consequently, an improvement in public transport's efficiency is likely to increase its patronage, it is thus important to understand and detail efficiency in public transport.

The Johannesburg spatial development framework plans to have a polycentric city by 2040, characterized by "…a strong urban core linked by efficient public transport…" (Department of Development Planning (DoDP), 2017:12). The plan emphasizes efficiently connecting areas where people live, play and work, thus placing efficient public transport as one of the main priorities of Johannesburg 2040 vision. The SDF refers to efficiency but does not explicitly characterize it; instead, it refers to the 25-Year Integrated Transport Master Plan (ITMP25). The plan's main objective is to "…regulate, plan and develop an efficient and well-integrated transport system that enhances mobility and is safe, secure and environmentally sustainable." (GPDRT, 2012:12). The ITMP25 define efficient public transport as encompassing various aspects, such as universal access, convenience, affordability, reliability (regarding scheduled services), environmental sustainability, use of NMT and integration of all transport options (GPDRT, 2012).

Abreha (2007) provides more detail into public transport efficiency, by stating that the concept can be placed into five categories, i.e., network operation, system, labour, utilization, and financial. Of the five

categories, network operation and system categories are most valued as they are the core functioning of an efficient public transport network. Network operation measures system connectivity connection between the different areas and clients served and interfacing between different modes, it thus deals with the design of the public transport system before its implementation. System efficiency on the other hand entails the appraisal of the availability, quality, and productivity of the service, focusing on how the designed transport system operates in real life and how users interact with it (*ibid*, 2007). Consequently, a way to improve system efficiency is to focus on service quality, which includes network speed, waiting time, travelling time, reliability, accessibility, and affordability (*ibid*, 2007). For the purpose of this study, the focus is on better understanding system efficiency, as it is commuter centred.

Hensher (2006) concurs with Abreha (2007) and GPDRT, (2012) in stating that in addition to reliability and affordability, public transport efficiency can be measured in service speed, frequent service and flexible routes. Mohan and Tiwari, (1999) further add that easy access to multiple modes that are safe and less polluting, coupled with good infrastructures provision, such as separate lanes and multiple stops, are important public transport efficiency parameters. Banister (2008) states that efficiency may also be achieved by reducing trip lengths through good urban form comprised of dense and mixed developments ; and also using alternatives to travel, such as working from home and internet shopping. Sampaio *et al.* (2008) supports the above authors in stating that efficient public transport is characterised by overall good system performance made up of high accessibility, speed, safety, reliability and cost effectiveness, all supported by efficient and newer vehicles using renewable or hybrid energy.

Table 2 lists public transport efficiency parameters across referenced literature. The common parameters which are also applicable to the context of the study are accessibility, travel time, reliability and use of NMT. These were utilised in the study to assess the efficiency of road public transport in Johannesburg. Each parameter is thus explained briefly below.

Accessibility is a measure of transport availability, proximity and ease of travel (**Section 2.4.1.1**). According to SACN (2016), South Africa targeted that by 2020 85% of all urban residents would be residing within 1km of a rapid public transport network, as easily accessible transport is more likely to be utilised. The achievement of this goal is to be determined. Travel time refers to the amount of time taken to complete a journey, this parameter is influenced by factors such as waiting periods, transfer time, vehicle speed and condition, number of stops along a route, road conditions, travel distance and urban form (**Section 2.4.1.2**). Reliability relates to the constant availability of a transport service, i.e., whether it has dependable schedules which are adhered to during peak and non-peak periods; this parameter is important as consistently available transport attracts commuters. The last parameter is use of NMT such as walking, cycling and cycle rickshaws. The incorporation of NMT into a public transport network fosters emission reduction and encourages the building of compact and walkable cities.

Table 2: Public transport efficiency parameters per literature

GPDRT (2012)	Hensher (2006)	Mugion *et al* (2018)	Mohan and Tiwari (1999)	Banister (2008)	Sampaio *et al* (2008)	Abreha (2007)
• Convenience • Universal access • Affordability • Reliability • NMT usage	• Service speed • Reliability • Affordability • Frequent service • Flexible routing • Operational flexibility	• Comfort • Cleanliness • Vehicle and stops condition • Available seats and space • Network coverage • Time efficiency	• Dedicated lanes • Use of NMT • Security • Non polluting	• Accessibility • Travel time • Modal shift • Reduced trip length • Vehicle engine design • Alternative fuels	• Accessibility • Travel time • Trustworthiness • Frequency • Maximum load • Vehicle characteristics • Adequate information	• Speed • Waiting time • Travelling time • Reliability • Accessibility • Affordability

Overall, literature indicates that energy efficiency is the main path towards sustainability in public transport and may be reached through system, travel and vehicle efficiency (Section **2.4.3**). Travel efficiency is the best option of these as it has a shorter implementation period and requires less financial investment in comparison to the other two methods. The measure further serves as a baseline for the implementation of system and vehicle efficiency and greatly increases their chances of success. Travel efficiency focuses on encouraging and prioritising mass transit and NMT usage, which must be efficient to retain current users and attract new ones. Consequently, an efficient public transport system provides the foundation for sustainable transport.

2.5 Conceptual Framework

The study's conceptual framework is graphically represented in **Figure 2,** and explains how sustainability in transport was explored. The framework shows how the three sustainability spheres, i.e., social, environmental and economic, and their aspects relate to one another. The diagram further illustrates prescribed measures in managing transport's adverse impacts and explores the interlinkages and dependencies of the three spheres. Sustainability indicators utilised in the study were extracted across the different sustainability spheres, as noted in detail in Chapter 2.

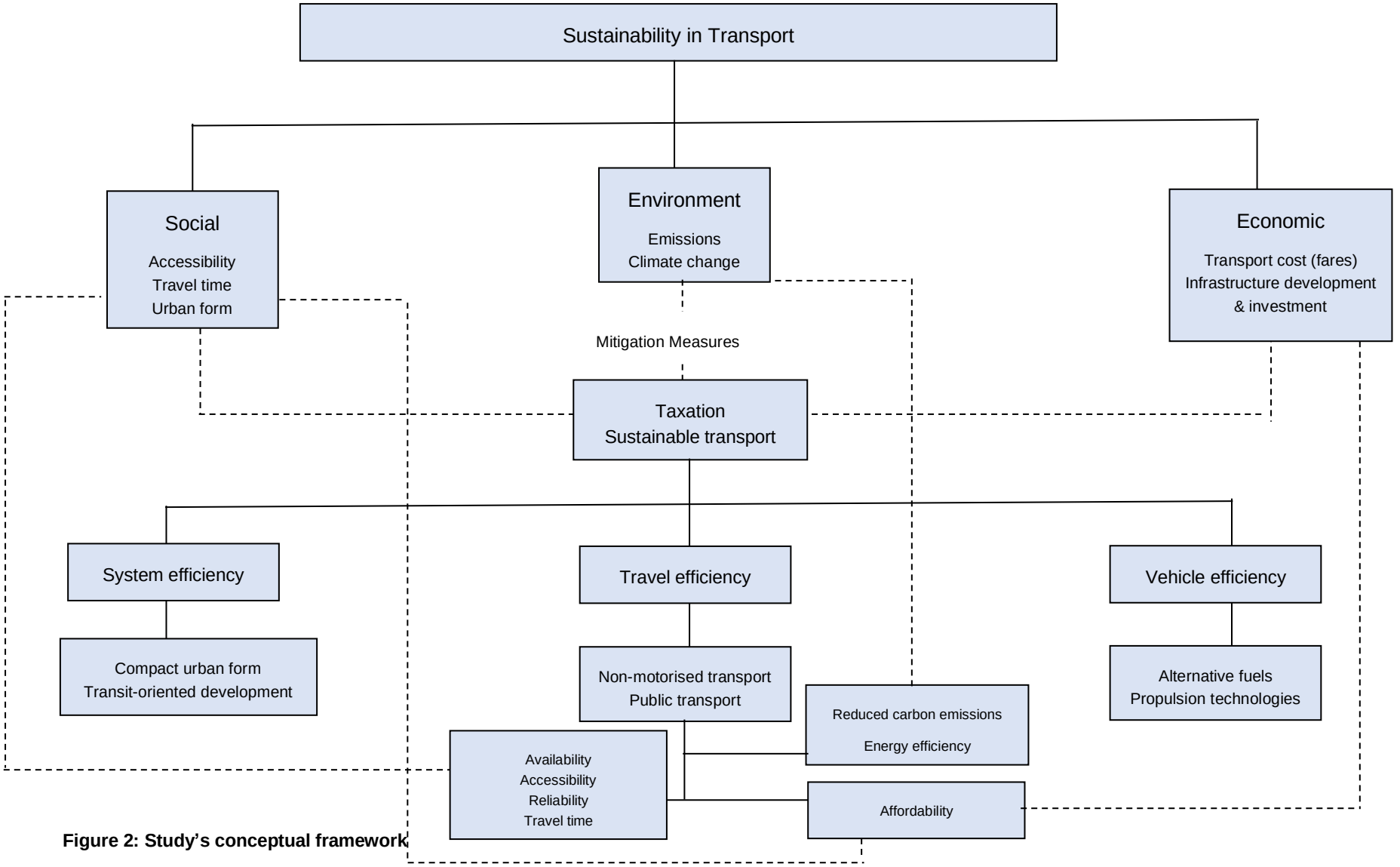


Figure 2: Study's conceptual framework

2.6 Study Area Overview

The research's study area is Johannesburg, located within the Gauteng Province, the smallest province in South Africa, nestled between Mpumalanga, Limpopo, Free State, and North West provinces (Figure 3). Johannesburg has a land area of 1 645km2 and is situated in the City of Johannesburg Metropolitan Municipality, one of the two biggest metropolitan municipalities within the province (Municipalities of South Africa, 2020). Johannesburg is the country's economic hub and, to an extent, the African continent (Todes, 2012), contributing approximately 16% to the national gross domestic product (City of Johannesburg, 2018). Johannesburg's status as the financial powerhouse is due to previous gold mining, which has given rise to multiple commercial and industrial businesses (Harrison and Zack, 2012).

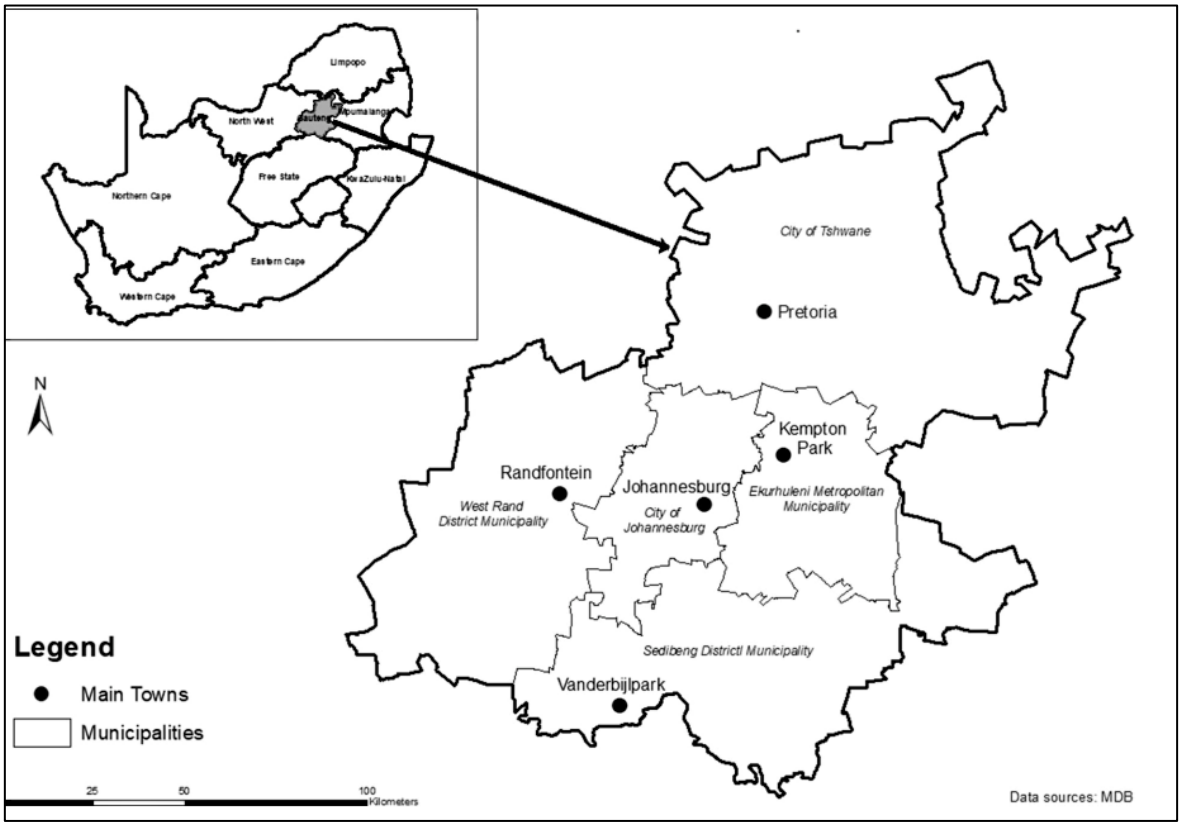


Figure 3: Gauteng Province map (Dlamini *et al*, 2020)

2.6.1 Johannesburg Road Public Transport

Johannesburg is home to multiple modes of road public transport options, inclusive of taxis, Metrobus and private buses, such as Putco and the bus rapid transit, Rea Vaya. The most popular of these options is the taxis, transporting 65% of commuters in the province, followed by buses at 15,9% (StatsSA, 2014). Transport is mainly available in the city centre; however, availability is reduced in the Northern and Southern parts of Johannesburg, including Midrand and Ivory Park (North), and Protea, Eldorado Park, Lenasia and Orange farm (South) (Mokgukulushi *et al*, 2018).

Though most commuters use taxis, they are still dissatisfied with crime at ranks, violence, and unsafe driving (Chakwizira *et al.*, 2011). The industry is riddled with criminality as observed by multiple issues of sexual harassment (including rape), robberies and pickpocketing (Mabaso, 2019). It also faces numerous cases of traffic regulations obstruction, which are a consequence of drivers needing to meet commuter or profit targets (Mtizi, 2017; Mthimkulu, 2017). Additionally, commuters note feeling

uncomfortable and unsafe in taxis (Vilakazi and Govender, 2014). The fighting and killings for routes is another factor that commuters are dissatisfied with.

In terms of energy use and emissions, the taxi industry has old, unlicensed and unroadworthy vehicles (Mtizi, 2017); exacerbating the release of pollutants as an ageing fleet is one of the leading causes of vehicle emissions due to lack of emission abatement technology (Liebenberg-Enslin *et al*., 2013). Taxis use petrol, the fuel responsible for 67% of emissions in a metropolitan city (SACN, 2016), with little consideration for alternative fuels which curb emissions. The government has previously introduced programmes like the Taxi Recapitalisation Programme (TRP) and hybrid fuels to assist in managing the industry's emission issues. The TRP aimed to replace old taxis with new diesel-fuelled ones (Du Plessis *et al*., 2003); whereas the latter programme involved moving taxis to hybrid fuels like a combination of petrol and CNG (SACN *et al.*, 2015), the uptake of this programme was however slow with only approximately 1000 taxis across three Gauteng metropolitan municipalities participating in the programme (SACN *et al*, 2015).

Buses (excluding Rea Vaya) in Johannesburg have a modal share of less than 20%, this mode is underutilised due to its inconvenience, unreliableness, and travel speed inefficiency (Sustainable Energy Africa (SEA), 2017). The Metrobus system only functions optimally during peak periods and has widely spaced bus stops requiring commuters to either walk or use a connecting mode (Mtizi, 2017), as there is no feeder system to main routes. This inaccessibility is mainly pronounced in areas located on the periphery of the city such as informal settlements (SEA, 2017). The Metrobus however also demonstrates some positive characteristics as commuters regard it as safe and comfortable, though safety and security concerns are still present at bus stops (Luke and Heyns, 2017). The mode also fairs well in energy efficiency as it uses Euro V buses and has converted some buses to Dual Diesel Fuel, running on a combination of diesel and CNG, to reduce vehicle emissions (Metrobus, 2016).

The bus rapid transit (BRT), Rea Vaya, was positively perceived due to its accessibility, service frequency, safety, and affordability (White 2009 in Mthimkulu, 2017). However, the system is built around existing economic routes, maintaining spatial inaccessibility and mobility challenges (Chakwizira *et al.*, 2011). Its accessibility is further challenged by bus stop's sparse location, requiring commuters to connect as many as three times, thus reducing the system's efficiency (Kgatjepe and Ogra, 2016). Similar to the Metrobus the Rea Vaya is energy efficient , as it operates CNG and low-sulphur diesel buses, which comply with Euro V vehicle emission standards (SACN, 2015a in SACN 2016). However, there is no continual improvement on these sustainable measures; as BRT expansion plans (Phase 1C) reflect sustainability in price and commuter accessibility but lack emission reduction technological advances (Seftel and Peterson, 2014).

The above indicate that road public transport options in Johannesburg show both sustainable and unsustainable measures. This phenomenon forces commuters to choose between sacrificing cost, energy efficiency and safety for accessibility, in the case of taxis, and enduring buses inaccessibility, unreliableness and long commutes for the sake of cost, comfort, safety and reduced emissions. Additionally, though there are multiple transport options, they are fragmented, with no integration across various modes and trip interchange segments (Department of Transport, 2016). They use different routes, operational times and fares, which does not provide the user with an effective transport system (Mostert, 2011 in Thomas, 2016). Overall, the public transport system is struggling to adequately meet citizen's mobility needs

2.6.2 Roads

The Johannesburg ring road is one of Africa's famous roads, consisting of the N1, N3 and N12. The N1 connects Johannesburg to Pretoria and links Gauteng to Cape Town in the Western Cape. It has one of the busiest and most traffic-filled interchanges in the country, the Gillooly's Interchange (CoJ, 2018).

The N3 connects the northern suburbs such as Midrand and Fourways to those in the east. The highway is also used to access OR Tambo international airport and connect Durban, KwaZulu Natal to Johannesburg. The last part of the ring road, N12, links Johannesburg to the North West (Potchefstroom), Northern Cape (Kimberley) and Free State.

The city has Metropolitan and Regional roads, including the M1, M2, R21, R24 and R59. The metropolitan roads were built to direct traffic into the city and are often gridlocked with traffic (CoJ, 2018). The seven regions within the city, as per Figure 4, are connected with more minor roads. Each suburb has a main road that serves as an entry and exit point.

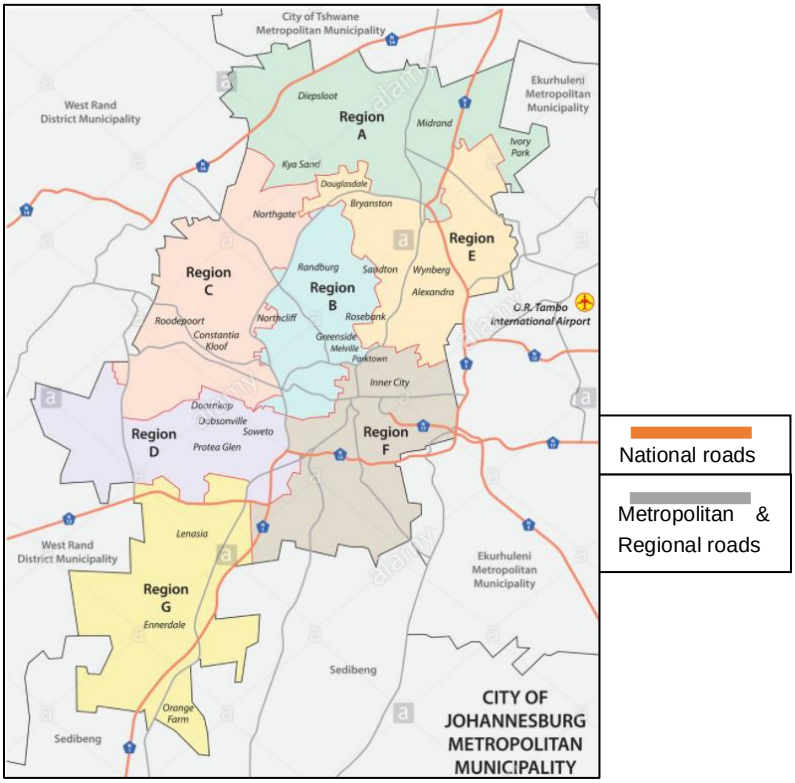


Figure 4: City of Johannesburg regions with roads (Source: alamy.com)

2.6.3 Demographics

Johannesburg has approximately 4,4 million people, comprising mainly of active economic participants aged between 15 and 64. Alike the country, Johannesburg's population mainly includes people of black ethnic origin (StatsSA, 2011). The city's population increased by 3,18% per annum between 2001 and 2011; this growth is due to migration from neighbouring provinces and countries as people search for suitable employment and academic opportunities (*ibid,* 2011). Johannesburg houses numerous higher education facilities, including the University of Witwatersrand and University of Johannesburg.

South Africa has one of the most considerable inequalities worldwide. In Gauteng, specifically, Gini coefficient[2] was reported at 0.61 in 2015 (StatsSA, 2019). Poverty, unemployment, and associated impacts are thus the city's top socio-economic issues. The inequality can be observed in Johannesburg suburbs and townships, with well-off areas located close to poor areas that struggle with mere essential services. Examples of this include Alexandra and Sandton; Diepsloot and Fourways; Tembisa and

[2] The Gini coefficient is a measure used to determine inequality in a country. It ranges between 0 and 1, where 0 indicates perfect equality (all individuals have the same income), and 1 indicates perfect inequality (where one person has all the income and the rest have none) (StatsSA, 2019:32)

Midrand; Zandspruit and Roodepoort; Cosmo city and Randburg. Other areas within Johannesburg include Soweto, Parkhurst and Northriding.

The inequality is geographical and represented in transport provision as the majority of well-off Johannesburg residents use private vehicles. In contrast, the poor rely solely on the available public transport options.

2.6.4 Study area justification

The study focused on Johannesburg due to the city's population diversity, road transport types and living conditions. The area was also familiar and easily accessible to the researcher, which assisted in better understanding the realities of the research topic. Johannesburg offers multiple road transport types, available in different quantities in various suburbs and townships. Its demographic and economic status also ensures that travel is constantly occurring; thus, producing a higher probability of obtaining usable data. The varying socio-economical stances within the city and the proximity of suburbs to townships provides an opportunity to investigate road transport similarities, differences, and general characteristics based on area and understand the impact that socio-economic issues have on transport sustainability. Overall, Johannesburg has characteristics that make for an interesting research area.

2.7 Conclusion

Transport planning should incorporate the urban environment, residents and area future use; however, in practice, auto-oriented planning design persists, with investment in the development and expansion of road infrastructure. Literature highlights the need to shift towards sustainable transport planning design, such as TOD, which entails the development and growth of cities around public transport nodes, with amenities located close together.

The concept of sustainability encompasses the use of natural resources in a manner safeguarding future generations. The literature distinguishes between three sustainability spheres, .i.e., social, economic and environmental. In the context of transport, social sustainability refers to transport accessibility and its impact on citizens socio-economic status. It further touches on urban form and whether city design enables the use of public transport and NMT. Economic sustainability relates to the affordability of transport, especially for impoverished communities, and sustainable funding for transport infrastructure provision and maintenance; and environmental sustainability focuses on reducing vehicle emissions through alternative energy sources and public transport usage.

Mitigation measures employed to deal with negative transport externalities are taxes and shifting to sustainable transport. The latter may be achieved through system, travel and vehicle efficiency. Based on the literature (Table 2), public transport efficiency may be improved by focusing on bettering parameters such as accessibility, travel time, reliability, affordability, and use of NMT.

Chapter 3

3 Research Methodology

3.1 Introduction

The research methods chapter aims to detail the research design, elaborating on the research type conducted, data gathering methods and analyses. Research is a process of gaining knowledge by gathering data and analysing it to give a new perspective on a topic (Walliman, 2011). Additionally, it is "a careful search, an investigation or a systematic investigation towards increasing the sum of knowledge" (Fellows and Liu, 2015:3). Research aims to allow people to better understand themselves and their surroundings (Walliman, 2011) by yielding new knowledge supporting existing theories or providing alternative views (Fellows and Liu, 2015). Important to note from the definitions is that research must be planned and systematic to ensure the production of good quality work.

Research theory categories include epistemological or metaphysical. The former is the "…the theory of knowledge…" and entails understanding how knowledge is gained and what is acceptable in a field of study (Walliman, 2011:16). It sees observations, interactions and senses as the primary source of knowledge (Punch and Oancea, 2014). Conversely, metaphysical theory is concerned with what it is to be, who we are, what is knowledge, what are things…" (Walliman, 2011:16). The epistemological theory is used in the study as data was gathered by interacting with participants regarding their experiences using road public transport in Johannesburg.

3.1.1 Research Approaches

There are two approaches that are generally utilised to gain knowledge through research, i.e., empirical and theoretical. The latter approach entails investigating beliefs and assumptions about a particular topic (Edgar and Manz, 2017). It has a philosophical approach and explains abstract concepts and scenarios that cannot be observed by the senses (Williams, 2007; Punch and Oancea, 2014), allowing for knowledge gaining through deductive reasoning (Walliman, 2011). In contrast, empirical research is sensory knowledge and is widely accepted as the truth due to its evidence (Williams, 2007). It has a philosophical approach that all knowledge stems from experience (Fellows and Liu, 2015) and focuses on observing daily life phenomenon's, collecting data, creating or responding to questions, and strengthening and assessing new concepts (Punch and Oancea, 2014).

The study was conducted from an empirical research lens and entailed understanding people's lived experiences through observation and analysis. This approach offered the best process to gain tangible and real life data on the research topic, i.e., to explore commuters daily travel patterns, behaviours and overall experiences using road public transport. The research approach was structured using questionnaires and interviews as data collection methods which are detailed in **Section 3.2**.

3.1.2 Research Types

Conducting research deals with defining research type and process. There are three primary methods to conduct research: quantitative, qualitative, and mixed methods. Quantitative research deals with mathematical and statistical data, it thus measures concepts as numbers (Walliman, 2011). On the contrary, qualitative research is exploratory in that it examines study topics to gain a better understanding of them or conceptualise new theories (Fellows and Liu, 2015). The goal is to "…gain an in-depth, holistic perspective of groups of people, environments, programs, or any phenomenon …" (Farber 2006:2).The research type focuses on examining participants ideas, opinions, customs, beliefs and lived experiences to develop concepts and linkages between them (Walliman, 2011).

A qualitative research type was selected for the study, as it provided the best chance for the research question and sub-questions to be answered from participants' viewpoints. The research was conducted from the researcher's perspective, in that research in the field of road transport sustainability often focuses on transport system design, neglecting the user's interaction with the system. Consequently, researching sustainability from a commuter perspective allowed the researcher to immerse herself fully and naturally in the participants' lives, which Stainback & Stainback, (1988) in Farber, (2006) notes as an important characteristic of qualitative research.

3.1.3 Research Design

Research design is a plan detailing the data collection process and analysis, and provides a rational linkage between the question, approach, data collection, and analysis (Walliman, 2011; Ritchie and Lewis, 2003). In selecting research design, it is important to be realistic, malleable and to consider external factors, including time, money and study area context. Common research designs include ethnographic, comparative, experimental, surveys, action and evaluation (Walliman, 2011; Mouton,2001). The latter design was selected for the study, and its applicability discussion is below.

Evaluation research main characteristic is the planned and purposeful approach in assessing the quality of a product, service, or intervention such as healthcare aid, education and transport (Wallace and Van Fleet, 2001 in Powell, 2006). In the context of the study, sustainable public transport provision by the government was viewed as the intervention to be implemented. Considering the identification of public transport as one of the primary issues facing a democratic South Africa (Thomas, 2016), citizens ranking transport as their third biggest concern (Heyns and Luke, 2016) and transport regarded as a top priority in implementing Johannesburg SDF 2040 plans (DoDP, 2017).

In conducting evaluation research, local context and the attainment of intervention set outcome are valuable aspects to consider; to enable a clear determination of the success of the intervention and to determine what action is most effective in specific situations or communities (Curtice, 1993, in Payne and Payne, 2004). In the context of the study, the aspects of reaching set objectives and local context consideration were scrutinised. The former considered the set goals and milestone for improved public transport provision as prescribed in the ITMP25. Local issues were examined by focusing the research on commuters' transport experiences within the study area, enabling an understanding of public transport efficiency parameters from a commuter's perspective.

3.2 Data Collection

The data collection section details the process and instruments used to answer research questions and reach the study's objectives. Data collection's primary objective is to provide data to answer a research question and contribute knowledge on the study subject. The process generally requires selecting variables to measure and a description of how that measurement is to proceed. On the latter, trustworthiness, reliability, and appropriateness are vital in maintaining the research's integrity (Clarke and Dawson, 1999).

Data collection instruments differ based on the research type and research topic. For the purpose of the study, questionnaire and interviews were utilised. The selected data instruments were flexible and provided sufficient interaction with participants enabling the collection of rich and informative data (Clarke and Dawson, 1999). Additionally, the data instruments were practical, which was a critical aspect as research was conducted during the Covid-19 pandemic, where physical contact and communication with study participants was highly discouraged. As a result, the data collection process was altered slightly to ensure adherence to health and safety protocols (see **Section 3.2.2** and **3.2.3**).

Research projects differentiate between primary and secondary data collection methods. The former refers to oral or written data gathered specifically for a particular research objective using acceptable

methodologies; whereas the latter is previously collected information used to answer or support in responding to a research question such as academic reports, government publications and library archives (Hox and Boeije, 2005; Walliman, 2011).

The study utilised both primary and secondary data sources. In Chapter 1, secondary data served to determine the need for the research and provide background information, whereas, in the current chapter, it assisted in directing the research methodology. In the Literature Review, secondary data gave a broader understanding of the research topic and associated aspects; and answered study sub-questions as illustrated in Table 3. Additionally, data from the literature helped identify key sustainability indicators that built the questionnaire and interview questions. Primary data were obtained through questionnaires and interviews, as discussed in upcoming sub-sections, to get insights into the knowledge, experiences and feelings of commuters and transport providers and subsequently answer the research question. Table 3 summarises the use of primary and secondary data in the research project.

Table 3: Research Method Summary

Research Question (RQ) & Sub-questions (RsQ)	Research Question Type	Data Source	Utilised Collection Method	Data Collection Method Achieved Objectives
To what extent is the current road public transport system in Johannesburg sustainable?	Research question	Primary sources Secondary sources	Questionnaires Interviews Academic literature Government publications	Used to meet the study's objective of determining the level of sustainability in road public transport
What does the concept of sustainability in transport mean?	Research sub question	Secondary sources	Academic literature Reports Government publications	Utilised to understand the characteristics of sustainable mobility, which formed the basis for conducting the research
What are the common or valuable indicators of sustainable mobility?	Research sub question	Primary sources Secondary sources	Academic literature Questionnaires	Drew out essential requirements that needed to be met for a public transport network to be deemed sustainable Determined indicators that required prioritisation for the goal of sustainable mobility to be achieved
What is the stance of Johannesburg commuters on identified sustainability indictors?	Research sub question	Primary sources	Questionnaires	Determined valued aspects to the commuter within the broader identified sustainability themes
How are sustainability indicators considered in road public transport planning?	Research sub question	Primary sources Secondary sources	Interviews Academic literature	Provided an understanding of the level of consideration of key sustainability indicators in transport infrastructure, transport planning and operation

3.2.1 Sampling

The sampling process of the research entailed selecting persons from different communities within the study area to get their opinion on the research topic. The research used non-probability sampling ,where a productive sample was created by designing a set criteria for participants based on literature, study area, researcher's knowledge and participant experience (Marshall, 1996; Oppong, 2013; Ritchie *et al.*, 2003). This sampling method allowed for the deep exploration of the research topic and was more applicable for small research projects, like the current study, where the main purpose was to understand complex societal scenarios with no intention of generalising the outcomes (Ritchie *et al.*, 2003; Walliman, 2011; Marshall, 1996).

In selecting study participants, aspects including age, gender, socio-economic status, location, experience and knowledge about research topic were considered. The sample frame as is presented in Table 4 was influenced by the StatsSA (2012) report, which indicates that South Africa has a young population, dominated by persons aged between 15 and 64, who are likely to travel daily. The target group for the study was thus persons aged 25 to 64, excluding minors. The study included both women and men to mirror real-life dynamics and discover different travel perspectives per gender. However, the main criterion was that participants had to be travelling within Johannesburg at least four times a week using road public transport. The interview sample frame was primarily based on experience and knowledge of the transport industry and thus included persons working in the public transport sector, either providing or facilitating service provision. Details about the number of participants or sample size follows below.

Table 4: Study sample frame

Demographic	**Sample Frame (Questionnaire)**	**Sample Frame (Interviews)**
Age	25 to 65 years	25 to 65 years
Gender	Male and female	Male and Female
Location	Johannesburg	Johannesburg
Socio-economic status	Employee, business owner or student	Working professional and/or executive
Experience or knowledge	Commuting within Johannesburg at least four times a week Using or having used road public transport in the past 3 years	Working within transport sector

3.2.1.1 Sample Size

Determining sample size is an integral part of conducting research. Sample sizes differ depending on the type of research conducted (Walliman, 2011). Quantitative research tends to have reasonably large samples for statistical analysis. In contrast, qualitative research sample sizes are acceptably small (Walliman, 2011). The study's purpose and objective generally determine sample size and what is deemed valuable and credible (Cleary *et al.*, 2014); thus, the appropriate sample size answers the research question (Marshall, 1996) and ensures the production of rich, dense and focused data (Cleary *et al.*, 2014).

In the current research, defining and refining the research topic was vital to steer the study correctly; and understand evaluated aspects. This was important as in the sampling process a well-defined research topic and questions for appropriately experienced and well-selected participants increases the likelihood of informative responses (Cleary *et al.*, 2014).

The study initially planned to have a sample size of 30 participants for questionnaires; that number rose to 51 participants during the data collection process. Interviews were conducted with four (4) experts; all were taxi operators. This sample size was deemed acceptable and appropriate for the research project as a point of saturation was reached and participants reiterated one another (Cleary *et al.*, 2014. Furthermore, the data obtained was descriptive and showed feelings, behaviours, attitudes and perceptions of participants, as recommended by Walliman, (2011). Overall, the sample size was sufficient for the study and allowed for detailed data gathering that assisted in meeting study aims and objectives as well as answering the research questions.

3.2.2 Questionnaires

The current study utilised questionnaire as the primary data collection tool due to their flexibility and convenience for both the researcher and the respondent (Jones and Rattray, 2007). Additionally, were quick to complete, relatively easy to analyse and easily manageable for the size of the project. They further allowed for reduced bias and ethical consideration as they were completed in the absence of the researcher (Walliman, 2011).

Questionnaires however have the disadvantage of assuming respondents' literacy, language and comprehension; and also restricting the amount of detailed information a respondent may provide (Jones and Rattray, 2007; Walliman, 2011). These factors were managed in the current study by ascertaining that questions were clear and lacked ambiguity, and that the design incorporated open-ended question where participants could detail their responses.

3.2.2.1 Questionnaire Types

There are two types of questions that may be contained in a questionnaire, namely, closed and open format questions (Walliman, 2011). The former refers to questions where a respondent is given choices to select from. In contrast, open format questions allow participants leeway in their response, enabling diverse data to be collected and reduced prejudice. The questionnaire used in the study was designed with a combination of both formats for the purpose of adding richness and depth to the data set (Krosnick and Presser, 2010).

A majority of questions were made to be closed, however where applicable respondents were asked to comment or specify details (Appendix A). Closed format question allowed for easier data processing due to the tailored response options; and open format questions enabled respondents to express views and opinions about the topic or any other related matters not covered in the questionnaire thus strengthening the quality of data collected.

3.2.2.2 Questionnaire Design

Questionnaire design is essential to ensure the satisfaction of study aims and objectives. In designing questionnaires, a link between the research question and study variables is paramount (Bowling, 2005). In the context of the study, the researcher first defined sustainability in road public transport as indicated in Chapter 2. The process resulted in public transport efficiency parameters, including accessibility, travel time, use of NMT and reliability, which were subsequently utilised as the building block for the questionnaire (Table 2). Accessibility questions probed into the ease of getting transport, connecting modes used and time taken to access the selected mode. Travel time enquired about trip duration and factors influencing it. The third parameter, NMT, asked about commuter's use of NMT. Reliability dealt with the service schedule, punctuality and delays. The last open format questions enquired about vehicle characteristics by asking commuters about selected mode's physical condition and overall view of public transport in Johannesburg.

The questionnaire considered four variables: independent, dependent, controlled, and uncontrolled (Parfitt, 2005). Independent variables entailed understanding the influence of age, gender and area zoning patterns on transport mode selection. Dependent variables are the "…main variables for which explanations are being offered in terms of the way in which the independent variables influence them." (*ibid*, 2005:80). They were identified as factors influencing road public transport to be sustainable or unsustainable, i.e., accessibility, travel time, reliability and use of NMT. Controlled variables were identified as the sampling frame (Table 4), which was maintained throughout the research project and allowed the exploration of the relationship between the dependent and independent variables. Lastly, socio-economic issues such as cost, safety and security, which might influence mode selection were identified as uncontrolled variables. The complete questionnaire is accessible in Appendix A.

3.2.2.3 Questionnaire Layout

The arrangement of questions and the language utilised in the questionnaire largely determines the number of responses a study is likely to receive (Parfitt, 2005; Krosnick and Presser, 2010). The current study's questionnaire was concise, clear and utilised simple language, to eliminate ambiguity and ensure that all respondents understand questions the same way. Furthermore, the questions were accommodative, with follow-up questions, thus enable the gathering of reliable and detailed data.

In the terms of the questions structure, the questionnaire began with an introductory statement informing participants about the study and the researcher (Appendix C). This was followed by simple questions about participants' personal details, which required minimal effort to complete. The preliminary questions were followed by categorised and detailed questions, enabling focus, ease of reference and understanding by the participant. The concluding questions were open format and "…provided some tension release for the respondent..." (Parfitt, 2005:88), by allowing participants to freely express their views, opinions, and experiences about road public transport usage. Lastly, the questionnaire was time conscious and took approximately 10 to 15 minutes to complete and consisted of questions with no more than 30 words.

Overall, the collection of data through questionnaires was an intricate process that necessitated proper planning and implementation. The main aspects were tying the questions to the aims and objective of the study, deciding on the questions' format, and designing the questionnaire with consideration for the different variables included. The final aspect was critical and included presenting questions in a layout and language that was easy to understand for participants.

3.2.3 Interviews

Interviews were the second data collection method used in the study and were conducted with transport industry experts to establish the extent of sustainability consideration in transport design and planning. Interview as a data collection method were selected due to their agility and pragmatism, which allowed the researcher to interact directly with respondents and probe into issues not originally considered in the research. Consequently, the collected data was "…rich, detailed and multi-layered…". (Burgess, 1984 in Valentine, 2005:111).

3.2.3.1 Interview Types

The study utilised semi-structured interviews, where the process was structured with a guide on question but flexible enough to probe into related topics as they arise (Walliman, 2011; Carter and Henderson, 2005). This interview type ensured that respondents stayed within the research topic's boundary while also being given opportunities to comment on related matters, thus producing detailed data about the research topic and associated matters.

3.2.3.2 Interview Design

An essential aspect of interviews is knowledge about the topic of discussion; questions asked must be substantiated by researched data (Valentine, 2005). The study's literature review and questionnaire responses provided this knowledge in the study and further ensured that all research aspects were covered.

Generally, interviews consist of three phases. The first entails research topic introduction and interviewee's basic information, and job experience, for experts (Carter and Henderson, 2005). The second phase involves asking open and explorative questions, whereas the last phase entails rounding open-ended questions, which may refer to matters in the interview that require clarity and discussion.

In the study, the first part of the interview consisted of introducing the researcher and the research, as illustrated by the information sheet in Appendix C. The introduction was followed by simple questions about the interviewee's position and work experience within the transport sector. Succeeding questions enquired about specifics; the accessibility category asked about the route planning process and involvement in determining taxi ranks and stops locations. Travel time category enquired about waiting times for taxis, transfers and connections. Questions also pertained to the incorporation of NMT in the taxi industry. The fourth category probed into the use of 'full capacity' method and its impacts on commuters' travel time. Lastly, the researcher enquired about the roadworthiness and maintenance of vehicles. Appendix B illustrates the complete interview questions.

3.2.3.3 Interview Process Characteristics

In planning interviews, the researcher needs to reflect on their positionality, i.e., how their personality and experiences shape the interview (Valentine, 2005) and consider gender, power, and cultural issues. Positionality was important as the researcher, a black female, was to interview personnel from the taxi-industry, which is male-dominated and has a history of violence and tolerating or inflicting women abuse (**Section 2.6**). Though the researcher understood the industry dynamics and reputation, the focus was on the research topic and associated matters. The researcher was thus objective and neutral as far as reasonably possible and made no judgement or assumptions. The aspect of objectivity and neutrality balanced with public transport problems was essential to remember as the researcher enquired from interviewees about the poor service experienced by commuters and lack of or inadequate infrastructure. Generally, during the interviews, the researcher was respectful, polite yet thorough in the questioning, allowing the interviewees to relax and provide the required information.

Griffee, (2005) and Valentine, (2005) states that location is a critical factor in conducting interviews, the selected place should be comfortable, quiet and not restrictive for both interviewer and interviewee. The satisfaction of these aspects enables a collection of in-depth data. Taxi operators' interviews were conducted at a taxi stop. Although this area was not quite, it was comfortable and provided rich data as interviewees gave practical examples of their experiences and roped in colleagues who also contributed to the interview process. Interviews adhered to COVID-19 regulations, with the researcher and interviewee wearing masks and social distancing.

Overall, the use of interviews was valuable as it enriched the data and offered a different view on existing public transport issues. Soft skills such as positionality, objectivity and selection of appropriate location and interview methods were highlighted. These aspects combined ensured that the data collection process was fruitful.

3.3 Data Analysis

The process of analysing qualitative research data is somewhat of an art, to an extent, as, unlike quantitative data, analysis is not systematic (Walliman, 2011), but rather involves carefully assembling data and presenting it understandably while maintaining the depth of the participant's experience, feelings and knowledge (Noble and Smith, 2018).The process is not linear but convoluted, as researchers often have to go back to the field to obtain more data or solidify already gathered data (Walliman, 2011). Qualitative data analysis may be through deductive or inductive methods. The current study utilised the latter, which involved drawing patterns from the raw data, with limited predetermined categories or layout (Burnard *et al., 2008).* This analysis method yielded detailed and comprehensive study findings and is explained in detail below.

3.3.1 Approaches in Data Analysis

Research data may be analysed through multiple approaches, including ethnographic, thematic, narrative and interpretative (Noble and Smith, 2018). Approaches are selected based on type of studies, content and objectives (Donovan and Sanders, 2005) The current study utilised the thematic data analysis approach, which entailed the identification of themes and relationship from raw data in multiple steps and further required efficient sample selection consisting of outliers and atypical participants (Donovan and Sanders, 2005; Burnard *et al.*, 2008). The thematic data analysis approach was selected due its thoroughness, as data was continuously and constantly compared, thereby increasing the quality of the findings. The sampling frame as indicated in **Table 4** further provided the required variety for the approach. The application of this approach is illustrated in **Table 5** below.

Table 5: Application of thematic data analysis approach in the study

Key steps in Thematic Approach	Application of Thematic Approach
Collect data in batches, where the previous batch informs the next and comparison takes place	• The first set of primary data was collected using questionnaires and focused on commuters who were actively using public transport • The second batch of primary data was collected through questionnaires, however this included motorists who had previously used public transport • The third batch of primary data was collected through interviews, where questions asked were based on preliminary findings and data from the first and second batch of data collection
Use the information gathered and compared to produce themes and identify relationships and interdependencies	• Collected data was coded and themed as presented in Chapter 4
Analyse the said relationships and themes to draw conclusions about the study subject	• Study results were analysed under the selected sustainability indicators • Linkages and dependence factors were identified between indicators

3.3.2 Data Analysis Steps

In analysing research data, Walliman (2011) observes three steps: data reduction, data display and verification, and conclusions. However, processing data into a readable format, such as the typing of handwritten note or transcription of audio recording, precedes the first step (Crang, 2005). In the study, questionnaire responses were transferred to a Microsoft Excel spreadsheet, and interview notes typed into Microsoft OneNote, for easier data management and analysis as data collection continued.

The first step in data analysis, data reduction or coding, involved changing bulky and unstructured raw data into text that could be easily and quickly read, understood, and analysed. This was done by sorting the data into unique codes, labels and tags (Walliman, 2011). Coding for the questionnaire data was predetermined and analysis involved identifying popular categories, as illustrated in Appendix. Interview data coding used an open system as interview notes were read through to identify common categories, which were the building blocks for themes and patterns identification.

The second step in data analysis is displaying data in easily read formats such as tables, graphs and diagrams (Walliman, 2011). A combination of tables and graphs were utilised in the current study to summarise, explain and compare data, as observed in Chapter 4.

The third step, data verification, needed to be transparent and show how conclusions were reached as qualitative research data analysis has the burden of not being seen as robust as the same data can be interpreted differently by different researchers (Noble and Smith, 2014; Burnard *et al.*, 2008). Burnard *et al.* (2008) recommends the inclusion of findings not aligned with the main conclusions and constant comparison to identify new themes. Another validating method is triangulation, where at least two sources are compared; this is achieved by conducting multiple interviews with the same person or using similar questions in various interviews (Griffee, 2005).

Data verification was addressed in the study by providing a detailed data analysis process, indicating how codes, themes and relationships were identified. Results outside the main topic were also presented as observed in Section 4.2.6 and 4.2.7; furthermore 47triangulation was utilised, as different taxi operators were asked similar questions during their interviews. Lastly the use of the thematic data analysis approach enabled the constant data comparison and new theme identification.

Overall, the data analysis section, indicates that data analysis in qualitative research requires deciding between deductive and inductive methods (**Section 3.3**), which feeds onto the selection of the analysis approach (**Section 3.3.1**). The study used an inductive method and followed the thematic data analysis approach. The selected method and approach were appropriate for the study considering its aims and objectives and selected data collection methods. The use of different coding systems was required to process the collected data. Overall, the data analysis process produced detailed results that helped in reaching solid conclusions.

3.4 Ethical Consideration

Ethics is an essential topic in research that is continually evolving and developing parallel to society; it involves moral behaviour to assist researchers in discerning right from wrong (Wiles, 2013). Ethics is vital throughout the study, especially in qualitative research, as it mainly involves human participants and exploration of their lives (Orb *et al.*, 2001). Researchers need to consider ethics from the initial stages of the study, looking at how they enter communities or access participants and the effect that their chosen approach has on the potential participants (Orb *et al.*, 2001) and in the final stages focusing on how the results of the study are presented.

Ethics include informed consent and competence, where participants are informed on what the study entails and are competent to decide whether to participate or not. In the current study this was done through the participant information sheet, which informed participants of the study's purpose and intention, explaining the lack of monetary compensation and voluntary participation (Appendix C).

Literature (Orb *et al.*, 2001; Benatar, 2002; Wiles, 2013) state that ethical consideration further includes duty of care, confidentiality, and anonymity, relating to protecting participants' personal and identifiable information and using pseudonyms to ascertain anonymity. For this purpose, the study utilised pseudo names and consent forms (Appendix D). Lastly, Walliman (2011) notes that ethics also deals with the researcher's honesty while conducting the research. The current study acknowledged other

researchers' work through references and was transparent with the data collection and analysis process.

Overall, the study was conducted per the ethical guidelines of the University of Witwatersrand and posed no harm to people, animals or the environment.

3.5 Limitations

The study results may not be generalised across all modes of public transport as the focus was on road public transport sustainability, specifically taxis, Metrobus, Rea Vaya BRT and privately owned buses. The study further focused solely on weekday commuting data as most travel in Gauteng is done over five days a week (StatsSA, 2014); thus, research results cannot be generalised to weekend travel.

The research was conducted during the 2020 COVID-19 pandemic lockdown in the Gauteng Province; as such, there were constraints in obtaining participants; however, alternative measures of communication and distribution of questionnaires were employed.

3.6 Conclusion

The research project is categorised under evaluation research, which aims to assess a product or program's quality or implementation level against a set standard. The study used qualitative research methods, where primary data was collected from commuters using questionnaires and from transport service providers through interviews. Secondary data sources included academic literature and government reports and policies. An inductive approach data analysis approach was selected, entailing the perusal, coding and pattern identification of data. The following chapter presents and analyses study results.

Chapter 4

4 Research Findings

4.1 Introduction

The findings chapter details the outcome of the data collection process, including any extracted relationships and linkages. The research findings are presented and discussed together for report congruency, straightforward relation of themes and showcasing of how the research question was answered.

The study aimed to establish the extent of sustainability in Johannesburg's road public transport. The aim was achieved by defining sustainability in transport, as indicated in Chapter 2. The outcome was that efficiency is paramount in sustainable transport; hence evaluating public transport efficiency parameters was vital. Parameters evaluated in the study include accessibility, travel time, reliability and NMT usage. The results of the evaluation are presented in the subsections below.

4.1.1 Fieldwork

The data collection portion of research entails the researcher going out to the field with knowledge from literature and questions that require responses. The study's data collection process commenced with the finalisation of the questionnaire sheets. Due to the Covid-19 health risk and restrictions, it was challenging to find participants, distribute questionnaires and conduct interviews. The researcher thus enlisted family and friends' assistance to find participants and further used colleagues, neighbours and acquaintances as study participants. In the physical distribution process of the questionnaire health and safety protocols inclusive of hand sanitization, mask wearing, and social distancing were maintained. Additionally, Microsoft Forms links sent through WhatsApp were utilised. Interviews were conducted during the lower levels of Covid-19 restrictions, in an open space, with both the researcher and interviewees wearing masks and social distancing. These challenges in the data collection process necessitated the research methodology to be more flexible and use electronic communication as it was a safe and quick way of collecting data.

The first few participants thought the research pertained to Covid-19 risk in transportation; this was because fieldwork was conducted during a period where Covid-19 transport regulations were topical and in the news. This confusion prompted the researcher to explain the contents of the information sheet verbally. Resultantly the impacts of Covid-19 on public transport were highlighted by study participants in their responses to open-ended questions as noted in **Section 4.2.6.4**.

The language barrier was the second challenge experienced; although the questionnaires used simple English, some participants did not fully understand some questions. In such cases, if there was an opportunity, the researcher explained the questions in the respondent's home language or in Setswana. In instances where there was no chance to do this, respondents left some questions unanswered. Overall, the questionnaire response rate was satisfactory, with participants responding to relevant questions and completing the open-ended ones. The data received was dense and made for an interesting analysis.

The second part of data collection involved interviewing taxi operators; this was a daunting task considering taxi operators' reputation (See Chapter 2); however, after identifying interviewees, the process unfolded with no challenges. It was interesting to understand the business behind the industry, something that the researcher was yet to find in literature. Their willingness to engage in the topic and respond to questions stood out and showed that the industry is often presented in one dimension, as only being violent and lawless, with little recognition of the essential service it provides.

Overall, fieldwork was both challenging and rewarding. It accentuated the road public transport challenges and gave hope that transport planning stakeholders would work together towards sustainable transport. As such, questionnaire and interview results are presented and discussed together below.

4.2 Findings

The data collection process utilised two questionnaires. The first was for commuters, i.e., people who currently use road public transport. The second focused on persons who had previously used public transport but now relied on private transport for travel. The use of two questionnaires was to align with the thematic data analysis approach, which required data collection in batches and the inclusion of outliers in the research sample. The other reasons were to establish the regression or progression in public transport challenges and gauge whether efficiency would attract motorists.

The findings section commences with a discussion of sample characteristics, followed by discussions on accessibility, use of NMT, travel time, reliability and general perception about public transport in the study area. The chapter concludes with a presentation of significant findings.

4.2.1 Respondents Characteristics and Travel Patterns

The study initially envisaged 30 participants; this number increased to 52 participants, comprising 38 commuters and 14 motorists. The increase enabled the production of rich and dense data, as more participants meant increased variety in the views provided.

Per the sampling frame, the study included both female and males aged between 25 and 65. Commuter study results indicate that most (69%) respondents were male, with females making up 21% of the participants. The wide gender split is due to participants' working environment, as a majority work in manufacturing (plastic packaging and rail signalling) and security industries, which are mainly male-dominated. The presence of females in the sample provided a different perspective of public transport travel, as is discussed in the following sections.

4.2.1.1 Age Range

Study results indicated that all age groups were present, though respondents between the ages of 25 and 35 dominated (52%), followed by those aged 36 to 45 (31%). There were limited participants below 25 and above 56 years.

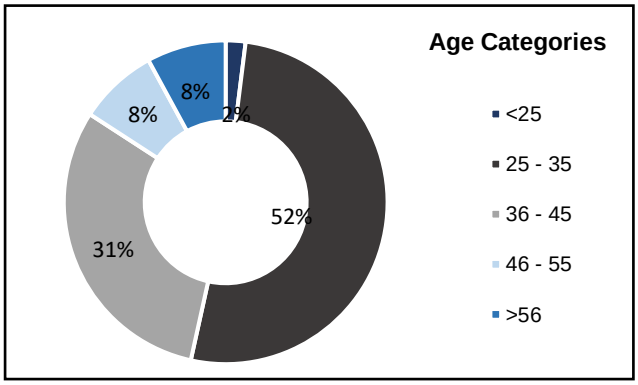


Figure 5: Study participant's age categories

Age ranges align with the country's population dynamics, where people between 20 and 34 dominate the age structure(StastsSA, 2011). The limited number of younger participants (below 25 years) is because the study participants were sourced from workplaces, and as the youth (15 - 24) unemployment rate was at 59% in the first quarter of 2020, the data aligned with the country's socio-economic status. Respondents over the age of 56 were also few, mirroring the population structure, which shows fewer people in that age group. The absence of this age group in the sample is likely because most are retired or nearing retirement, which results in little or no commuting. (**Figure 5**).

4.2.1.2 Travelling Areas

The study included participants who travelled within the city of Johannesburg, even if their destination was in another municipality. This was to assess ease of travel across the city and into other areas or municipalities. Participants travel patterns varied; trips were from multiple regions of the city and province, including Alberton (2%), Olievenhoutbosch (4%) ,Ivory Park (8%), Midrand (6%), Soweto (6%) and Tembisa (12%), there was no clear dominating area (**Table 6** and **Figure 4**). Travel destinations were however dominated by two areas, as 35% of participants travelled to Northriding and 31% to Samrand.

Participants also travelled within the same suburbs and townships. An example is Midrand, where participants trips were from Noordwyk to Halfway house (approximately 7km), Randjespark to Noordwyk (approximately 5km) and Sagewood to Randjespark (approximately 6km). The second example is travel within Randburg, with trips from Kyasands and Cosmo city to Northriding (approximately 5km). Data from these trips provided similitude between local travel (within the residential area) and regional travel (between towns).

The study findings indicate that public transport travel is dynamic and not controlled by municipal borders, as exemplified by participants travelling through Johannesburg to other municipalities. An example is a 20km trip across three metropolitan municipalities, beginning in Tembisa (City of Ekurhuleni) through Randjiespark and Midrand (CoJ) and completing in Samrand (City of Tshwane). However, taxis are the only mode traversing through multiple municipalities, as the Rea Vaya and Metrobuses are restricted to CoJ.

The above data show that while investment and development in municipal transit are essential, there is a need to govern public transport centrally. Kennedy *et al.* (2002) support this point in stating that sustainable transport requires establishing urban transport management bodies for large cities. In the context of the Gauteng province, this statement leads to an enquiry on whether the solo establishment of Rea Vaya[3]', 'A Re Yeng[4]' and 'Harambee[5]' BRT systems were in line with sustainable transport principles, considering the existing linkages between municipalities.

Table 6: Study participant residential areas

City of Johannesburg Region	Residential Areas
Region A	Kya sands, Diepsloot, Midrand, Olifantsfontein, Fourways and Ivory park
Region B	Randburg and Greenstone
Region C	Northriding, Lanseria, Cosmo city, Roodepoort ,Northcliff, Bram Fischerville
Region D	Soweto, Zola, Protea Glen and, Dobsonville

4.2.1.3 Travel Hours

Travel hours refer to the time of day commuters use public transport; this aspect affects the overall time spent on the road and availability of selected mode. Study results indicated that most (66%) participants

[3] Rea Vaya refers to the City of Johannesburg BRT system

[4] A re yeng refers to the City of Tshwane BRT system

[5] Harambee refers to the City of Ekurhuleni BRT system

began their morning trips before 06:00, followed by between 06:00 and 07:00 (26%), only a few (8%) between 07:00 and 09:00 and none travelled after 09:000 **(Figure 6)**. Afternoon travel mostly (45%) occurred after 18:00, followed by between 16:00 and 17:00 (39%). Only two commuters reported travelling back before 16:00 (**Figure 7**).

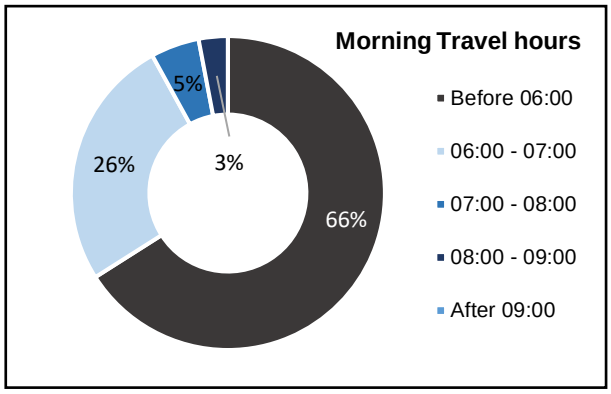


Figure 6: Morning Travel Hours

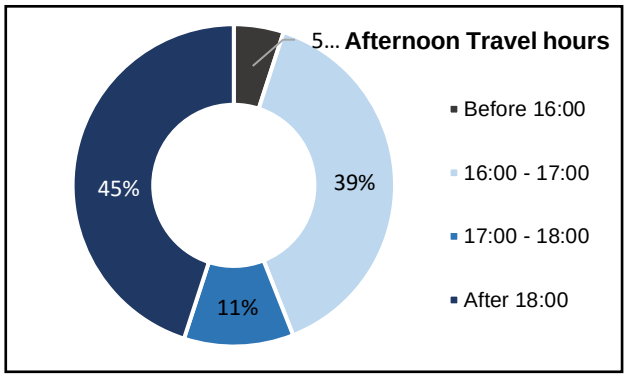


Figure 7: Commuter travel hours – Afternoon

It is evident that most (66%) study participants began their trips before peak time (before 06:00); however, they reported experiencing traffic congestion along the way due to multiple connections and long-distance travels. Afternoon travel had reduced traffic congestion but had the challenge of reduced transport availability, as there are fewer public transport options available after peak time.

Work hours dictate travel hours. Most study participants began work at 07:00; hence most trips were made before 06:00 to be on time for work . Participants began their commutes earlier to cater for potential delays along their routes caused by long waiting periods, unavailability of transport, traffic congestion and long travel distance. These aspects are explored in detail in the subsections below.

Taxi operators substantiated the above travel times by indicating that they were busiest between 05:30 and 10:00 and between 16:30 and 18:30. Interestingly, operators were aware of commuters' schedules, in that early mornings (05:30 – 06:30) were dominated by the factory and industry workers, mid-mornings (07:00 – 08:30) by office employees and late mornings (>09:00) by retail sector commuters. This knowledge enables the taxi industry to provide a better service to commuters by ensuring availability during these periods.

Reduced transport availability after 18:00, as noted by commuters, aligns with taxi operators' schedules in that after 18:30, services begin to slow down. The availability aspect discussion follows in the subsections below.

4.2.1.4 Travel Frequency

Travel frequency in the study refers to the number of times a week commuters used public transport. The results showed that 47% of commuters used public transport daily and 34% used it three to four times a week (**Figure 8**). Only one participant used public transport once a week. The varying public transport usage was influenced by shift work, as some participants had off-days during the week. Another reason is that some (10%) commuters used a combination of lift clubs, private cars and public transport for their travels (**Figure 9**). All motorist in the study sample indicated that they had previously used public transport and could thus offer information on their experience. Overall, the travel frequency of participants met the set sampling criterion set in **Table 4**.

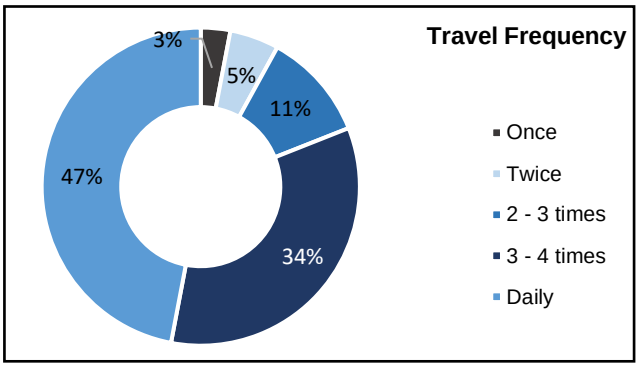


Figure 8: Study participant public transport usage frequency

4.2.2 Accessibility

Accessibility, as detailed in Chapter 2.3, encompasses the availability of a service, the ease of access to the service and the proximity of the service to residential and employment areas (Venter *et al.*, 2019; Vilakazi and Govender, 2014; Mokgukulushi *et al.*, 2018). The questionnaires were designed to explore Johannesburg commuters' and motorists' experiences regarding these accessibility characteristics as detailed in the subsection below.

4.2.2.1 Availability

In assessing availability, the aim was to establish the most used and preferred road public transport options and the reasons behind them. The study inquired about the available modes in participants' residential areas and into their preferred mode; to establish whether diversity exists in the type of transport available and whether commuters had a choice when selecting transport. The latter is vital as availability also includes access to multiple transport options (Vasconcellos, 2001 in Kgatjepe and Ogra, 2016).

Results indicated that taxis were the most available road public transport, present in all participants' residential areas. Private buses were the second most available mode, followed by Rea Vaya and other (**Figure 9**). The "other" category included lift clubs, Gau-bus, estate or private bus and the train. Taxis domination aligns with StatsSA, (2014) statistics which indicate that 65% of Gauteng Province commuters use taxis. Metrobus availability was low, with only Randburg and Northcliff participants indicating availability (**Figure 9**).

The Johannesburg Metrobus schedule was inspected to corroborate the results. The schedule revealed that buses were available in other residential areas, such as Midrand. However, the issue was that buses were infrequent and travelled at odd times, i.e., too early. Additionally, routes mostly travelled to the inner city of Johannesburg and not to neighbouring suburbs. This misalignment in commuter

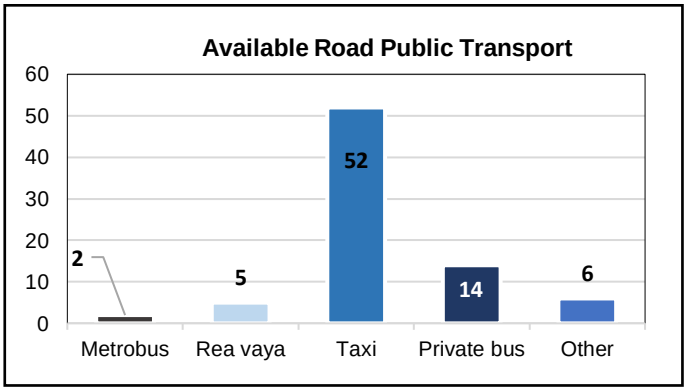


Figure 9: Available road public transport

needs highlights that the Metrobus has archaic route plans that increase commuter travel time (Kgatjepe and Ogra, 2016).

Further analysis revealed that the Metrobus was available in affluent and older suburbs and not in the townships. This scenario stems from South Africa's public transport history, where taxis are popular in townships as they developed due to the need for alternative transport for township dwellers (**Section 2.6.1).** The Metrobus has tried to improve its service by adding more routes and some cross-town routes (CoJ, 2018); however, its service is still insufficiently available across most parts of the city.

Commuter responses to an enquiry into their preferred mode indicated that most (73%) preferred taxis, followed by private buses (13%) and other modes (11%). Only 4% of the sample reported using the Metrobus and Rea Vaya (**Figure 10**). In certain areas, commuters chose to use taxis even with other modes available; whereas some commuters used taxis because they were the only form of public transport available. The latter phenomenon was observed in Tembisa, Ivory Park and Diepsloot. This situation results in 'captive users', where commuters have limited transport options and are more likely to accept bad service as there are no alternatives. One participant noted that over-reliance on taxis is especially catastrophic for commuters during taxi strikes, as they are left destitute with no means of getting to work.

Commuters selected transport based on three main characteristics. Firstly accessibility, followed by reliability and cost. Speed was the least prioritised characteristic, whereas reduced traffic congestion fared well but was not a good motivator as it was a regular occurrence across the modes (**Figure 11**). The prioritisation aligned with comments and concerns noted by participants, as below.

"Our public transport is bad, bad, availability is bad…" - QR_P40[6]

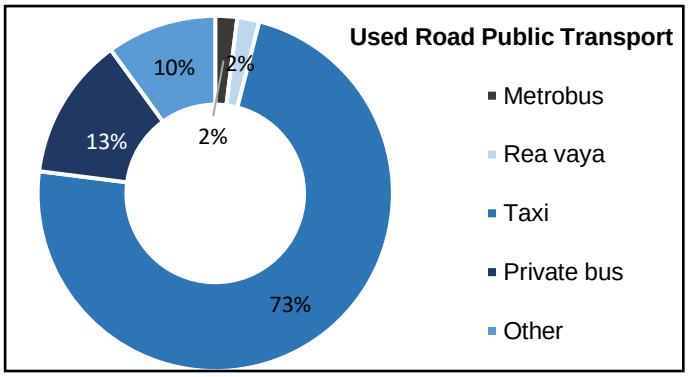


Figure 10: Used road public transport

"… while taxis seem viable for many, these are unreliable, unsafe…." - QR_P39

"…its unreliable, you have to be early if you want to be at work on time..." - QR_P37

According to taxi operators, taxis are popular due to their reliability and flexibility, and as they do not use schedule, they are constantly moving and always available to commuters. The latter characteristic also enables taxis to outperform buses, where commuters have to travel within operating hours, regardless of weather conditions or emergencies.

Their popularity was also because taxis can deliver commuters close to their residential area and serve as a connecting mode for buses and other taxis. This is achieved by allowing commuters to dictate, within limits, the routes taken, thus increasing the mode's flexibility and attractiveness to commuters. In contrast, buses have rigid routes that cannot be adjusted. In comparing commuter's top priority in transport, accessibility, and taxi service, it is evident why commuters prefer taxis to other available modes. They are available in most areas and are relatively flexible.

According to Kgatjepe and Ogra (2016), poor communities located on the city's periphery struggle with accessing public transport. This study shows that it is not only poor communities, but also residential areas located on the outskirts of a suburb. For example, commuters expressed dissatisfaction with

[6] QR_P# refers to Questionnaire Respondent Person number

public transport availability when travelling to high-income areas such as Randjespark equestrian estate in Midrand. Study participant QR_P40 noted that: *"My area does not really have public transport; I have to rely on taxis from Clayville or Pretoria…".*However, it is noted that the intersectionality of public transport availability and poverty is far more severe as in most instances, poor communities are far more limited in transport options than middle or high-income communities. This is due to socio-economic issues such as affordability and inadequate road infrastructure which characterises most poor and informal settlements.

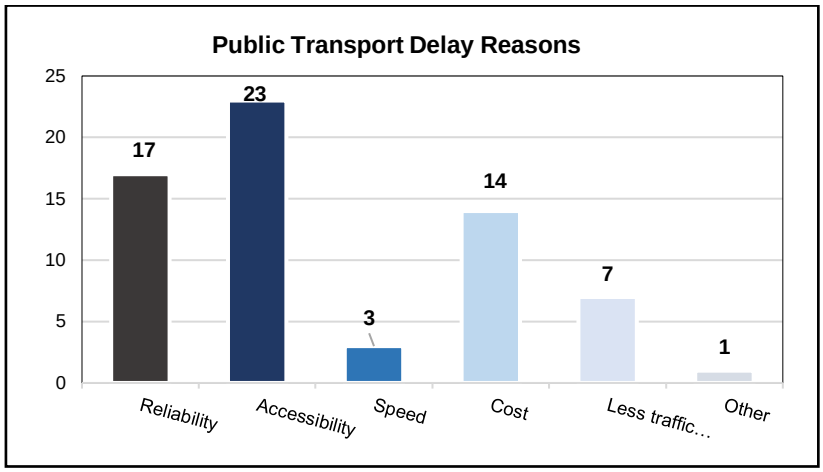


Figure 11: Commuter reasons for selected public transport modes

In adding to the dynamics of public transport availability in specific communities, taxi operators indicated that their availability in communities is demand-driven. Before deploying taxis on a route, a pilot project is done to determine route viability. The process is performed for new residential and business areas, i.e., informal settlements, residential and business complexes. Therefore, the more popular the route, the higher the taxi availability. The above highlights two primary factors about taxi operation; firstly, that at its core, the industry is a business, and its primary focus is profitability. Furthermore, it has no legal mandate for public transport provision, unlike government-run public transport services. Secondly, it illustrates the industry's ability to adapt to change and shows how it maintains its dominance over other service providers.

The above shows that the formal public transport options provided by the government, i.e., Metrobus and Rea Vaya, are not well planned and managed, thus less accessible to commuters. In contrast, 'informal' public transport such as taxis are more accessible and can adapt to commuter demands, and as a result, have higher patronage. If this scenario continues, the government may need to provide the required infrastructure, such as roads and traffic lights, and work with the taxi industry to ensure that the mandate of public transport provision is met. In this collaboration, the government also needs to ensure commuters' safety by insisting on better vehicle maintenance within the taxi industry. A discussion on commuter health and safety follows in the upcoming subsections.

4.2.2.2 Ease of Travel

In assessing the ease of travel, explained as the easy at which a commuter is able to gain access to a road public transport mode, the research enquired about travel to work and to other areas within the city. The second aspect was asked to assess whether travel constraints or benefits were localised or extended regionally to other areas. Results showed that it was easy (32%) and moderately easy (32%) to travel to work (**Figure 12**). Only 22% of participants had difficulty accessing transport; respondents who had the latter experience resided in Ebony Park, Tembisa and Bramfisherville and travelled from work after 18:00. As mentioned earlier (**Section 4.2.1.3**), public transport options reduce after 18:00.

There was a slight difference concerning the ease of access to transport to other areas within the city. Most participants (42%) found it easy to access transport, and only one participant found it difficult (**Figure 13**).

The above indicates that travelling locally within residential areas is more manageable than travelling regionally. Furthermore, it suggests that service providers prioritise local travel and that urban form in some suburbs and townships enable ease of movement. In looking within the study area, the researcher observes that retail stores, schools, entertainment, and places of worship are in fair proximity to residential areas and public transport nodes in Tembisa, Midrand and Cosmo city. Consequently, commuters in these areas easily access public transport and travel between amenities is easier.

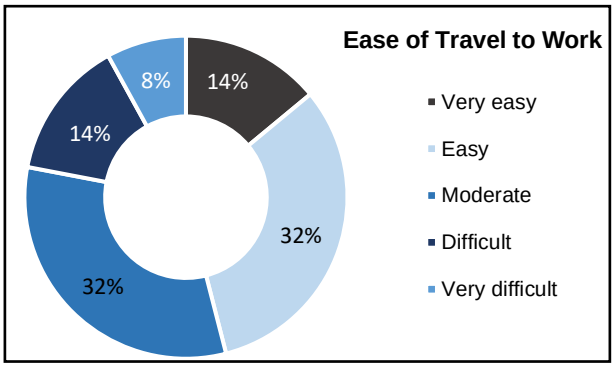


Figure 12: Commuter ease of travel to work

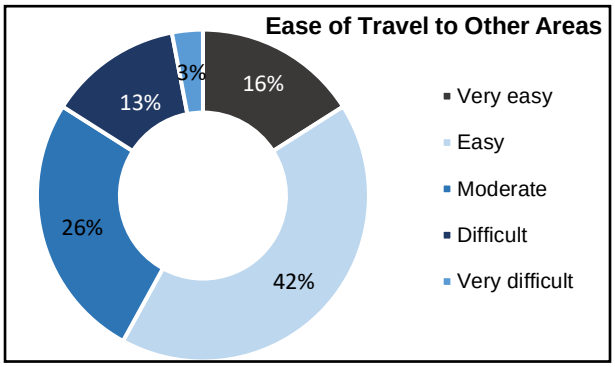


Figure 13: Commuter ease of travel to other areas

4.2.2.3 Proximity to Public Transport

In assessing proximity, the research investigated the time commuters took to reach public transport nodes. This aspect was analysed for commuters as time because most commuters walk to access their preferred mode and calculate proximity as lapsed time. Results showed that most commuters (44%) travelled less than 10 minutes, whereas 22% travelled between 21 and 30 minutes. Only 8% travelled more than 30 minutes to access transport (**Figure 14**). Most participants (71%) indicated that they walked to access their primary mode, whereas 24% used local taxis and 5% used 'other' modes such as lift clubs (**Figure 15).** There were no participants who cycled.

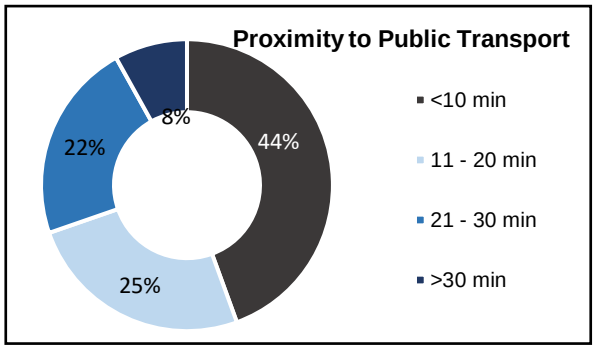


Figure 14: Commuter proximity to public transport

The prevalent commuter walking time, 10 minutes translates to a distance of one kilometre (1km), as Cronkleton, (2019) states that an average person takes ten minutes to walk said distance. Comparing these results to the target set by South Africa, that by the year 2020, 85% of urban residents should have been 1km from a public transport network (SACN, 2016). The goal is yet to be achieved for most commuters in the study area.

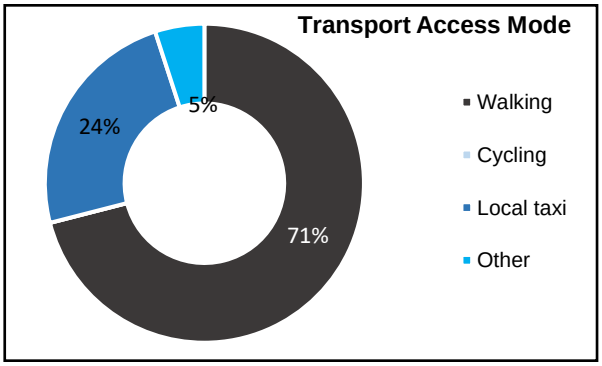


Figure 15: Transport access mode

4.2.3 Use of Non-Motorised Transport (NMT)

The use of NMT transport through walking, cycling or use of cycle rickshaws is one of the characteristics of TOD and a public transport network efficiency measure(Dittmar *et al.*, 2004). In public transport, NMT is often utilised as a connecting mode to travel short distances within the city; hence its more favourable for compact urban form (Bohler-Baedeker and Huging, 2012). It is environmentally friendly as its use does not produce carbon emissions and benefits the user's health as it is a form of exercise.

Results show that walking is integral in the public transport network, as most commuters walked to access transport (**Figure 15)**. A small percentage of commuters used local taxis and other modes to access transport; however, even in those instances, walking is still the primary access mode. The results further noted the absence of cycling; this is attributed to a lack of cycling infrastructures, including lanes and safe parking. The domination of motor vehicle travel, lack of cycling culture (Koglin and Rye, 2014), and social issues like the perception that cycling is a 'poor man's car are additional contributing factors.

On the latter, a taxi operator indicated that residents of developing informal settlements mainly use bicycles due to the absence of other modes of transport in their area and socio-economic issues about the affordability of taxi or bus fares. The idea of incorporating cycling in the taxi system was welcome by taxi operators, as some passengers already use a combination of cycling and taxis to commute. Rea Vaya already incorporated cycling in their design, with cycling lanes in specific areas (Rea Vaya, 2021). However, the infrastructure is underutilised and incorrectly utilised as taxi drivers use the lanes as taxi stops or an extra lane. The above indicates that there is an opportunity to incorporate cycling into the public transport system.

Overall, it is clear that walking is inherent in Johannesburg's public transport; however, commuters walk due to limited transportation options. Furthermore, cycling and associated infrastructure require investment and development. The incorporation of NMT in a public transport network should thus not focus solely on NMT use. However, it should also consider conditions surrounding NMT use, such as distance travelled, safety and availability of infrastructure.

4.2.4 Travel Time

Travel time refers to the overall time it takes a commuter to complete a journey. Factors influencing travel time include selected route, road conditions, traffic congestion and waiting and transfer time. The study assessed this parameter by enquiring about commuter trip duration, waiting periods and connecting modes.

4.2.4.1 Trip Duration

The purpose of assessing trip duration was to find out how long commuters travel to their destination and use benchmarks to determine whether the duration was acceptable. The question assessed travel for a single trip, i.e., one way. Responses showed that 32% of commuters travelled 15 to 30 minutes to reach their destination, whereas another 32% travelled 31 to 45 minutes. Only 18% of study participants spent more than an hour commuting **(Figure 16**). Long travel times (>45 minutes) were due to distance travelled, where some participants travelled approximately 70km one way, from Sebokeng to Northriding. This distance exceeds the 20km South African commuters travel daily (Kgatjepe and Ogra, 2016).

Other contributing factors were traffic congestion, long and winding routes, and poor road conditions. The long distance travelled coupled with traffic congestion has an energy efficiency implication as longer vehicle idle time and more kilometres travelled results in higher energy consumption and emissions.

Focusing on routes, taxi operators indicated that taxi routes mainly run along main roads, close to businesses, schools, malls and leisure facilities. Connecting modes and local taxis subsequently have stops along these main routes. Routes may be altered to accommodate passengers, .i.e., in cases where most passengers are going to one location, that destination takes priority. This routing system may reduce or increase travel time and energy consumption depending on the mix of passenger destinations. Overall, the system's flexibility to alter routes and adapt to specific situations such as traffic congestion and road or lane closures increases its demand and popularity.

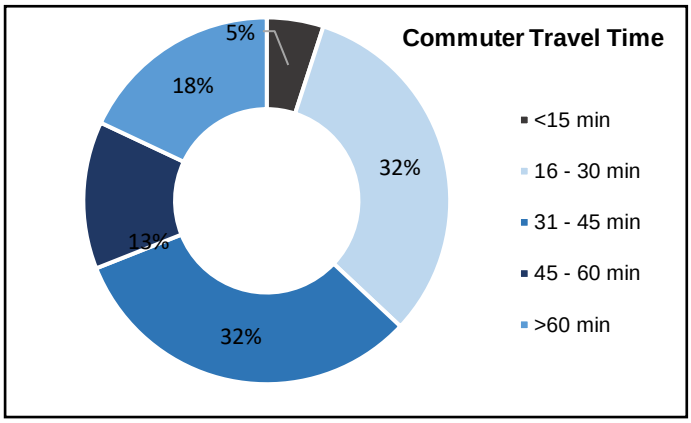


Figure 16: Commuter Travel Time

4.2.4.2 Waiting Time

The above section focuses solely on transport travelling time; however, another aspect of travel is time spent waiting for transport. The study results indicated that 50% of respondents wait between 11 and 20 minutes for their transport to move, followed by 34% of participants who wait less than 10 minutes. Only 3% (one commuter) waits for more than 30 minutes (**Figure 17**). Waiting periods are primarily applicable to taxis due to the 'full capacity' system used, as commuters lose time waiting for taxis to get full; this situation is more pronounced during non-peak travel time.

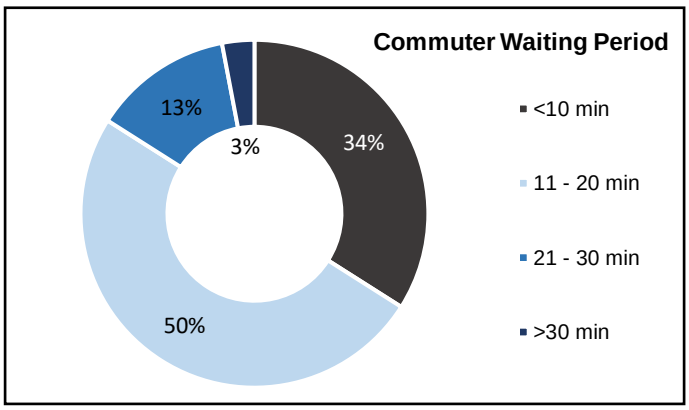


Figure 17: Commuter waiting period

Heavy traffic congestion during peak periods is another cause of increased waiting periods, as taxis are often unable to reach ranks in time to service commuters, resulting in long queues at taxi ranks. Buses (privates and Metrobus) are also often caught in traffic and unable to reach stops at the scheduled or specified time, thus increasing commuter waiting time.

The results further showed that some taxi delays are system operation and planning related. An example is time lost during a trip due to being stuck without petrol (QR_P19) or refuelling at a filling station. Specific to private buses, results show that commuters often experience delays due to distance travelled, selected routes and mechanical failure (**Figure 18**). The latter is illustrated by two bus commuters, who indicated that they have to factor in potential time loss due to mechanical failure in their travel time, as their bus breaks down frequently. Due to the limited number of study participants who use the Rea Vaya, the mode's waiting time was not adequately assessed. However, as Rea Vaya is a newer system with dedicated traffic lanes it may not be subject to the same issues as older bus systems.

Overall, results indicate that waiting periods in the current public transport network are increased by factors before and during the trip. This illustrates the inefficiencies in the planning and operation of the system and further increases energy/fuel spent per trip.

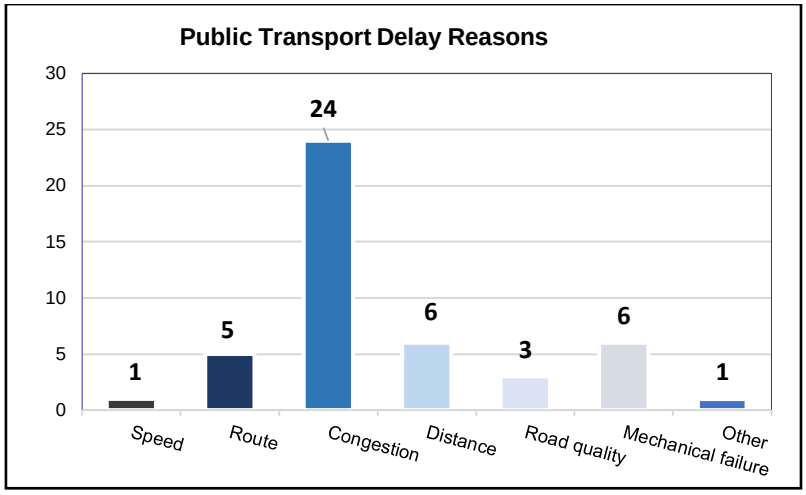


Figure 18: Public transport delays reasons per commuters

4.2.4.3 Transfer Time

Transfer time refers to the time taken to move from one transport to another in a single trip. Connecting modes are used for this purpose and include walking, bicycle, tuk-tuks and local taxis. The study planned to determine which connecting mode commuters utilised and their experience with it.

Connecting modes are popular in Johannesburg, with 45% of study participants indicating that they need to connect to reach their final destination (**Figure 19**). A majority (71%) of commuters connect once; however, in worst cases, commuters connect three times in one trip (**Figure 20**). Multiple connections are popular for participants that travel long distances across municipalities. An example is a participant travelling 45km from Germiston to Northriding and connecting three times. Most connections are made using local taxis or on foot; there is no mention of cycling (**Figure 21**). The dominance of local taxis as the connecting mode indicates the public transport system's heavy reliance on motorised transport which increases energy inefficiencies and adverse environmental impacts (see **Chapter 2**)

The study results show that commuters are dissatisfied with connecting and the setup of the connecting process. Some indicated that they 'lost' time' while accessing connector modes, which increases overall trip duration and others noted needing to supplement their motorised connector modes with walking to reach their destinations.

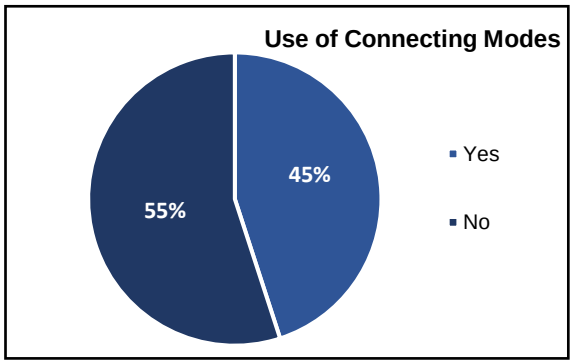


Figure 19: Public transport commuter use of connecting modes

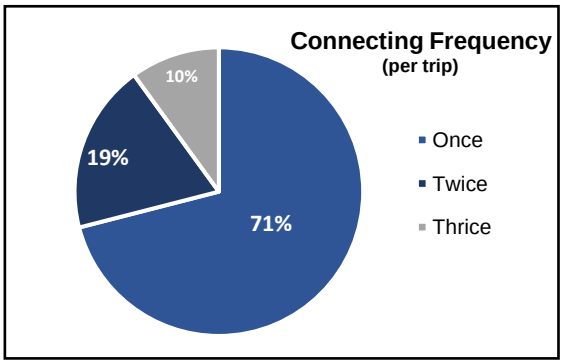


Figure 20: Number of times commuters connect

According to taxi operators, multiple connections result from the presence of various taxi associations in an area, which operates a feeding system, where local taxis feed into long-distance taxis and association feed into other associations. One interviewee indicated that *"…taxis drop you at a certain boundary [taxi association boundary], where others can pick you up until you reach your destination*" (I_P2). Taxi operators noted that eliminating connecting modes would be costly for commuters due to charges on extra distance travelled. Furthermore, the urban form and passenger travel patterns do not allow for many direct routes, as commuters come from one location but have various destinations, thus necessitating connecting modes. Connecting modes are not unique to taxis, as Rea Vaya uses a similar system where feeder busses provide commuters to main or trunk route buses. However, the Metrobus and private buses do not have official connecting modes but instead rely on commuters to walk or use local taxis to reach bus stops.

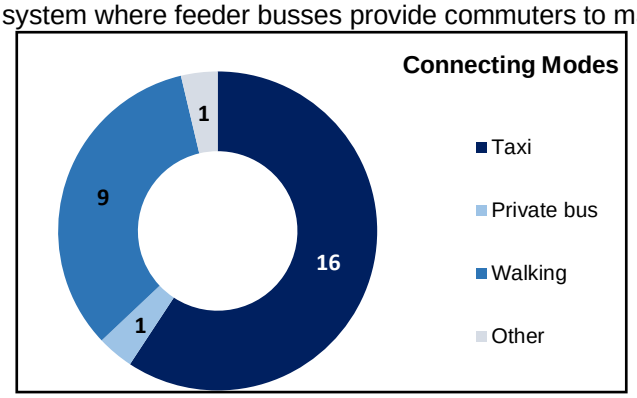


Figure 21: Connecting modes

Overall, the use of connecting modes is inherent in any public transport system; route networks, whether for taxis or buses, often run along main roads; thus, commuters need another transport mode to complete the trip. However, the essential characteristic is the time taken to access a connecting mode. A reduction in transfer time would reduce overall travel time.

4.2.5 Reliability

Reliability in the context of the study entails the consistent availability of transport to deliver commuters to their destination, i.e., service availability at the desired time, using schedules, and schedule punctuality (Abreha, 2007). Consequently, scheduled services availability is an essential indicator of efficient public transport per the ITMP-25 (GPDRT, 2012).

Results from enquiring about the reliability of public transport indicate that 34% of commuters find their selected mode reliable 'sometimes', whereas 26% found it 'usually' and 'always' reliable respectively (**Figure 22**). Unreliability was expressed in the form of delays, which mainly lasted between 11 and 30 minutes (**Figure 23**). Delays were due to increased demand for transport, traffic congestion and the need to use a connecting mode to complete a journey. Another important unreliability factor was the delays caused by the taxi industry's 'full capacity' system. Commuters stated the following in this regard.

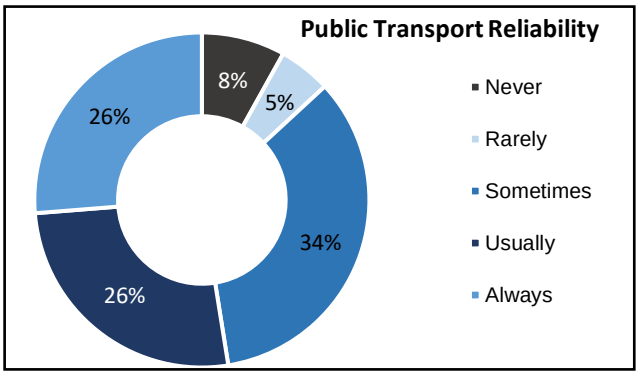


Figure 22: Public transport reliability status

Waiting for the taxi to be at full capacity"- QR_P6

"Taxis hardly travel until they are fully occupied . The preferred route also counts" - QR_P38"

Based on these results commuters find Johannesburg's road public transport 's reliability unsatisfactory, with delays improvement required across the modes.

The betterment particularly of delays due to traffic congestion is to be beneficial to commuters and the environment as it would result in reduced fuel consumption and exhaust emissions.

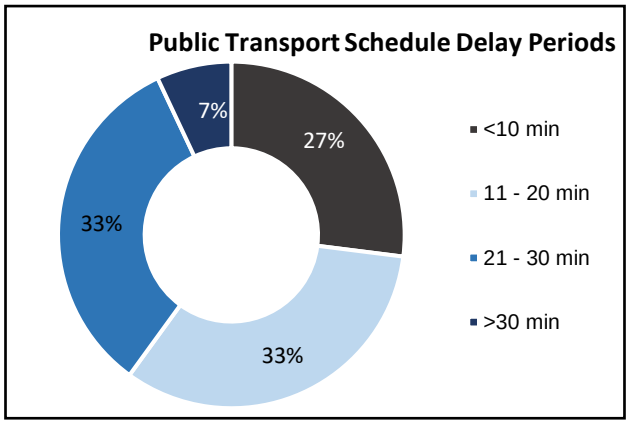


Figure 23: Schedule delay periods

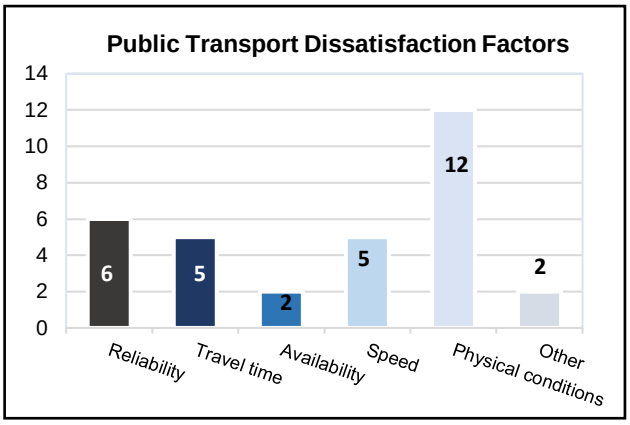


Figure 24: Dissatisfaction reasons - Motorists

Motorist questionnaire results indicated that public transport's unreliability, time inefficiency and vehicles physical conditions (**Section 4.2.6.1**) motivated the move to private car usage (**Figure 24**). The shift to the private car provided convenience, time efficiency and flexibility (**Figure 25**); however, it also had negative externalities, including traffic congestion, air pollution and high fuel cost (**Figure 26**).

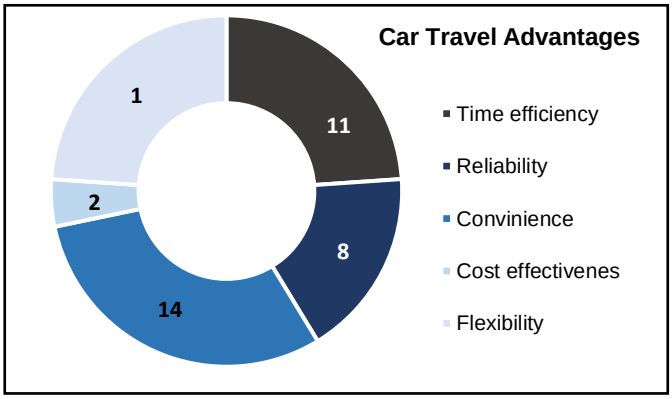


Figure 25: Car travel advantages

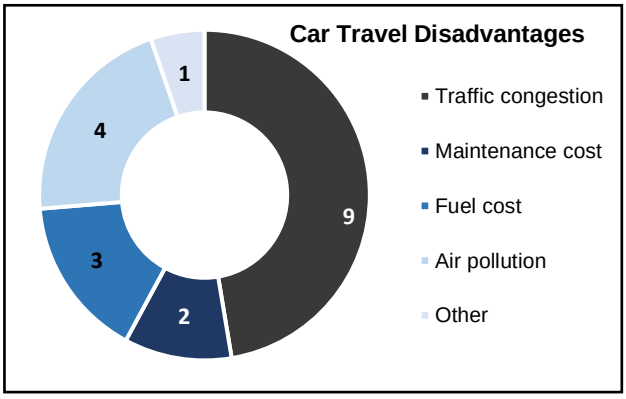


Figure 26: Car travel disadvantages

Overall, commuter comments link transport reliability with waiting periods, in that increased waiting periods are associated with unreliable transport, thus linking aspects of travel time and reliability. This linkage shows how different aspects of efficient transport have to be satisfied to have a sustainable public transport system.

On delays caused by using the 'full capacity' system, taxi operators indicated that waiting periods are part of various businesses, including theirs. However, this thinking disregards the importance of people's mobility and fails to see public transport as an essential service. It further lacks customer service orientation and lessens the efficiency of taxis.

The findings further reveal that the common concern between commuter and motorists is traffic congestion, the minimisation of which would benefit both parties by reducing delays, energy consumption and air pollution. Literature (Knoflacher, 2009; Newman *et al.*, 2016 and Mackett and Edwards, 1998) indicates that one method of reducing congestion is moving to public transport; however, this measure depends on the convenience, time efficiency, flexibility and reliability of the system. On shifting to public transport usage, most motorists (71%) indicated that they would return to

using public transport provided their primary concerns (**Figure 25)** are solved. In this regard, the modes of choice would be taxis, Rea Vaya and Metrobus; no motorists selected private buses.

These findings indicate that public transport needs to be more attractive and competitive for current users and for persons with alternative modes of transport. This translate to ensuring that public transport is convenient and easily accessible with reduced and predictable waiting time. It further means efficient connection between modes and trips. This thinking aligns with Carey *et al.* (2009) and Knowles *et al. (*2020), who note that as public transport is inflexible, inconvenient and inaccessible, improving these parameters will potentially attract more users.

4.2.5.1 Scheduling

Schedules are used in public transport systems to prevent delays and efficiently manage the service rendered. Schedules differ for peak and non-peak travel. The latter has less frequent service and the former more. Most (81%) of study participants noted that their selected modes do not use schedules. The responses align to previously presented data, which show taxis as the most used public transport option, using the 'full capacity' system instead of schedules. The public transport options using schedules include the Rea Vaya, Metrobus and private bus. Schedules were generally adhered to except in situations of significant traffic congestion and mechanical failures in private buses.

Most (52%) commuters viewed schedules as an advantage that would save time and enable better trip planning, which would have a positive impact on other aspects of their lives. Inversely, 48% of commuters deemed schedules unfavourable and instead supported the taxi's 'full capacity' system as it ensured transport availability throughout the day. Schedule use, per commuters, is likely to reduce accessibility as travel would be limited to specific times. It also has the risk of increasing waiting periods and delays caused by mismanagement of schedules. Commuter comments are as follows:

The above comments show that taxi commuters view schedule use differently, where some see value in it, and others do not. The conflicting views stem from personal experience where some commuters experience delays and extended waiting periods, and others are satisfied with the service received. Overall, the varying stances indicate that the taxi industry may benefit from using schedules during non-peak time, when commuters experience longer waiting periods. However, during peak periods, the 'full capacity' system serves commuters best. Schedule use for buses is the norm; however, mechanical failures interrupt set schedules, resulting in delays or extended travel time; vehicle maintenance should thus be a top priority. The impact of mechanical failures in public transport efficiency is discussed in detail in **Section 4.2.6.1**.

Based on the above findings, it is essential that schedule use should not inhibit accessibility and increase delays and waiting time but should assist with better management of the service provided and enable commuter flexibility. One commuter sums up the opposing opinions in stating that:

"I am a bit on the fence about this[schedules]. It could benefit us because I would know that transport is there for real, always. At the same time, it is convenient to have taxis at random cos it doesn't restrict your schedule as a commuter" - QR_P41

4.2.6 Road Public Transport Conditions

The study questionnaire asked participants for their opinion on the state of the public transport mode they used. The results showed that 50% of commuters ranked their selected mode as 'average', 21% as 'poor' and 16% as 'very poor' (**Figure 27**). Inversely, 57% of motorists indicated that their previously used public transport mode was 'poor', and 21% found it 'very poor' (**Figure 28**). The contrast indicates that current public transport users find transport more acceptable as it gets them to work, though late or with challenges. This acceptance may emanate from limited travel options due to accessibility and

other socio-economic issues, as explained in the following subsection. In comparison, participants with options and financial means find the provided service inadequate and have subsequently found alternative modes of transport. These results are more aligned to taxis as majority of participants use the mode to commute, and less to the Rea Vaya as it had low ridership in the study sample.

The study further asked participant's opinion on public transport factors that need to be prioritised. The varying comments were analysed and clustered into five categories as presented below.

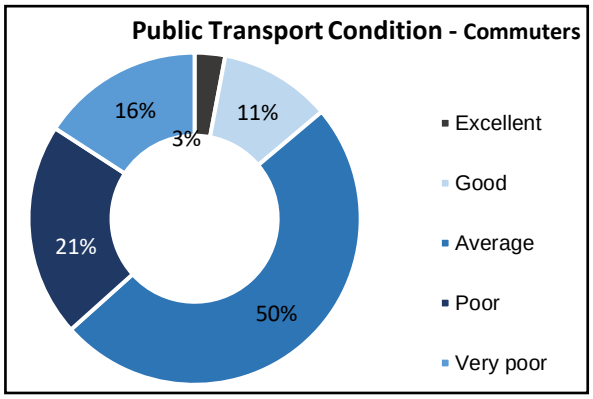


Figure 27: Public transport condition per commuters

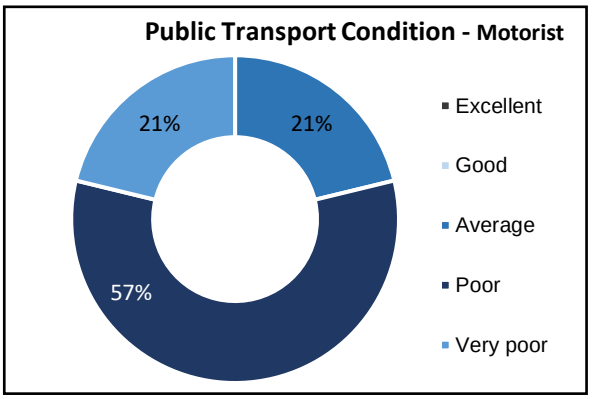


Figure 28: Public transport condition per motorists

4.2.6.1 Vehicle Maintenance

The top category in the study was vehicle maintenance, consisting of a well-maintained fleet that is visibly in good condition. From the interviews, it was evident that vehicle maintenance issues are a common concern as commuters noted being stuck on the road several times and referred to vehicles as 'scrap' and 'unroadworthy'. According to taxi operators, the upkeep of vehicles is the owner's responsibility, who are sometimes unwilling to finance the servicing work due to the high costs caused by the nature of the business, where vehicles are constantly on the road. Another constraint to servicing vehicles is the time required, which translates to reduced time on the road that impacts profit margins. Taxi operators also mentioned the lack of subsidies for taxis, noting that private buses such as Putco have a financial shied, which allows for easier absorption of maintenance costs. In contrast, taxis fund themselves, albeit they are the most widely used mode of public transport. Poor vehicle maintenance is not only a concern in the taxi industry but also for private buses, as has been indicated in previous sections. The Rea Vaya BRT and Metrobus did not exhibit similar issues.

The lack of taxi maintenance touches on all spheres of sustainability, including governance, as sustainable transport requires appropriate and well-functioning governance structures (Kennedy *et al.*,2005). In the past, the government has attempted to mitigate this challenge of poor vehicle maintenance by introducing the taxi recapitalisation project. However, the issue has persisted, indicating that old taxis are not de-commissioned and new ones are not maintained. The presence of dilapidated and unroadworthy vehicles on the roads also indicates a lack of law enforcement by the Johannesburg Metropolitan Police Department.

From a socio-economic perspective, commuters have to use poorly maintained taxis, as there are no better alternatives, epitomising captured users. The poor maintenance of taxis and private buses is also an energy and environmental matter as old, poorly maintained vehicles are less fuel efficient and emit more pollutants (Liebenberg-Enslin *et al.*, 2012), impacting human and environmental health. The Rea Vaya and Metrobus vehicles however have improved energy efficiency due to their use of alternative propulsion technologies and renewable fuels as noted in **Section 2.6.1.** The above thus illustrates that the provision of sustainable public transport is embedded in all three spheres of sustainability.

4.2.6.2 Infrastructure and Policing

The second category of concern related to visible policing and infrastructure provision. Based on commuter responses, there is a need to ensure that vehicles contravening traffic rules and regulations are held liable by the police and judiciary. Improved policing would further assist in the reduction of unroadworthy and dilapidated cars on the road thus improving the energy efficiency of the public transport system as noted in Section 4.2.6.1. The second aspect, infrastructure provision, encompassed the expansion of roads, increased traffic lights, and more public transport options. This showed that commuters are unsatisfied with the current system, as it cannot meet their travel needs. It further emphasised that commuter experiences and perceptions are significant factors in transport system sustainability, and as such, any sound public transport system should be people-centric.

The provision of adequate infrastructure such as streetlights and traffic lights have social and environmental impacts. On the former, well-lit streets and stops may curb crime and sexual harassment (Potgieter *et al*, 2006); this aspect is particularly important for taxis and buses as crime at ranks and bus stops is one of the main commuter concerns (**Section 2.6.1**). The provision of traffic lights, specifically ones synchronised will assist in reducing traffic congestion and energy consumption of vehicles, thereby also reducing exhaust emissions (Hemmerle *et al*, 2016).

4.2.6.3 Customer Service

Customer service was ranked third in the study. It focused on good service, where drivers communicate with commuters clearly and respectfully while also avoiding reckless driving. Statements from commuters indicate that bad driver behaviour is a common concern throughout the taxi industry, with some commuters indicating that,

"*They must teach the driver to respect the passenger" – QR_P31*

"Improve service, better communication…" – QR_P19

"….rude taxi drivers must not be tolerated" – QRD_P46

The above highlights commuter desperation for travel and mirrors the public transport system as a whole, in that commuters have to endure poor service due to limited transport options, essentially choosing the best among the worst.

On reckless driving, operators indicated that traffic congestion and the need to increase patronage necessitates emergency lane driving. Mthimkulu (2017) similarly notes that the lack of subsidies for the industry is a contributing factor to bad driver behaviour. The lack of subsidies is evident also in the minimum infrastructure provided for the industry, such as taxi ranks and stops. An operator stated that the Rea Vaya has dedicated lanes, which are often unutilised due to the BRT's operating times and the number of active buses; in contrast, multiple taxis operate throughout the day. As such, the sharing of lanes should be encouraged to improve the service provided to commuters and reduce reckless driving.

In asking taxi operators about collaboration with other modes such as buses and trains, responses were negative. Compared to the above statement about sharing of BRT, these views indicate that the taxi industry wants to benefit from government support while remaining independent and not part of the bigger public transport system; this is concerning as sustainable public transport requires the inclusion and cooperation of all available modes.

4.2.6.4 Safety, Health and Security

The fourth improvement category consolidates social aspects of safety, health and security. It pertains to reducing violence, cleanliness of vehicles, ranks and stops, reduced road traffic accidents and maintaining roadworthy vehicles. The latter aspect reiterates the need for vehicle maintenance. Under

the health and hygiene umbrella, commuters expressed concern with adherence to Covid-19 regulations and keeping vehicles and related infrastructure hygienic and waste-free.

As the taxi industry is synonymous with violence (**Section 2.6.1**), where taxi owners fight and kill for routes. Study participants noted the need for the industry to be better managed and for roadworthy and safe public transport vehicles (buses and taxis) to be utilised.

4.2.6.5 System Efficiency

The last category of improvement was system efficiency, inclusive of the betterment of transport reliability, accessibility, scheduling, cost and congestion. The various aspects of system efficiency and their relationships were discussed in detail in the above section (**Section 4.2**)

Overall, the overlapping nature of some aspects' characteristics shows how different variables are dependent on each other. An example is reckless driving which is a characteristic of both the third (customer service) and fourth (safety, health and security) aspect. These five categories of concern indicate that public transport efficiency focuses not only on transport system efficiency but also on socio-economics issues. The challenges expressed are localised in that they are not explicitly dominant in international literature. Good examples are driver behaviour (under customer services) and vehicle maintenance. Tackling these challenges will require multi-stakeholder involvement, inclusive of government and private sector service providers.

4.2.7 General Perception of Road Public Transport

The last question from the questionnaires asked participants for their general perception, experiences and feelings about road public transport in the study area. The comments indicated that participants were generally dissatisfied with the operation of the public transport system, specifically the travel inefficiencies. Participants further expressed unhappiness about the quality of service, vehicles conditions, governance and social issues such as health, emotional well-being and safety.

Though these categories are similar to those noted in **Section 4.2.6**, it was interesting to observe the change in dominating categories. In the overall perception of public transport, participants' comments mainly referred to travel inefficiencies, such as extended travel time, inaccessibility to multiple modes and unreliability of available modes. Inversely, responses from the previous question revealed that participants regarded public transport maintenance as an issue that required urgent attention.

The varying and almost contradictory nature of these results implies that participants see the maintenance of public transport as a quickly resolved aspect, considering that it is solely the responsibility of taxi and bus owners. In contrast, system inefficiencies are more layered, requiring extended periods and multi-stakeholder engagements to resolve. Another reason for the contrast is that inefficiencies are normalised and expected in the current public transport system; as such, participants do not view them as priorities for government and other public transport stakeholders. A third reason may be that socially, public transport usage is seen as a steppingstone, i.e., a mode for the poor or one people use while working towards a car. This notion brings forth the socio-economic issues of public transport provision as illustrated by the comments below, where participants indicate that the type of transport and its reliability is dependent on economic class and location.

"Our public transport ….availability is bad; I feel like because it is mostly people who are of a lower income class who use it, they are not prioritising it, like everything in this country – QR_P40"

"I feel there are different classes of public transport depending on your area of commute/residence. With each class, there is a difference in service quality and reliability. This indirectly reflects the inequalities of the society we live in" – QR_P2

The social aspects of public transport came out strongly as participants noted that using public transport is stressful and frustrating, causing anxiety and fatigue. Participants noted feeling unsafe and dissatisfied with the cleanliness of taxis and taxi ranks. Another concern was the overloading of buses, especially during the Covid-19 pandemic, where social distancing was highly encouraged.

Per the study findings, very few commuters regarded public transport as "low cost" and "cheap". Most commuters who found it costly alluded to the cost implications of connections, as in most cases, commuters have to pay for each trip taken. The issue of public transport affordability is relative to one's income level, as such, a blanket approach stating whether transport is affordable cannot be utilised, especially considering the local context, where South Africa has one of the highest income gaps in the world and a relatively high poverty level.

The study results showed that transport environmental impacts were not a popular topic for participants, with only two participants mentioning the need to shift to a less polluting and more carbon conscious public transport system. The unpopularity may be due to numerous factors, the first being that environmental impacts seem not to be a concern for the general public, as in most cases, air pollution impacts are non-tangible, presenting themselves as something else, such as smog, fumes and respiratory illnesses, which can be attributed to other issues. The second reason is that air pollution is not a topical issue, in that the general public has limited awareness of it. These findings, however, do not mean that transport environmental impacts should be less prioritised but rather that governing bodies have more to do in educating the public and implementing emission reduction measures, as ultimately, the right to a healthy environment is one of the basic human rights per the South African constitution.

The above reiterates the linkages between good public transport and other aspects of people's lives, demonstrating that sustainable public transport is inclusive of social, economic and environmental aspects.

4.3 Conclusions

Overall, the study results show that most participants were between 25 and 35 years, residing in various regions within the city, but with Tembisa and Northriding dominating. The study sample comprised 69% male and 31% female. Most commuters utilised public transport daily, travelling in the morning before 06:00 and in the afternoon after 18:00.

The study assessed four public transport efficiency parameters extracted from literature; namely, accessibility, use of NMT, travel time and reliability. Accessibility looked into the availability of different modes of public transport, the ease of travel, and transport proximity to commuters. The results indicated that taxis were the most available transport option, followed by private buses and Rea Vaya. The Metrobus lagged, with only a few commuters indicating its presence in their residential area. Metrobus inaccessibility stems from using old routes which are yet to be fully updated to cater for the growing and expanding city. The study reiterated literature findings by highlighting that residential areas on the city's periphery had low public transport availability. Reduced availability in these areas was due to unprofitability for taxis, whereas for Rea Vaya, it was because of the infancy of the service. Commuters indicated that it was reasonably easy to travel regionally; the ease of travel improved with local travel as essential amenities are close to residential areas. Most participants walked a distance exceeding 1km to access public transport or stayed more than 1km from a public transport node. The target set was that by 2020, 85% of urban residents would be residing 1km from a public transport network.

Overall, accessibility findings indicate that the availability of multiple public transport options was lacking, resulting in the higher usage of taxis as they were the most accessible public transport option.

Results further noted that improvements were required in ensuring that urban residents have access to public transport within a fair walking distance.

Non-motorised transport incorporation in the public transport network was assessed by evaluating walking and cycling within the system. Study findings indicated that walking was inherent in public transport usage as most commuters walked to access public transport; however, concerns arose with walking conditions such as distance, safety and security. Cycling was uncommon among study participants, likely due to the absence of cycling infrastructure and socio-economic issues. Generally, findings revealed that NMT usage conditions have to improve to achieve sustainable transport.

Travel time assessment comprised of the evaluation of trip duration, waiting time and transfer time. Results showed that trip duration hardly exceeded 45 minutes. Trips that lasted longer were a result of long-distance commutes. Commuter waiting periods ranged between 11 and 20 minutes and were more applicable to taxi users due to the industry's 'full capacity' system. Private buses waiting periods were mainly due to mechanical failure. Traffic congestion was the common reason for increased waiting periods for taxis and buses, where congestion interrupted schedules for the latter and caused delays in getting to taxi ranks. Increased trip length and traffic congestion further made the public transport system energy inefficient.

Another factor influencing travel time is inter-modality; study findings indicated that most commuters use a connecting mode to complete a trip. Connections were mainly made once in a trip, using local taxis, even by bus users. Commuters were dissatisfied with using connecting modes due to inefficiencies which resulted in increased travel time. Connecting modes are part of any public transport network; however, time efficiency is critical to reducing travel time. Overall, the study results indicated that small inefficiencies increase commuter travel time within the system, such as increased waiting periods and transfer time.

In assessing the reliability of the public transport system, study findings note that commuters found their selected modes partially unreliable, as there were delay concerns due to factors mentioned earlier. The unreliability of public transport was one of the primary reasons for people shifting towards private car usage. Generally, to improve and ensure reliability, public transport systems use schedules. Findings indicate that 52% of participants were for schedule use, whereas 48% were not. The latter group feared reduced accessibility and flexibility, whereas the former thought schedules would result in better time management and reduced delays. Overall, participants views indicated that the reliability of public transport needs improvement.

Study participants found the condition and service of public transport poor, leading to the categorisation of aspects that required improvement. They included vehicle maintenance, governance in the form of infrastructure provision and transport regulations enforcement. The poor maintenance of vehicles resulted in reduced fuel efficiency and release of more carbon emissions. The third aspect was improved service provision inclusive of commuter ill-treatment and reckless driving. The fourth aspect was social issues classed under safety and security and pertained to the unsatisfactory health and hygiene of bus and taxi stops, as well as crime and violence experienced in public transport. The last aspect was system efficiency which detailed aspects covered above such as the accessibility and reliability of the system.

Findings further indicated that generally, commuters are unsatisfied with the inefficiency of public transport, focusing on accessibility, travel time and reliability. Furthermore, public transport's social, economic and environmental (energy) aspects were also noted, where commuters observed the current public transport as stressful, costly and polluting. Overall, the above indicates that sustainable public transport must satisfy all sustainability spheres.

Chapter 5

5 Conclusions and Recommendations

5.1 Introduction

The research project set out to evaluate the sustainability of road public transport within Johannesburg, including minibus taxis, Metrobus, private buses such as Putco and Amogelang, and the CoJ BRT system, Rea Vaya. The transportation sector is vital in people's daily lives as it allows for the movement of goods and services across multiple areas; however, over the years, this process has unfolded in a manner that produces adverse impacts such as air and noise pollution, traffic congestion and urban sprawl (Schipper, 2002). The design and implementation of sustainable transport is thus essential for social, economic and environmental benefits.

The current chapter discusses the main findings from Chapter 4 and summarises how research questions were answered. The chapter begins with a background on the research, encompassing main points from the literature review, followed by an overview of the main points from the results and analysis. The chapter ends with recommendations.

5.1.1 Background

Sustainable transport has multiple definitions, which mainly stem from sustainable development as per the Brundtland commission report of 1987. The various definitions summarised note that sustainable transport balances current and future economic, social and environmental needs while reducing the aforementioned negative externalities (Santos and Ribeiro, 2013; Schipper, 2002).

The goal of sustainable transport is achievable in three ways: system efficiency, which relates to the setup of the urban structure. An example is a shift from auto-oriented city design to transit-oriented design (Bohler-Baedeker and Huging, 2012). The second measure is travel efficiency which primarily focuses on using public transit and non-motorised transport (Bohler-Baedeker and Huging, 2012). The third method is vehicle efficiency which entails the use of alternative energy sources such as biodiesel and CNG (Bohler-Baedeker and Huging, 2012; Stanley and Lucas, 2014); and change in propulsion technology like moving from the combustible engine to hydrogen-powered fuel cells (Bohler-Baedeker and Huging, 2012; D'Agosto *et al.*, 2013).

The study focused on one sustainability measure, i.e., travel efficiency; however, others arose due to the interconnectedness of these efficiency measures. Travel efficiency prioritises efficient public transport and NMT; thus, it is vital to understand what efficient public transport entails. Literature lists multiple characteristics, including availability, accessibility, reliability, affordability, travel time, flexibility, environmental consciousness, comfort and security (GPDRT, 2012; Hensher,2006; Mugion *et al.*, 2018; Mohan and Tiwari,1999; Banister, 2008; Sampaio *et al.*, 2008). The common indicators from literature were selected and subsequently used as a baseline to assess the sustainability of road public transport in Johannesburg. These indicators were accessibility, travel time, use of NMT and reliability.

The study was defined as evaluative research and followed the qualitative research type, where questionnaire and interviews were the data gathering tools. The selected data collection methods allowed for the effective gathering of rich and dense information through close and open-ended questionnaires and semi-structured interviews. They further encouraged study participants to express their experience on the research topic freely.

5.2 Main Findings and Conclusions

This section of the report presents the main findings and conclusion from the study. **Table 7** shows the main finding with the standard of measure extracted from literature and conclusions drawn from the

comparison. The table further indicates whether, per the study findings, sustainability indicators are considered and present in Johannesburg's road public transport.

Accessibility results indicate that commuters are limited in the availability of transport options and, as a result, are forced to use whichever available transport even if it is inadequate in service. Accessibility issues extend to proximity to a public transport node as most commuters walk extended distances to access public transport. This situation leaves commuters vulnerable to socio-economic issues such as crime, indicating that public transport inaccessibility safety and security issues. Results further indicated that accessibility for local travel was better than for regional travel, implying that service providers prioritise local travel. This aspect forms a good foundation for the implementation of transit-oriented development in the city.

Under the incorporation of NMT into the public transport system, study results indicate that walking is the only form of NMT present; participants do not cycle or use cycle rickshaws, though the BRT has cycling lanes. Generally, walking is a good sustainability indicator for a transport system; however, its conditions must be conducive, safe and comfortable for the commuter. These factors lack in the Johannesburg public transport system.

Generally, results show that the transport system fails in providing multiple travel options to commuters, which are close to their residential areas. Furthermore, the distance travelled between work and home is not excessive; however, trips are often long due to the inefficiencies of the transport system, such as multiple connections, winding routes, waiting periods and frequent breakdowns stemming from poor vehicle maintenance. These factors combined with traffic congestion increases travel time and energy consumption, leaving commuters dissatisfied with using public transport and steering them towards private car usage. Consequently, commuter found public transport unreliable due to these factors and reduced transport availability during non-peak periods. However, the transport system displays some good traits, such as the ease of local travel (as mentioned earlier) and buses schedule use.

Table 8 assess the sustainability of individual road public transport modes included in the study. Taxis were found to be accessible due to their presence in all participants' residential areas. However, the use of 'full capacity system factored adversely into their travel time and reliability as the system resulted in delays. The Metrobus performed poorly in accessibility; however, its use and adherence to schedules is positive. Private buses were underutilised, indicating a challenge with availability. Travel time and reliability were also a challenge due to mechanical failures. Rea Vaya satisfied three parameters, except accessibility; the BRT system was accessible only to a few commuters. In the four modes assessed, only the BRT incorporated NMT into the system. At first glance, **Table 8** shows that Rea Vaya is the most sustainable of all public transport options as it scores 'satisfactory' for three of the four parameters assessed, , however, the BRT system fails the parameter most valuable to commuters, which is accessibility. This shows that if a mode is inaccessible, its other good aspects cannot be experienced and are less valued by the commuter. Based on this, taxis are the most sustainable of all four road public transport options due to their accessibility.

Study results noted five categories to improve transport system status. At the top was vehicle maintenance, followed by infrastructure provision, customer service, safety, health and security, and system efficiency. These concerns may be improved through better policing that ensures that public transport vehicles are roadworthy, bus stops and taxi ranks are safe, and taxi and bus operators adhere to traffic regulations. Another solution is providing subsidies to all public transport services in return for a more service orientated system. Overall, the study found that Johannesburg road public transport system displays both good and bad sustainability characteristics; hence it is deemed partially unsustainable (**Table 7 and Table 8**).

Table 7: Study results main points and conclusions

Sustainability Indicator		Sustainability Indicator Standard of Comparison	Study Results	Conclusion	Sustainability Outcome
Accessibility	Availability of multiple travel modes	Access to multiple options or modes for travel (Vasconcellos (2001) in Kgatjepe and Ogra, (2016); Mohan and Tiwari (1999)	• Taxis were the most available option, followed by private buses and Rea vaya. • Metrobus was mainly available in affluent older suburbs and not in townships • Most commuters opted for taxis even though other modes were available in their area. Others were captive users, as taxis were the only transport option available	Availability of multiple road public transport in the study area is unsatisfactory. Commuters are forced to use the available options, regardless of conditions or situations	
	Ease of travel	Defined as part of accessibility relating to the ease at which one can arrive at an opportunity such as employment (Litman, 2020)	• Local travel found to be easier than regional travel, due to the urban form where amenities are near • Ease of travel declined during off-peak periods, such as during the evening (after 18:00)	Based on the results the ease of travel within the study area was fairly satisfactory, with improvements required during off-peak periods i.e., evening and weekend	
	Proximity to public transport node	Commuters are supposed to travel 400m to reach a public transport node (Mokgukulushi *et al,* 2018) Urban residents should reside within 1km from public transport network (SACN, 2016)	• Access to public transport was mainly through walking • Most study participants not within 1km of public transport node • Most commuters walk an excess of 400m to access transport	Majority of commuters reside an unacceptable distance away from a public transport node; and subsequently walk longer distances to access transport Walking has safety and security risks, which is listed as the fourth factor that needs improvement	
Use of Non-motorised transport	Incorporation of walking and/or cycling into the system	Major part of TOD, which is the city design most suitable for achieving sustainable public transportation (Newman, 2009)	• Walking is the only NMT used, no study participant cycled • Lack of cycling is due to inadequate infrastructure and social issues • Taxi industry is willing to incorporate bicycles into their network • Incorporation of NMT should consider socio-economic issues including safety and cost	Walking is inherently part of Johannesburg road public transport system; however, its incorporation is not per system design, but rather out of commuter desperation and need	

Sustainability Indicator		Sustainability Indicator Standard of Comparison	Study Results	Conclusion	Sustainability Outcome
Travel Time	Trip duration	Johannesburg commuters travel an average of 20km to work (Harrison *et al,* 2003 in Kgatjepe and Ogra, 2016)	• Trips generally lasted between 15 and 45 minutes. Longer commutes were due to excessive distance travelled. • Trip duration is increased by traffic congestion, long winding routes and poor road infrastructure • Taxis are able to alter routes to avoid long travel distance and delays, however buses must maintain set routes	Generally, commuter trips are not long, however the duration is increased by other factors, including traffic congestion and long routes, stemming from the inefficiencies of the system and poor urban form. These factors resultantly increase vehicle kilometre travelled and fuel used, thus rendering the system energy inefficient and emission intensive	
	Waiting time	Satisfaction on waiting periods. Savings on waiting time are three times more valued by commuters than actual savings in travel time (Millonig *et al*, 2012)	• Waiting periods are longer during off-peak periods and mostly applicable to taxis due to 'full capacity' system used • Private bus commuters experience delays due to mechanical failures • Selected routes and distance travelled increase waiting time • Waiting periods are not only applicable before moving but also during the trip due to mechanical failures or refuelling	Commuters are unsatisfied with waiting periods, especially during off-peak periods Other transport planning issues such as vehicle maintenance and poor trip planning encroach on waiting periods	
	Transfer time	Transferring from one mode to another adds 15 minutes to commuter journeys (Mokgukulushi *et al*, 2018)	• Inter-modality is common across the transport system • Majority of commuters connect once, in worse cases thrice • Commuters are unsatisfied with multiple connections • Connections are mainly done by local taxis, even for Metro and private buses, whereas Rea vaya uses feeder buses. Other commuters utilise walking as a connecting method	Commuters are unsatisfied with transfer time, which adds time to overall travel time and is costly	

Sustainability Indicator		Sustainability Indicator Standard of Comparison	Study Results	Conclusion	Sustainability Outcome
Reliability	Constant availability of public transport	Unavailability of transport listed as deterrent to efficient public transport system (StatsSA, 2014) One of the main concerns in public transport per commuters is the consistent availability of transport (Heyns and Luke, 2016).	• Public transport reliable sometimes • Unreliability a factor of delays due to traffic congestion, inter-modality, peak periods demand, and taxis use of 'full capacity' system • Unreliability and time inefficiency of public transport encourage the move towards private car usage	Reliability of public transport deemed unsatisfactory; and mainly associated with delays, caused by multiple factors mentioned earlier	
	Schedules	Efficient public transport network must have scheduled services (GPDRT, 2012) System reliability relates to dependability of schedules i.e., presence of service during peak and non-peak time and days (Abreha, 2007)	• Use of schedule uncommon among commuters as most use taxis which operate the 'full capacity' system • Schedules for buses generally kept, except during traffic congestion or mechanical failure • Participants nearly equally split between those against and those for use of schedules • Proponents of schedules viewed them as potential time savers; whereas those against feared their use would result in delays and reduced accessibility	Overall, use of schedules was viewed positively, provided that they are adhered to, to avoid delays.	

Legend

 Satisfactory

 Partially satisfactory

 Unsatisfactory

 Partially unsatisfactory

Table 8: Sustainability comparison of Johannesburg's road public transport

Sustainability Indicator	Road Public Transport Mode in Johannesburg							
	Taxi		Metrobus		Private bus		Rea Vaya	
Accessibility	✓	Most accessible mode, available across the study area and easy to access. Runs feeder systems, such as local taxis, which bridge the gap of proximity to a public transport node	✗	Very limited availability across the study area	⊗	Not commonly utilised	⊗	Only available in specific areas. Planned expansion plans will likely increase accessibility in some areas.
Use of NMT	✗	Currently no official incorporation of NMT, however there is willingness to do so	✗	No official incorporation of NMT into system. Commuters walk due to limited choice	✗	No official incorporation of NMT into system. Commuters walk due to limited choice	✓	Presence of bicycle lanes on certain routes
Travel time	⊗	Increased waiting periods due to the 'full capacity' system, however, can change routes to accommodate commuters or avoid delays.	⊘	Limited number of users in the study, as such parameter could not be fully assessed	⊗	Delays due to mechanical failure increase travel time	✓	Time efficient due to use of separate lanes and feeder buses,
Reliability	✓	Generally reliable due to long operating hours, however, delays due to use of 'full capacity' system reduces reliability	⊗	Have schedules, however routing and travel hours are not conducive for commuters	✓	Has schedules which are generally adhered to	✓	Has schedules which are generally adhered to

Legend

✓ Satisfactory ✓ Partially satisfactory ✗ Unsatisfactory ⊗ Partially unsatisfactory ⊘ Not assessed

5.3 Overall Conclusions

The study aims as per **Section 1.4** were met by determining that sustainable transport encompasses three spheres. i.e., social, economic and environmental. Sustainable transport is achievable through system, vehicle and travel efficiency. In the context of the study, travel efficiency took priority as it focuses on improving the current public transport system's efficiency. Four parameters were selected to assess Johannesburg's road public transport efficiency; they were accessibility, use of NMT, travel time and reliability. Results of the assessment indicated that accessibility, described as availability of multiple modes, distance from transit nodes and ease of travel, was most important to commuters. Taxis were the most sustainable public transport option due to their accessibility and flexibility.

Overall, the answer to the research question of to what extent is the current road public transport system in Johannesburg sustainable is that the system is partially unsustainable. This is because Johannesburg road public transport system comprises all four sustainability indicators; however, these are not integrated but rather spread across the different modes. The disconnection thus inhibits the system's sustainability. Taxis are the most accessible transport mode, however not the most sustainable; in contrast, the Rea Vaya is the most sustainable mode, but it is inaccessible. This shows that the accessibility of a public transport system is more valuable for commuters than its overall sustainability. Recommendations on how to improve this are below.

5.4 Recommendations

Recommendations are made based on study findings and identified opportunities. Study findings revealed that local travel is easier as amenities in townships such as Tembisa and Cosmo city are near residential areas. This compact urban form is an opportunity to introduce NMT, such as bicycles and rickshaws, to be utilised to complete short trips. As a result, investment in NMT infrastructures such as cycling lanes and secure parking is recommended; implemented in conjunction with existing transport structures. On improving travel time, a recommendation for the taxis industry is to reduce waiting periods by implementing a limit on maximum commuter waiting time and ensuring that transfer times are limited to between five and seven minutes.

In terms of knowledge growth through research, a gap is identified for research that is focused on system and vehicle efficiency, as the current study evaluated sustainability from a travel efficiency lens only. Vehicle efficiency research may entail research on the renewable energy fuel best suited for the Johannesburg context. i.e., considering climatic conditions, access to resources and financial implications. Research in system efficiency could assess whether the current SDF and other government plans are likely to result in a shift to sustainable public transport i.e., does the planned city layout enable sustainable mobility.

The study findings gave more details on the operation of the taxis; a mode referred to as para-transit or informal. Its dominance in the study was due to its dominance in ridership. Based on this, an opportunity exists for future research that solely focuses on bus and rail sustainability. Continuing with taxis, past sustainability or energy efficiency measures implemented, such as the taxi recapitalisation and conversion of taxis to hybrid vehicles projects have not yielded the required results, consequently research into the issues and reasons leading to the slow uptake of these measures is required to assist in the better implementation of future sustainable projects.

Lastly, as a sustainable public transport is people centric, it is imperative to understand social, cultural and personal aspects and aspirations of commuters that could impede the move towards sustainable mobility. These may include the view of car ownership as a measure of success or wealth, and the use of public transport seen as a steppingstone to 'better' forms of travel.

Overall, this research indicates that it is essential for government and other transport service providers such as the taxi industry to continuously engage and find ways to improve the service provided, as commuters should be the main priority in a public transport system

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7 Appendices

7.1 Appendix A – Questionnaires

QUESTIONNAIRE SHEET - Commuters

Kindly assist by answering the following questions in the best and honest way you can. Thank you.

Participant Details

7.2 Participant age range (yrs.)	☐Less than 25 ☐25 - 35 ☐36 - 45 ☐46 – 55 ☐>56
7.3 Gender	☐Female ☐Male
7.4 Where do you stay and travel to?	Residential place: ---------- Destination of travel: ----------
7.5 Which road public transport are available in your area? Select more than 1 if applicable	☐Metrobus ☐Rea vaya ☐Taxi ☐Private bus (e.g. Putco, Amogelang) ☐Other ----------
7.6 Which road public transport do you use? Select more than one options if applicable	☐Metrobus ☐Rea vaya ☐Taxi ☐Private bus (e.g. Putco, Amogelang) ☐Other ----------
7.7 Why do you use selected transport type? Select more than 1 if applicable	☐Reliability, ☐Accessibility ☐Speed ☐Cost ☐Less traffic congestion ☐Other ----------
7.8 How often do you use selected transport?	☐Once a week ☐Twice a week ☐2 to 3 times a week ☐3 to 4 times a week ☐Daily
7.8.1 Travel time - What time do you usually travel to work or school?	☐Before 06:00 ☐06:00 - 07:00 ☐07:00 - 08:00 ☐08:00 – 09:00 ☐After 09:00
7.8.2 Travel time - What time do you usually travel back	☐Before 16:00

	from work or school?	☐16:00 - 17:00 ☐17:00 - 18:00 ☐After 18:00

Accessibility

7.9	How easy is it for you to get transport when you travel to/from work or home?	☐Very easy ☐Easy ☐Moderate ☐Difficult ☐Very difficult
7.10	How easy is it for you to get transport when you travel across the city for other purposes?	☐Very easy ☐Easy ☐Moderate ☐Difficult ☐Very difficult
7.11	What do you use to get access to your main travel mode?	☐Walking ☐Cycling ☐Local taxis ☐Other ----------
7.12	On average, how long do you travel to access your preferred travel mode?	☐Less than 10min ☐11 – 20 min ☐21 – 30min ☐More than 30min
7.13	Does the available transport get you where you want to go always & timely?	☐Never ☐Rarely ☐Sometimes ☐Usually ☐Always
7.14	If not, what are some of the reasons for that?	---------- ----------

8 Travel time

8.1	Usually, how long is your commute – One way	☐Less than 15min ☐16 – 30min ☐31 – 45min ☐45 – 60min ☐More than 1hr
8.2	How long do you generally wait before your selected transport mode moves?	☐Less than 10min ☐11 – 20 min ☐21 – 30min

		☐>30min
8.3	How satisfied are you with the waiting period given in 3.2?	☐Very unsatisfied ☐Unsatisfied ☐Moderately safisfied ☐Satisfied ☐Very satisfied
8.4	What contributes to the long/short travel time in your opinion? If other, specify Select more than one options if applicable	☐Driving speed ☐Selected route ☐Traffic congestion ☐Distance travelled ☐Road quality ☐Other ----------
8.5	Does your selected transport get you to your destination, or do you have to use a connecting mode?	☐Yes ☐No
8.6	If yes, what is your connecting mode and how many times do you have to connect?	☐Metrobus ☐Rea vaya ☐Taxi ☐Private bus (e.g. Putco, Amogelang) ☐Walking ☐Other ---------- ☐Once ☐Twice ☐Three times ☐Four times

Reliability and Trustworthiness

8.7	Does your chosen mode have a schedule or timetable?	☐Yes ☐No
8.8	If yes, how reliable is it, i.e. how often is it on time?	☐Never ☐Rarely ☐Sometimes ☐Usually ☐Always
8.9	If not reliable (4.2) Usually how long are the delays?	☐Less than 10min ☐11 – 20 min ☐21 – 30min ☐>30min
8.10	Is there a difference in delays during peak and non-peak traffic? Please explain	☐Yes ☐No ----------

	----------
8.11 If applicable, from your experience, what are the reasons causing delays?	☐Driving speed ☐Selected route ☐Traffic congestion ☐Distance travelled ☐Road quality ☐Mechanical failure ☐Other ----------
8.12 If "No" to 4.1, do you think your mode of transport & you would benefit from having a schedule and how?	☐Yes ☐No ---------- ----------

9 Vehicle Characteristics

What is the general condition of the public transport you travel in? Explain	☐Excellent ☐Good ☐Average ☐Poor ☐Very poor ---------- ----------
What in your opinion needs to be prioritised in improvements?	---------- ----------

Tell me your feelings and experiences about public transport in general, anything

Thank you for taking the time to respond to my questionnaire. Greatly appreciated.

Didintle Modisamongwe

QUESTIONNAIRE SHEET - Motorists

Kindly assist by answering the following questions in the best and honest way you can. Thank you.

Participant Details

9.1	Participant age range (yrs.)	☐Less than 25 ☐25 - 35 ☐36 - 45 ☐46 – 55 ☐>56
9.2	Gender	☐Female ☐Male
9.3	Where do you stay and travel to?	Residential place: ---------- Destination of travel: ----------

Travel Information

Which road public transport are available in your area? Select more than 1 if applicable If "Other" please specify	☐Metrobus ☐Rea vaya ☐Taxi ☐Private bus (e.g. Putco, Amogelang) ☐Other ----------
How far are you from your nearest public transport node?	☐Less than 1km ☐1 – 2km ☐2 - 3km ☐3 – 4km ☐4 – 5km ☐More than 5km
Have you previously used public transport? If "Yes" select mode used. Select more than one options if applicable	☐Yes ☐No ☐Metrobus ☐Rea vaya ☐Taxi ☐Private bus (e.g. Putco, Amogelang) ☐Other ----------
How satisfied were you with the transport used?	☐Very unsatisfied ☐Unsatisfied ☐Moderately safisfied ☐Satisfied ☐Very satisfied
If not satisfied in 2.4, what were the concerns or issues with selected transport mode? If "Other" please specify	☐Reliability of transport ☐Travel time ☐Cost ☐Availability and accessibility ☐Speed

	☐Vehicle physical condition ☐Other ----------
Why do you use private car as opposed to public transport? If "Other" please specify	☐Time efficiency ☐Reliability ☐Convenience ☐Cost effectiveness ☐Flexibility ☐Other ----------
Do you have any issues with car travel? If "Yes", please select or specify	☐Yes ☐No ☐Traffic congestion ☐Vehicle maintenance cost ☐Fuel cost ☐Environmental (air) pollution ☐Other ----------
If the issues in 2.5 were to be resolved would you use public transport? If "Yes", which one?	☐Yes ☐No ☐Metrobus ☐Rea vaya ☐Taxi ☐Private bus (e.g. Putco, Amogelang) ☐Other ----------
Why did you select the mode in 2.8? (if applicable)	☐Availability and accessibility ☐Cost ☐Efficient route ☐Speed (fast) ☐Vehicle physical condition ☐Other ----------

Vehicle Characteristics

What is the general condition of the public transport you travel in? Explain	☐Excellent ☐Good ☐Average ☐Poor ☐Very poor ---------- ----------
What in your opinion needs to be prioritised in improvements?	----------

General

Tell me your feelings and experiences about public transport in general, anything

Thank you for taking the time to respond to my questionnaire. Greatly appreciated.

Didintle Modisamongwe

9.4 Appendix B – Interview Questions

Interview Questions

Availability and Accessibility

- Taxis are the most widely used mode of road public transport, why do you think it is that way?
- Why do you think busses are not popular anymore ?
- One of the advantages is that you are everywhere, how is that achieved?
- Even with that said, most people on the outskirt of the city and also in the suburbs complain about not having enough taxis, why are those areas neglected?

Travel Time

- How do you determine the route to take, who is involved in that process?
- Do you ever review the routes as situations change?
- Commuters complain about the run around looking for people, is it something that you can sort out?
- Sometimes there are no direct route from a place to another place, why is that, why do taxis have to go to the rank all the time?
- Most commuters have to connect with another taxi to get to their destination – How do you see that situation?
- In this connection, do you think the taxi industry would be open to working with other modes of NMTs , maybe having a bicycle parking section at the rank or using amatuk tuks for short distances?

Trustworthiness and Reliability

- You use the concept of a full load, no timetable, why and do you think its beneficial for the commuter
- When in the day do you get most of your customers?
- Have you done anything to ensure that you serve those people better and reduce long ques?
- Mechanical failures on the road due to lack of maintenance, why are taxis not maintained or kept in optimum condition?
- Most commuters don’t like having to wait for taxis – Anyway that can be improved?

General:

- Do you think the industry would welcome another player, maybe the Gaubus travelling between more areas?
- Ok, so you drive on the yellow lane a lot – Do you want your own lane and how would that influence the service you provide to commuters?
- Most commuters complain about driver attitude, that you are rude, is this matter ever communicated in your forums and what are the solutions offered?
- What do you think transport will look like in years to come?
- Is the industry ready to move with the times and improve?

9.5 Appendix C – Participant Information Sheet

PARTICIPANT INFORMATION SHEET - Questionnaire

University of Witwatersrand
1 Jan Smuts Ave
Johannesburg
2000

Faculty of Engineering and the Built Environment
School of Architecture and Planning
Contact number: 011 717 7014

Good day,

My name is Didintle Modisamongwe, I am currently completing my Masters degree in Sustainable Energy Efficient Cities, with the University of the Witwatersrand in Johannesburg. As part of my studies, I am conducting a research project, where I am evaluating the sustainability of road public transport systems in Johannesburg. The aim of the research is to understand the extent of sustainability in road public transport within Johannesburg and identify the most sustainable road public transport type from the existing public transport system.

As part of this project I will be gathering data to facilitate my research and would sincerely like to invite you to answer a questionnaire. This will entail answering questions regarding your daily experience with public transport as a commuter and will take approximately 30 minutes to complete. With your permission I would like to keep record of the conversation on my WhatsApp server and the completed questionnaire sheets.

You will not receive any direct benefits from participating in this research, and there are no disadvantages or penalties for not participating. You may withdraw at any time or not answer any question if you do not want to. The questionnaire will be anonymous as I will not be asking for your name or any identifying information and the information provided will be stored safely in a password protected computer and in digital form with all identifying features removed. Pseudonym (false name) or unique identifiers will be utilised to represent your participation in my final research report. If you experience any distress or discomfort at any point in this process, we will stop the interview or resume at another convenient time.

If you have any questions during or afterwards about this research, feel free to contact me on the details listed below. This study will be written up as a research report and if you wish to receive a summary of this report, I will be happy to send it to you. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email hrec-medical.researchoffice@wits.ac.za

Yours sincerely,

Didintle Modisamongwe

Researcher: Didintle Modisamongwe

Email: 1507719@students.wits.ac.za

Cell: 081 023 9652

Supervisor: Muhammed Suleman

Email: muhammed.suleman@wits.ac.za

Tel: 011 717 7732

PARTICIPANT INFORMATION SHEET- Interviews

University of Witwatersrand
1 Jan Smuts Ave
Johannesburg
2000

Faculty of Engineering and the Built Environment
School of Architecture and Planning
Contact number: 011 717 7014

Good day,

My name is Didintle Modisamongwe, I am currently completing my Masters degree in Sustainable Energy Efficient Cities, with the University of the Witwatersrand in Johannesburg. As part of my studies, I am conducting a research project, where I am evaluating the sustainability of road public transport systems in Johannesburg. The aim of the research is to understand the extent of sustainability in road public transport within Johannesburg and identify the most sustainable road public transport type from the existing public transport system.

As part of this project I will be gathering data to facilitate my research and would sincerely like to invite you to an interview, where we would discuss consideration of sustainability indicators in road public transport. The interview is expected to last approximately one hour and will be conducted over the phone or digital meeting platform such as Microsoft Teams. With your permission I would like to record this interview.

You will not receive any direct benefits from participating in this research, and there are no disadvantages or penalties for not participating. You may withdraw at any time or not answer any question if you do not want to. The interview may be anonymous where your name or any identifying information is not required, or you may elect not to be anonymous. The information provided will be stored safely in a password protected computer and in digital form with all identifying features removed. Pseudonym (false name) or unique identifiers may be utilised to represent your participation in my final research report. If you experience any distress or discomfort at any point in this process, we will stop the interview or resume at another convenient time.

If you have any questions during or afterwards about this research, feel free to contact me on the details listed below. This study will be written up as a research report and if you wish to receive a summary of this report, I will be happy to send it to you. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email hrec-medical.researchoffice@wits.ac.za

Yours sincerely,

Didintle Modisamongwe

Researcher: Didintle Modisamongwe
Email: 1507719@students.wits.ac.za
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Supervisor: Muhammed Suleman
Email: muhammed.suleman@wits.ac.za
Tel: 011 717 7732

9.6 Appendix D – Participant Consent Form

CONSENT FORM

Form information: This form has the intention of requesting individuals to be study participants and obtaining their consent to use information gathered in the research project.

Title of project: Evaluating the sustainability of road public transport systems in Johannesburg

Name of researcher: Didintle Modisamongwe

I, ……., agree to participate in this research project. The research has been explained to me and I understand what my participation will involve. I agree to the following:

(Please circle the relevant options below).

I agree that my participation will remain anonymous	☐ YES ☐NO
I agree that the researcher may use anonymous quotes in his / her research report	☐YES ☐NO
I agree that the information I provide may be used anonymously after this project has ended, for academic purposes by other researchers, subject to their own ethics clearance being obtained.	☐YES ☐NO
I agree to the use of direct quotes	☐YES ☐NO

Participant

…….. (Name)

…… …… (Signature)

…….. (Date)

Researcher

…… (Name)

…… ……(Signature)

……. (Date)

9.7 Appendix E – Coding Format

ACC	Accessibility			Driver behaviour
C	Cost		Customer service	Service level
CNN	Connections			Education
DB	Driver behaviour			Speed
DL	Delays			
ED	Education		Vehicle maintenance	Maintenance
EW	Emotional wellbeing			Physical condition
GOV	Governance			Traffic rules
INFR	Infrastructure			Infrastructure
MTC	Maintenance			System
PC	Physical conditions			Governance
POL	Pollution			
RL	Reliability		Governance	
S,H&S	Safety, health and security			Schedule
SDL	Schedule			Reliability
SL	Service level			Accessibility
				Traffic congestion
SPD	Speed			Proximity
TC	Traffic congestion			Cost
TR	Traffic rules			Pollution
TT	Time travel			Delays
PRX	Proximity			Connections
SYS	System		System efficiency	Time travel
				Covid-19
			Safety, health and security	Security
				Emotional Wellbeing