A Total Social Cost Approach to Public Transport Planning in South Africa

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This thesis is dedicated to my family, friends, and partner. First, to my family specifically, my mother, thank you for the support you have given me throughout my studies. Your prayers and phone calls have carried me through my undergraduate studies and postgraduate studies. Secondly, to my friends, thank you! It would not have been possible without your support. I just have to recall all the nights I was picked up from the airport after each block week. Lastly, to my partner, thank you for being my *Proverbs 31.* Without your love and support this would not have been possible.

To God be the Glory.

Abstract

Public transport has a significant role in addressing economic, social and environmental issues resulting from motorised mobility. Motorised travel, including that offered by public transport, has positive and negative impacts. It is particularly true in the case of public transport that the magnitude of the impacts is a function of how resources are allocated as well as of the spatial arrangement of transport options to service the demand. In the past, the allocation of modes of travel to service demand along corridors has primarily been based on the evaluation of marginal economic benefits. The emphasis is placed on net economic costs, despite the presence of external costs generated by the transport system and that are ultimately borne by society. External costs include costs due to accidents, pollution, noise, visual intrusions and amenity losses. Appraising transport interventions solely on the basis of net economic benefits (operator costs) is insufficient to meet the goals set out in the *White Paper on National Transport Policy,* which requires the provision of transport infrastructure and services to be in line with sustainability goals (DoT, 1996 & 2017). Fundamentally, Section 24 of the Constitution bestows ecologically sustainable development the status of a human right.

This thesis evaluates the effectiveness of a total social cost (TSC) approach to guide the selection of a public transport mode to service passenger travel demand along a given corridor. By definition, total social costs comprise internal and external costs. Internal costs include all the costs borne directly by the consumer of the good or service in question, whilst external costs are borne by society, including costs such as the risk of accidents and emissions. The external costs can be significant. For example, it is estimated that, in the European Union, the proportion of external costs as a percentage of GDP ranges from 3.4% in Norway to over 7% in Portugal and Luxemburg (European Commission, 2019).

Welfare theory argues that an optimal price charged to the users should also reflect external costs, and the failure to internalise external costs means that the use of the transport system is inefficient (Maibach et al., 2008). To this end, the work in this thesis is important because it may be used to facilitate the internalisation of public transport-related costs through the use of regulations-based and/or market-based instruments.

In this thesis, the effectiveness of the total social cost (TSC) approach to guide the provision of transport infrastructure and services was evaluated against the conventional modal hierarchy approach for the development of the Atteridgeville-Pretoria CBD corridor. The total social cost (TSC) approach suggest that effective road-based public transport modes for the 18 km corridor are as follows, measured in terms of passengers per hour per direction:

- minibus taxi (0-2 000),

- standard bus (2 000- 4 000),
- articulated bus (4 000- 8 000), and
- BRT standard bus greater 6 500.

The most effective mode for the Atteridgeville-Pretoria CBD corridor turned out to be the BRT standard bus when assessed using the total social cost approach. On the other hand, it was found to be an articulated bus when applying the modal hierarchy approach. Society would pay R4.70 to produce a passenger-kilometre of BRT standard bus service. However, if the assessment had been only based on marginal operator costs, the articulated bus would cost the least when compared to the other technologies. The operator costs would amount to R3.05 in order to produce a passenger-kilometre of articulated bus service. However, the marginal total social cost for an articulated bus was R5.20, which is higher in comparison to that of the BRT standard bus service. In addition, the study found that marginal external cost (measured rand per passenger-km) ranged from 0.6% for a commuter rail service to 6% for a minibus taxi.

The failure of planning approaches to capture these external costs and user costs might have undesired consequences in the long term. For instance, for the Atteridgeville- Pretoria CBD corridor case study, when assessing based-on operator cost, it was estimated that the effective mode is the articulated bus. However, when assessed for total social costs, it was the BRT standard bus. The total social cost imposed by the articulated bus resulted from high user costs compared to the BRT standard bus. From the analysed corridor, the total social cost approach is important in unpacking the trade-off required to determine the transport mode required to service demand along a corridor. The modal hierarchy does not explicitly detail the trade-offs between the operator, user and external costs. The lack of detail might then result in unintended consequences in the long term.

TABLE OF CONTENT

ANNEXURE

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

AfDB	African Development Bank
ASC	Average Social Cost
BRT	Bus Rapid Transit
CBD	Central Business District
CITP	Comprehensive Integrated Transport Plan
CoCT	City of Cape Town
CoT	City of Tshwane
CSP	Cities Support Programme
DEA	Department of Environmental Affairs
DoT	Department of Transport
EC	European Commission
GDP	Gross Domestic Product
GDRT	Gauteng Department of Roads and Transport
GHG	Greenhouse Gas/es
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPTN	Integrated Public Transport Network
ITF	International Transport Forum
ITMP25	25-year Integrated Transport Master Plan
NATMAP	National Transport Master Plan
NMT	Non-Motorised Transport
NO_x	Nitrogen oxides
pkm	Passenger per kilometer
PRASA	Passenger Rail Agency of South Africa
RSR	Railway Safety Regulator
RTMC	Road Traffic Management Corporation
SARB	South African Reserve Bank
SDG	Sustainable Development Goals

SEA	Sustainable Energy Africa
StatsSA	Statistics South Africa
TCQSM	Transit Capacity and Quality of Service Manual
TCT	Transport for Cape Town
TDA	Transport and Urban Development Authority
TECs	Total External Costs
TOCs	Total Operator Costs
TSC	Total Social Cost
TUCs	Total User Costs
UN	United Nations
WHO	World Health Organisation

1. INTRODUCTION

The principles of sustainability and sustainable development should guide the provision of public transport; that is, there should be a balance between social, environmental, and economic costs (Department of Transport (DoT), 1996; Kennedy, 2002; Litman, 1997). Despite the acknowledged need to provide sustainable transportation (DoT, 1996), public transport provision is often based on financial considerations to the detriment of social and environmental considerations (Sun, Guo, Schonfeld, & Li, 2017; Cities Support Programme (CSP), 2018). Financial factors are emphasised because funding for transportation competes with other priorities in other sectors such as housing, healthcare, water, and so on.

Apart from direct costs in the provision of transport, other indirect costs are generated through accidents, emissions, congestion, and so on, but they are, in most instances, not borne by users of the transport system (Maibach, Schreyer, Sutter, Essen, Boon, Smokers, Schroten, Doll et al. 2008; Litman, 1997). From a welfare theory perspective, optimal prices charged to the users should also reflect external costs, and the failure to internalise external costs means that the use of the transport system is inefficient (Maibach et al., 2008). The quantification of not internalising costs in transport systems, together with the impacts this has, is well documented (European Commission (EC), 2019). Suffice to note that external costs have been found to range from 8% to 25% as a proportion of total costs in some studies (Avenali Catalano, Gregori, & Matteucci, 2020).

The failure to capture external costs may already occur in the planning stages. Transport planners typically depend on decision support tools, such as the use of a modal hierarchy approach to select an appropriate public transport mode or technology to service a particular demand along a specific corridor or route (Gauteng Department of Roads and Transport (GDRT), 2013; Transport for Cape Town (TCT), 2013). The modal hierarchy approaches used in South Africa typically segment the demand into categories where each category is assigned a technology. The lowest categories are commonly assigned technologies with the lowest capacity (such as minibus) and the highest demand categories are assigned high-capacity technologies (such as rail). The *25-Year Integrated Transport Master Plan* (GDRT, 2013) provides the rationale for using a modal hierarchy, although there is little research or documentation unpacking theories underlying a modal hierarchy approach. In South Africa, one of the detailed studies on modal hierarchy that needs to be taken into account is the peer-reviewed work done by Del Mistro and Aucamp (2000) in which they estimate the cost per one-way trip per direction per hour to evaluate the "optimum mode" for different demand segments. For instance, their work showed the relationship between monetary costs for different modes and the incremental demand levels for a 20 km one-way service. The review of the underlying concepts of the modal hierarchy approach as used by Del Mistro and Aucamp (2000) predominantly addresses aspects of financial and fiscal sustainability. These financial and fiscal sustainability metrics may not necessarily translate into overall system sustainability, in terms of balancing social, environmental, and economic factors (Sun et al., 2017).

The literature demonstrates the failure of decision support tools to capture other sustainability and sustainable development concepts (Pérez, Carrillo, & Montoya-Torres, 2015; Keshkamat, Looijen, & Zuidgeest, 2009; Browne & Ryan, 2011). In particular, the overemphasis placed on factors such as demand, financials and quality of service in technology selection has been criticised (Sun et al., 2017; Li & Preston, 2015). Whilst the literature underlines the importance of using sustainable approaches, important questions are left unanswered, such as: (i) How are the impacts of change in technology and policy intervention to be measured? (ii) What would be the impact of analysing sustainability? and (iii) How is consensus to be reached on sustainable policy measures? (Alonso, Monzón, & Cascajo, 2015).

Given the need to account for social and environmental costs in addition to economic impacts, the thesis evaluates the efficacy of using a total social cost approach as an alternative approach to mode selection in South Africa. This is because a TSC approach purports to comprehensively incorporate user, operator, and external costs (Avenali et al., 2020; Brand & Preston, 2003; Li & Preston, 2015). A TSC approach compares the average and marginal social costs for different public transport services or technologies along a corridor. The technology that results in society paying the least is then recommended (Brand & Preston, 2003; Li & Preston, 2015). The evaluation of total social costs is important in terms of driving work being done by policymakers to ensure that the transport costs are internalised and are not ultimately borne by society. Moreover, the thesis strives to contribute to the total social cost literature in developing economies, and in particular in South Africa. Finally, the thesis sets out to contribute to the broader literature on corridor analysis.

The thesis is presented in seven chapters as follows:

Chapter 1 is the introductory section and summarises the broad study aims.

Chapter 2 presents the research problem, questions, and objectives.

Chapter 3 presents the literature review on sustainable provision of transport, highlighting the balancing role the provision of transport has to accomplish in terms of costs and benefits. The relationship between internal costs and external costs is discussed with reference to welfare theory. The review also shows the importance of internalising costs in the provision of transport. Approaches that aim to internalise the costs in the planning phases are explored through reviewing the different families of approaches for selecting the mode of travel to service demand along a corridor.

Chapter 4 discusses the research design. The case study's limitations, assumptions and approach are pointed out.

Chapter 5 unpacks the Atteridgeville-Pretoria CBD case study and the reasons for selecting the corridor.

Chapter 6 presents the results of application of the research design to corridor selected for the case study.

Chapter 7 is the final section and it provides the concluding remarks and makes recommendation for future research.

2. RESEARCH PROBLEM, QUESTIONS, AND OBJECTIVES

2.1. Research problem

External costs are generated in the provision of transport (EC, 2019). These external transport costs include accidents, pollution, noise, visual intrusion and amenity loss (Ortúzar & Willumsen, 2011). It has been shown that some external costs are not borne (or internalised) by those responsible for generating them; however, the external costs are ultimately borne by society (EC, 2019). Moreover, studies have found that these external costs primarily affect vulnerable transport users, such as pedestrians and public transport users (Litman, 1999). Furthermore, studies have shown that these external costs as a proportion of a country's GPD are significant (EC, 2019).

Arguments are made to internalise the external costs to the system user that produced the external costs (Maibach et al., 2008; United Nations (UN), 2001). In contrast, there are also counterarguments against internalising costs, especially for low-income users (Litman, 1999). However, the counterarguments against internalising costs have been noted to be unsustainable in the long term (Litman, 1999). Policy instruments allow for the internalisation of transport costs through regulation-based and market-based mechanisms (e.g. taxes, charges, emission trades) (EC, 2019). Moreover, in terms of mitigating external costs, studies have also shown that external costs may be minimised by allocating the appropriate travel mode to service a transport corridor (Vu & Preston, 2020; Li & Preston, 2015).

Albeit the significance of external costs, there is little research in South Africa to inform how public transport modes should be allocated to corridors by minimising external costs and considering total social costs. Notwithstanding the work done by the National treasury that looked at the financial and fiscal sustainability of the current system (CSP, 2018; Van Ryneveld, 2014). For instance, in the modal hierarchy used in the Gauteng Province, there is little documentation on how external costs are minimised (Gauteng Department of Roads and Transport (GDRT), 2013). Therefore, more research is required in South Africa to incorporate external costs in supporting decision-making regarding which mode of public transport should be allocated to which corridor.

2.2. Study objectives

The following research objectives are adopted for the study:

1. To review approaches, and in particular the modal hierarchy type approach, currently used for selecting public transport modes internationally as well in South African cities.
2. To evaluate the effectiveness of the TSC approach for public transport mode selection and decision support in the context of South African cities.
3. To compare the TSC approach with existing mode selection frameworks in terms of resource requirements, quality of decision-making, ease of making decisions and sensitivity to key planning variables.

2.3. Research questions

The following research questions are adopted for the study:

1. To what extent is a modal hierarchy approach suitable for evaluating the sustainability of public transport mode selection?
2. To what extent is a total social cost approach effective for evaluating the sustainability of public transport mode selection in the context of a city in South Africa?
3. To what extent is a TSC framework suitable to support decision making about the mode of travel selection in South Africa as a developing country?

3. LITERATURE REVIEW

3.1. Introduction

The literature on sustainability and sustainable development in transport is discussed in this section. A review is done of studies that estimated the proportion split between internalised costs and costs that are borne by society in different countries. Then the impact of the excluded costs is discussed with reference to welfare theory. Finally, a review is done of families of approaches used to select a mode of travel along a corridor in terms of sustainability and sustainable development concepts and theories.

3.2. Sustainability

3.2.1. Sustainable development and sustainable transport

A transport system is an effective driver for economic and social development in any city (Miller, De Barros, Kattan, & Wirasinghe, 2016). Passenger and goods movement is essential for the competitiveness of a city (Gudmundsson et al., 2016). However, in "automobile-dependent" developments where transport and land use patterns result in increased private vehicle ownership and usage to the detriment of non-motorised and public transport, there tends to be long-term negative impacts (Litman, 1999).

A transport system, whilst it is important for economic development, can impact negatively on ecological integrity and biological diversity if the system is not properly designed and implemented (Gudmundsson et al., 2016). The detrimental impacts of the expansion of transport infrastructure on habitats are placed by the European Commission into three categories, viz., habitat loss, habitat fragmentation and habitat degradation (EC, 2019). The detrimental impacts are expected to increase with the increase in demand for travel. The International Energy Agency (IEA) anticipates, for example, that increased travel demand will require 60% more infrastructure worldwide by 2050, when baselined to the 2010 infrastructure (Dulac, 2013). This will clearly have significant financial, social and environmental impacts. The associated maintenance costs will also be considerable (Dulac, 2013).

The increasing need for mobility is also expected to result in an upward trend in the consumption of non-renewable resources (Dulac, 2013). Specifically, transport systems' consumption and reliance on oil contribute to the concentration of emissions and pollutants in the atmosphere; thereby contributing to climate change and global warming (Gudmundsson et al., 2016). The IEA's report estimated that 22% of the CO_2 emissions were due the transport sector (Dulac, 2013). Locally, the transport sector has also been found to release particulate matter, which directly impacts on human health and wellbeing. Also, it is forecasted that the transport sector's contribution will increase under the do-nothing scenario (or business-as-usual scenario), which has a significant climate and global warming consequences (Dulac, 2013). Whilst vehicle emissions are well investigated in transport, linking emissions to their exact emission location is problematic and, consequently, the number of people who are exposed to transport emissions and the country of origin of the emissions are unknown (EC, 2019).

From a social perspective, the transport sector imposes risks such as the risk of accidents, which was estimated to be 1% and 2% as a percentage of GDP for developed and developing countries, respectively (World Health Organisation (WHO), 2015). As the transport system expands because of increased travel demand, these impacts will also increase (Dulac, 2013; WHO, 2015).

To mitigate transport impacts and ensure that development is sustainable, there is a move to introduce vehicles that rely on energies other than primary fossil fuel energy, such as, hybrid, plug-in hybrid, and all-electric vehicles (Gudmundsson et al., 2016). In most countries, however, the primary energy source of these electric vehicles remains fossil fuels (IEA, 2020). There are also investments in moving people efficiently by means of public transport as a critical mechanism in reducing reliance on private vehicle usage whilst also enabling transport to continue (Miller et al., 2016).

The concept of a sustainable economy emphasises efficient use of natural resources and sensitivity to environmental and social constraints (Litman, 1999). In economics, sustainability is explored through concepts of market failures which deal with systems that create waste and fail to account for the long-term impacts (Litman, 1999). Richardson (2005) argues that conflict within transport provision may be summed up as a conflict between economic benefits and their social costs. To achieve sustainable transport planning, it is argued that long-term economic efficiency, equity, environmental and social enhancements should be taken into account (Litman, 1999).

In the literature, it is recognised that sustainability is a complex field of research. The complexity is attributed to the interdisciplinary nature of sustainability. As a result, there are several definitions of sustainability (Miller, 2014; Kane, 2010). Having noted that, sustainability is often explored through the concept of sustainable development, with the Brundtland Commission defining sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN, 1987:38). The concept of sustainable urban development, as initially defined, has been further explored and expanded within the field of transport through various studies (Newman & Kenworthy, 1996; Black, Paez, & Suthanaya, 2002). For instance, Newman & Kenworthy (1996) have argued that the adoption of Transit-oriented planning presents a viable sustainable solution, as it simultaneously improves a city's environment and economy.

Additionally, the research conducted by Black, Paez, & Suthanaya (2002) emphasizes that a sustainable urban transport and land use system should incorporate the following provisions:

- "Provides access to goods and services in an efficient way for all inhabitants of the urban area;
- Protects the environment, cultural heritage and ecosystems for the present generation; and
- Does not endanger the opportunities of future generations to reach at least the same welfare level as those living now, including the welfare they derive from their natural environment and cultural heritage."

Richardson (2005) points out that definitions of sustainable development and formulations of sustainable transport indicators typically depend on committees, meetings, discussions, and task teams appointed to investigate the topic and find empirical evidence. Kane (2010) also notes that sustainable transport indicators need to account for limited resources, uncertain political landscapes and changing policies.

Sustainability and sustainable development are defined in different ways by different institutions Newman & Kenworthy, 1996). Concepts are developed to explore a specific problem of for a specific concept (Alonso et al., 2015). This means that, when aiming for sustainable development in a specific context (such as in the context of transport as in this thesis), planning should take the following into consideration (Alonso et al., 2015):

(i) How can we measure the impacts of change in technology and policy intervention in our context?

(ii) What would be the impact of analysing sustainability in our context?

(iii) Must we reach consensus regarding a vision of a sustainable transport system?

(iv) And if so, how do we reach a consensus?

3.2.2. Triple bottom line framework

Irrespective of the definition that is adopted for sustainable development, the departure point for sustainable development and sustainable transport should be a "triple bottom line" framework that looks at sustainability in three dimensions, viz., economic, environmental, and social sustainability (Richardson, 2005; Jones Tefe, & Appiah-Opoku, 2013; Newman & Kenworthy, 1996). It should, however, be noted that the indicators that will comprise each of the categories, groups or themes in the triple bottom line framework, i.e., economic, social, and environmental, are different for various studies (Richardson, 2005).

Other studies expand on these themes, groupings, or categories (Newman & Kenworthy, 1996). Whilst most sustainability issues may be fitted into any one of the categories or groupings; there are some areas of overlap between the categories (Litman, 2006). The following broad definitions can be given of each of the categories in a triple bottom line framework for transport planning and development:

Economic: This category deals with issues of affordability, fair and efficient functioning, choices of transport mode and supporting a competitive economy as well as regional development (Alonso et al., 2015).

Social: The social aspects of the framework deal with issues of equity and inclusion (Miller, 2014).

Environmental: This category deals mainly with issues about how to limit vehicle emissions and transport waste to what the planet can absorb (Alonso et al., 2015). Common environmental issues include consumption of resources, anthropogenic climate change and degradation of local environments (Miller, 2014). Environmental issues will probably become more significant due to increases in GDP per capita and vehicle ownership (Department of Environmental Affairs (DEA), 2014).

3.2.3. Sustainable transport goals and indicators

Table 3-1 shows some of the internationally adopted development goals that apply to sustainable transport (SLOCAT Partnership, 2018). The United Nations developed sustainable development goals or SDGs, of which the most important goals relate to poverty, climate change and inequality. Despite the importance of the internationally adopted SDGs as they relate to transport, they have shortcomings, including an oversimplification of transport systems and a failure to represent inequalities accurately (Brussel, Zuidgeest, Pfeffer, Van Maarseveen, 2019).

Table 3-1: Transport-relevant SDG indicators

SDG number	Points of concern
3.6.1	The death rate due to road accidents
9.1.1	The proportion of the rural population living within 2 km of an all-season road
9.1.2	Passenger and freight volumes, by mode of transport
11.2.1	The proportion of the population with easy access to public transport, by sex, age and persons with disabilities
12.c.1	Fossil-fuel subsidies per unit of GDP (production and consumption) and as a proportion of total national expenditure on fossil fuels

(Source: SLOCAT Partnership, 2018)

Alonso et al. (2015) reviewed the commonly used urban transport indicators that focus on sustainable urban passenger transport systems. The review found that indicators are used differently within the triple bottom-line framework depending on the study under review (Alonso et al., 2015). For example, within the triple bottom line framework, issues may appear confined to specific categories; however, in practice, these issues often have primary and secondary effects that extend beyond their initial categorisation (Litman, 2006). The study by Litman (2006) cited pollution as an illustrative example. While pollution is commonly perceived as an environmental concern, it also significantly impacts human health, thus becoming a social concern. Moreover, pollution has far-reaching consequences on other industries, such as fisheries and tourism, creating economic challenges, and this example is further illustrated by Figure 3-1.

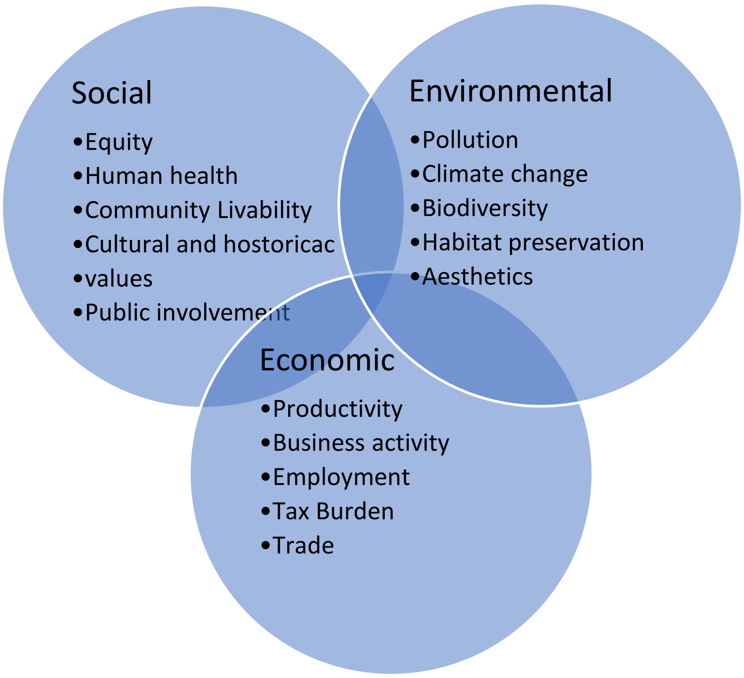


Figure 3-1: Sustainability issues

(Source: Litman, 2006)

3.3. South African perspective

3.3.1. Legislative and policy environment

The vision for the South African transport system set out in the *White Paper on National Transport Policy* articulates that the vision for the transport system, in South Africa, is to "provide safe, reliable, effective, efficient, and fully integrated transport operations and infrastructure which will best meet the needs of freight and passenger customers at improving levels of service and cost in a fashion which supports government strategies for economic and social development **whilst being environmentally and economically sustainable**" (DoT, 1996) (emphasis added). The *Draft Revised White Paper on National Transport Policy* (DoT, 2017) echoes similar objectives.

In addition to what is said in the vision statement, the *National Transport White Policy Paper* of 1996 sets out to develop approaches that are underpinned by principles and concepts of sustainable transport. To this end, the *White Policy Paper* lists the following policy goal or objective: "To invest in infrastructure or transport systems in ways which satisfy social, economic, or strategic investment criteria" (DoT, 1996).

3.3.2. Public transport provision challenges

In South African cities, a high proportion of transport users are captive to the public transport system (Cameron & Kingma, 2002). However, according to Statistics South Africa, public transport users increasingly find public transport systems inaccessible (StatsSA, 2013). The *Gauteng Household Travel Survey* analysis further found that the percentage of household income used towards public transport has significantly increased from a baseline of 2002 to 2014 (GDRT, 2014; GDRT, 2020). Similar patterns have been found nationally (StatsSA, 2013; StatsSA, 2020).

In terms of economic impacts, it has been shown that South African cities have the highest cost of transport as a percentage of GDP compared to cities in other countries (Van Ryneveld, 2014). The escalating costs of providing public transport services and the capital investments required have resulted in public transport systems which are financially, and fiscally unsustainable (Van Ryneveld, 2014).

According to a report released by the World Health Organisation (WHO) in 2015, there is a high accident risk associated with the South African transport system (WHO, 2015). A study by the Road Traffic Management Corporation (RTMC) shows towards the significant economic impacts of these accidents and it has estimated that the cost of crashes in South Africa is 3.4% of the total GDP of the country (RTMC, 2016).

Last, the transport system in South Africa also faces challenges in terms of environmental impacts as, in general, it contributes significantly to emissions and pollutions compared to other sectors. For instance, in terms of energy consumption, the transport sector performed significantly worse in category A and B municipalities, with the transport sector accounting for 60-70% of the total energy consumption and accounting for a third of the emissions produced (Sustainable Energy Africa (SEA), 2015).

3.3.3. Local sustainability indicators

Research done by Kane (2010) for the City of Cape Town is among the notable and comprehensive work in developing sustainable transport indicators at city level. The study by Kane (2010) argues that there are two pressing issues that sustainable transport provision in South Africa is confronted with, the first being, in the light of post-apartheid South Africa, social equity and social justice and the second, energy and climate change issues with the available economic resources constraining the debate.

Research by Hitge and Gqaji (2011) used a different lens, noting that transport in South African cities is characterised by dual economies, with one economy servicing the affluent and the other servicing the needs of the poor and disadvantaged. The transport economy servicing the rich is characterised, according to Hitge and Gqaji (2011), by access to private vehicles and rapid rail service such as the Gautrain, whereas the poor are captive to public transport services.

Table 3-2 shows the sustainable transport indicators developed for the City of Cape Town through an extensive consultative process in collaboration with Sustainable Energy Africa (Kane, 2010). The indicators were intended to inform sustainable transport in the City of Cape Town and were developed over a period of 14 years, with specific focus on the period from 2007 to 2009 (Kane, 2010). The study provides a detailed account of the process through which sustainability agendas are translated into indicators, considering various constraints such as staff resources, volatile politics, and evolving policy priorities (Kane, 2010). The indicators developed for the City of Cape Town aim to assess the performance of the transportation system, track progress towards sustainability objectives, and identify areas for enhancement, all with the ultimate goal of ensuring that resource allocation is guided by a sustainability agenda rooted in the triple bottom line principles (Kane, 2010).

Table 3-2: Sustainability transport indicators for Cape Town

Indicator	Unit
Environment	

Indicator	Unit
Energy use for transport	Consumption of non-renewable resources (litres or MJoule)
Greenhouse gas (GHG) emissions	Total GHG emissions (megatonnes of CO_2 equiv.)
Per capita expenditure on roads and parking supply services	Total GHG emissions (megatonnes of CO_2 equiv.)
Commuters using non-motorised transport (NMT) as main mode	Percentage
Population living within 500 m of nearest public transport facility and service	Percentage
Public right of way (+ public parking) per capita	m^2/capita
Economic	
Average total journey time	Time unit
No. of job opportunities, commercial services and educational facilities within 5 km of residents	Number
Modal split	NMT: mass transit: private transport
The ratio of No. of daily passenger trips by public transport: Public transport standing + sitting capacity	Utilisation: capacity
Generalised cost of movement of goods and services	Percentage of the total cost of goods and services to the customer
Condition of transport infrastructure	Visual condition index of 70+
Social	
The portion of household income devoted to transport	Percentage
Per capita accident cost for fatal and serious accidents only	Rands/persons involved in accidents
Accessibility of infrastructure by mobility disadvantaged, children, elderly	Survey: During a typical week day trip on a typical journey, count the number of inaccessible locations; sum all and determine average
Car and bicycle ownership per 1 000 population	Number of cars and bicycles per 1 000 population

Indicator	Unit
Transport impacts on community liveability	Survey: Converted to a scoring unit
Public participation	Structured sessions with civil society and other transport stakeholders

(Source: Kane, 2010)

3.4. Public transport costs

Cost for public transport system comprises fixed costs and variable costs (Litman, 1999). Fixed costs are standard and independent of the use of the vehicle, i.e. insurance, salaries and depreciation (Litman, 1999). Gattuso and Restuccia, (2014) notes fixed cost as Investment costs includes all the purchases of components that are required for production for the public transport services.

Variable transport costs are expenses directly associated with vehicle usage, such as fuel, travel time, and the risk of accidents, they are considered as variable costs. Sunk costs are defined as costs that have zero resale value or those that have exceeded their economic life (UN, 2001). In practise, it is not always clear whether to classify some costs as fixed costs or as sunk costs (Gattuso & Restuccia, 2014).

The total social cost framework expands on the framework of fixed and variable costs by accounting for external costs and non-market costs (Litman, 1999). The following is the unpacking cost concepts:

- **Internal versus external costs**: Internal costs refer to the costs that are borne directly by the consumer of a good or service whereas external costs are usually costs generated by a sector or a market but borne indirectly by society rather than directly by the consumer (Litman, 1999). In terms of transport, Jakob, Craig and Fisher (2006) define internal cost as "out-of-pocket" costs, money paid to access a transport system by the user. The *Handbook on external costs of transport* (2019) identified seven main externalities of transport, i.e., accidents, air pollution, climate change, noise, congestion, well-to-tank emissions and habitat damage (EC, 2019).
- **Market versus non-market costs**: Market costs involve goods and services regularly traded in a competitive market, whereas non-market costs include costs that are not regularly traded in the market, i.e., air quality, risk of accident, and noise (Litman, 1999).

3.5. Total social costs

The total social cost of transport includes direct and indirect costs while the market prices of transport do not cover the full costs (Quinet, 1997). The estimation of the total social cost of transport is argued to be complex because there is no agreement on the estimation of indirect costs (Quinet, 1997).

Indirect transport costs that are disputed include, for example, environmental costs and safety costs (Quinet, 1997).

Work has been done to estimate the total magnitude and distributions of the transport cost (Litman, 1997; Gudmundsson et al., 2016; EC, 2019). Studies have found that external costs accounted for a significant portion of total costs. In transport systems, the externalised costs include costs associated with accidents, pollution, noise, visual intrusion and amenity loss (Ortúzar & Willumsen, 2011). In one study, external costs were estimated to be 2.23% of the GDP and private transport costs accounted for 28 times the cost of public transport (Jakob et al., 2006). A separate study estimated that external costs as a percentage of GDP in the European Union ranges from 3.4% in Norway to over 7% in Portugal and Luxemburg (EC, 2019).

The economic argument for internalising the indirect costs has been thoroughly explored by Litman (1997), Gudmundsson et al. (2016), and the EC (2019). The arguments explored include the failure to internalise the indirect costs, which means that society bears the burden of these costs. Moreover, capital investments that could have been utilised elsewhere in the economy are instead used to subsidise the underpricing of the transport system.

The internalisation of transport costs also depends on the assessment. For instance, from an economic efficiency perspective, marginal costs should be considered whereas, from the "equity" perspective, average costs should be included (EC, 2019).

A literature review explored by Profillidis, Botzoris and Galanis (2014) the environmental effects and externalities associated with the transport sector. The review examined the causal relationship between per capita GDP, annual global GDP growth, and CO2 emissions. Additionally, the paper investigated the correlation between traffic flow and noise emissions and delved into the implications of transport infrastructure on the landscape and environmental aesthetics (Profillidis, Botzoris & Galanis, 2014). Moreover, the study addressed the implications of increased global mobility on social and public health, raising concerns about transport accidents and their impact on injuries, impairments, and fatalities. Lastly, the paper reviewed the externalities generated by the transport sector and quantified their magnitudes. The study concluded by discussing the potential effects of internalizing these external costs (Profillidis, Botzoris & Galanis, 2014).

A later study by Litman (1999) identified several issues concerning underpricing transport costs:

(i) It encourages people to make trips they would otherwise not have made and these extra trips result in additional external costs.

(ii) It encourages land use developments that promote private vehicle usage at the detriment of other modes.

(iii) It results in adverse environmental impacts.

There is, however, also an argument to be made for the exclusion of external costs and Litman (1999) points out that, in the short term, underpricing enables a more equitable use of transport modes. According to Litman (1999), underpricing allows the participation of low-income private vehicle users but this argument was found to be unsustainable in the long term (Litman, 1999).

Various policy instruments are proposed to allow for the internalisation of transport costs and these include regulation-based as well as market-based instruments (e.g. taxes, charges, emission trades) (EC, 2019). It is possible to combine these instruments in order to internalise costs, although market-based instruments are the most efficient method of internalising the costs (EC, 2019).

In estimating the total social costs, Avenali et al. (2020) conducted a comprehensive analysis that incorporated exogenous demand, meaning that improvements in service levels did not influence the shift in passenger demand across modes of travel. Additionally, the study investigated factors that could make the bus system more economically desirable in comparison to the rail system. The researchers proposed an approach that treated capital investment costs in rail and road infrastructure as sunk costs. This proposed approach was applied to an Italian case study. The study's findings were that buses have lower total social costs compared to rail at the current demand level in the case study. However, the study acknowledged certain limitations, suggesting that future research should consider incorporating the introduction effect of endogenous demand. Furthermore, it should simulate the factors that influence the economic viability of the bus and rail modes and vice versa. Lastly, the study emphasised the importance of conducting a detailed geographic analysis by incorporating land use into the analysis.

3.6. Overview of technology selection

The selection of the public transport mode or technology, which relies on spatial resolution, constitutes a critical stage in transport planning (Vuchic, 1976; Ortúzar & Willumsen, 2011; Shirzadi et al., 2013). The suitability of public transport modes (or technology) is contingent upon the spatial attributes of the serviced area, taking into account factors such as population density and distance covered (Scorcia & Munoz-Raskin, 2019). In the context of South Africa, Scorcia and Munoz-Raskin (2019) conducted research to assess contrasting urban form factors, which led to the identification of specific characteristics in South African cities' transport systems. These characteristics include long travel distances, and unidirectional trips with high peak-to-base ratios, distinguishing them from their Latin American counterparts. Although variations exist across different hierarchical planning resolutions, it is acknowledged that there are inter-dependencies between urban form and mode of travel (Vuchic, 1976).

Public transport technology selection criteria aim to find a balance between supply and demand and there are generally two types of responses to the technology selection problem in response to a change (increase or decrease) in demand (Sun et al., 2017). Sun et al. (2017) explains that, in the case of an increase in demand, the supply can be adjusted to meet the demand by improving the level of services through an increased service frequency. This would mean that the technology used remains the same even if the system capacity increases. Second, it may happen that the demand levels increased in a way that increasing system capacity results in congestions or is simply not feasible and then a partial or full replacement of the current technology may be introduced. In the case of partial replacement, the transport system is generally implemented in phases; that is, a particular portion of the network will be prioritised, with another part of the route continuing to be serviced as usual. In the case of a full replacement, the route length of the service generally gets replaced by the proposed technology with a supporting feeder system if warranted. This latter scenario is true of the focus of this study.

Several approaches are currently used worldwide when planning and allocating a technology or mode of travel to service an estimated demand along a transport corridor. Most studies agree that selecting a public transport mode or technology for a particular corridor should mainly be based on the demand to be served, although other factors, including external costs, should also be considered (Sun et al., 2017). The approaches and methods discussed here are not meant to be exhaustive. However, the aim is to highlight the extent to which families of approaches considers the concepts of sustainability and sustainable development using the triple bottom line lens for evaluation, i.e. environmental, financial, and social issues. Among the families of approaches that will be reviewed are (i) approaches that emphasise financial aspects, (ii) those that look at the service quality, and (iii) those that follow a holistic approach by considering financial, social and environmental issues.

3.6.1. Families of methods and approaches

One approach to allocating a technology to a particular corridor to service the demand is to estimate the financial cost of providing the service by using the different technologies and to select the technology that costs the least. For instance, Casello Lewis, Yeung and Santiago-Rodríguez (2014), where a model was developed that selects a technology based on computed annualised costs and the technology that will cost the least is then selected. The model is based on user and operational datasets. The study found that small changes in input variables result in changes in the selected modes to service demand along a corridor.

Chen, Li, and Lam (2015) approached the problem differently by proposing a model that selects a technology based on maximising social welfare. The model achieves this by optimising a combination of factors, including public transport line length, the number and locations of stations, station spacing, headway, and fare. The study examined the selection of alternative modes of public transport from the perspective of transport authorities. The investigation encompassed modes such as metro, light rail transit, and bus rapid transit. Various scenarios were conducted, considering factors such as population density, transit investment cost, transit line parameter design, and the comparison between social welfare maximisation and profit maximisation regimes. Notable findings indicated that the type of public transport, urban population density, and public transport market conditions influence the optimal solution for the public transport line being investigated. Furthermore, the viability of capital-intensive projects was found to be significantly impacted by the phasing of investments.

Besides financial costs, a total social cost approach introduces external costs and user costs. The total social cost model evaluates for a given corridor or routes the sum of total operator costs, total social costs, and total external costs for different technologies and the technology with the least cost to society selected (or allocated) (Li & Preston, 2015). The following costs are considered in terms of external costs: environmental and risks of accidents. In terms of the user costs, travel time-related costs are considered.

A study by Brand and Preston (2003) followed a total social cost approach in an Oxford case study to evaluate 10 different public transport systems. The total social cost associated with the various technologies was estimated as a demand function in the study. The result was demand segments associated with a technology that results in the least societal cost. The study by Li and Preston (2015) further developed the total social cost model by relaxing the assumption around speed-flow curves, introducing queue models, and changing the demand model to be endogenous in response to the service quality attributes such as waiting and travel time.

Besides the static models, there are also dynamic models which are outside the scope of this study. Suffice to say, to account for the ramp-up of the demand and required changes in terms of technology allocation, there are also Dynamic hybrid approaches. A two-stage approach (i.e. first stage is static and the second stage is a dynamic model) is used by Sun et al. (2017) to select a public transport technology to service a demand along a particular corridor. In the first phase, a static model was built and forecasted over a planning horizon. The model developed also considered a transition between bus only, partial rail and bus and finally, full rail service. In the final phase, a separate dynamic model was created to look into different factors that make economic sense to start implementing a full rail service given the economies of scale.

Research was done by Vu and Preston (2020) to estimate the total social cost modes for low and middle income countries with a corridor of 7 kilometres in length in Hanoi, Vietnam for their case study. One of the reasons for the study was the lack of studies comparing the costs associated with motorcycles, cars, demand-responsive and public transport technologies in order to identify the most cost-effective transport mode. The Vu and Preston (2020) study found that motorcycles were best suited for low demand levels areas and bus service were best suited for medium to high demand level areas. Worth noting is that the research by Vu and Preston (2020) adopted the exogenous demand in the evaluation of total social cost for low-income countries. The study argued that for low and middle countries, the public transport users are captive to the public transport system.

Some approaches, such as Hubbell , Wirasinghe, McKendrick, Morgan, Wong, and Thilakaratne (2009) looked at the quality of the service required in order to allocate the public transport technology required to service demand. They then develop an approach that selects a technology based on capacity and service speed as these attributes directly impact the waiting times and in-vehicle times as well as on operating costs.

Some studies use multi-criteria decision-making approaches to identify a route, allocate a technology, and determine the level of service required. For instance, Shirzadi et al. (2013) followed a multi-criteria decision-making approach to allocate technology to a specific corridor considering several factors and geospatial elements.

Most of the transport technology selection approaches discussed estimate the net economic benefits and the technology with the most economic benefits is selected to service demand along a particular corridor. A total social cost and multi-criteria decision-making approaches, by contrast, explore impacts beyond net economic benefits. These approaches also consider environmental and social impacts.

3.6.2. Technology selection in South Africa

The review of mode section approaches in South Africa to service demand along a corridor or along a route was not meant to be exhaustive. Most of the transport plans do not include the rationale used for selecting a specific approach over another from the reviewed literature. In South Africa, two categories of approaches that need to be taken note of are prescriptive and performance-based approaches. Prescriptive approaches focus primarily on allocating modes of travel as a function of demand whilst performance approaches expand on that by introducing other public transport-related performance measures (GDRT, 2013; City of Cape Town (CoCT), 2016; TCT, 2013). The approach used by the *Gauteng 25-year Integrated Transport Master Plan* (Gauteng ITMP25) is prescriptive, whilst that used in the City of Cape Town is a performance-based approach (GDRT, 2013; CoCT, 2016; TCT, 2013).

In the Gauteng ITMP25 the Gauteng Department of Roads and Transport (GDRT) identifies challenges to urban transport in Gauteng, which include the following:

- The land use layout is not supported sufficiently by the public transport system
- There is a lack of policy implementation, a high frequency of policy change and several implementing authorities are siloed in their approach
- The level of service of the current operating service is below internationally acceptable standards (GDRT, 2013).

One of the solutions offered to address the identified challenges include establishing an Integrated Public Transport Network (IPTN) to address the fragmented mode-specific routes that serve a variety of origin-destination pairs (GDRT, 2013). As a guiding principle, the Gauteng ITMP25 states that they will aim for “network hierarchy and continuity; meaning different modes will be deployed where appropriate, linking the different networks in an effort to ensure passengers can travel throughout the province by using one ticket and transferring at acceptable interchanges” (GDRT, 2013:36).

The Gauteng ITMP25 establishes the role of modes and service hierarchies to direct mode allocation (GDRT, 2013). The principles of network hierarchies are functions of specific links and corridors in an integrated public transport network. These functions are determined by the passengers' level of mobility and access when travelling on specific links (GDRT, 2013).

The modal hierarchy type approach, as explained in the Gauteng ITMP25, generally looks at demand segments in transport, where each demand segment is then assigned a mode of travel. The segments with the lowest demand are typically assigned technologies with the lowest capacity where segments with the highest demand are assigned high capacity modes of travel.

Figure 3-2 shows the modal hierarchy technology selection criteria for the *Gauteng 25-year Integrated Transport Master Plan*. Besides demand, another technology criterion is the length of the corridor. A review of the *Comprehensive Integrated Transport Plan* (CITP) of 2013, which has been developed by the Transport and Urban Development Authority (TCT, 2013), shows that most cities in South Africa have a similar modal hierarchy.

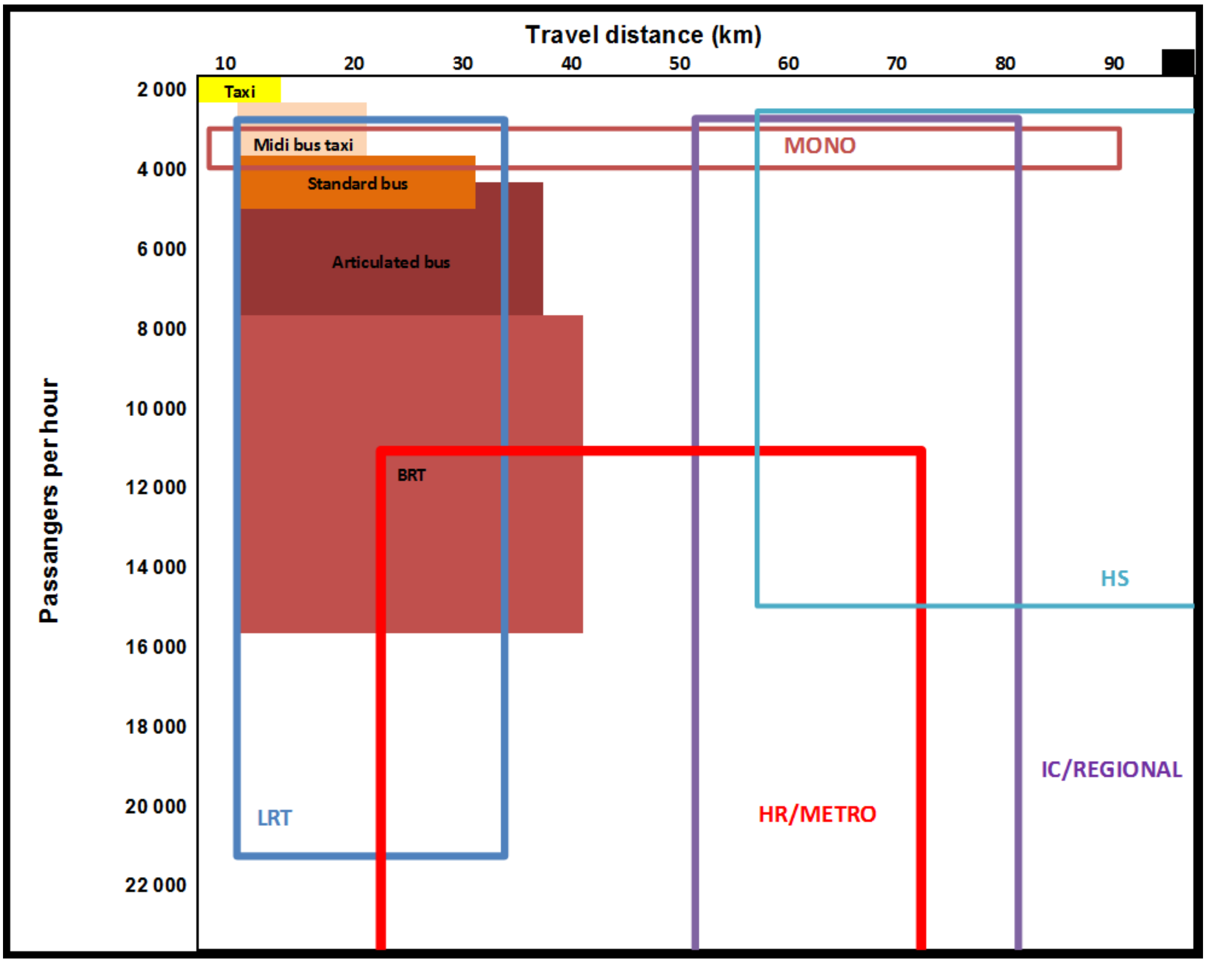


Figure 3-2: The *25-year Integrated Transport Master Plan* modal hierarchy

(Source: GDRT, 2013)

Cities in South Africa typically rely on strategic transport models to estimate the travel demand for specific corridors and route alignments (CSP, 2018). The strategic models enable the planner to identify bottlenecks and inefficiencies at a city-wide level (Ortúzar & Willumsen, 2011). Then, by using a modal hierarchy approach, specific modes of travel are selected based on the demand along the given routes.

Table 3-3 shows the different factors used to select an appropriate mode of travel, including capacity, travel speed, and frequency of service for the City of Cape Town (TCT, 2013). Like the approach prescribed by the *Gauteng 25-year Integrated Transport Master Plan*, the approach adopted in the Cape Town is based on demand segments. However, in Cape Town other performance-based measures are also introduced in allocating the transport mode to corridors.

Table 3-3: Four levels of the hierarchy of the IPTN (City of Cape Town)

Services	Cape Town Spatial Development Framework	Capacity (pax/hr/dir)	Average operating speed (km/hr)	Frequency/ headway (min)	Station/stop spacing (m)	Service type	Technology
Level 1 (Trunk and express service)	Metro-regional level	20 000 – 50 000	35 – 60	5 (peak) 10 (off-peak)	1 500 – 3000	Dedicated right of way	Heavy rail
Level 2 (Trunk)	Metro-regional	5 000 – 20 000	30 – 40	8 (peak) 15 (off-peak)	1 000 – 1 800	Semi-dedicated right of way	Heavy rail, light rail, BRT
Level 3	District-local	2 000 – 7 000	25 – 35	15 (peak) 30 (off-peak)	500 – 1 200	Feeder distributor	Light rail, BRT, bus, minibus taxi
Level 4	Neighbourhood	0 – 3 000	5 – 30		< 500	Local access	Minibus taxi, metered taxi, and alternative technologies (pedicabs, tuk-tuk)

(Source: TCT, 2013)

3.7. Summary

The literature review of relevant studies and policy documents has yielded the following important findings:

- A business-as-usual approach where nothing changes in transport planning is unsustainable, especially considering environmental impacts, such as high levels of emission gases, or new infrastructure required to support increases in demand for travel.
- It was highlighted that some costs are externalised from costs calculated to provide transport to users and these external costs are ultimately borne by society. External transport costs further make up a significant percentage of the total costs in transport or as a proportion of the GDP.
- The argument for internalising the total costs was discussed with reference to welfare theory. It was noted that the result of users not bearing total transport costs is an inefficient transport system.
- The counterargument for internalising total costs was also presented. Proponents who are against internalising all costs argue that this prevents participation of low-income users. However, this argument was found to be unsustainable in the long term.
- Various approaches used to select a mode to service demand along corridors were detailed. In summary, there are varying degrees to which the different families of approaches account for the different facets or categories of sustainability.
- The legislative and policy framework governing the provision of transport in South Africa supports the provision of sustainable transport.
- In brief, questions that can be asked about the evaluation of sustainable transport include:
    - How can we measure the impacts of change in technology and policy intervention in our context?
    - What would be the impact of analysing sustainability in our context?
    - Must we reach consensus regarding a vision of a sustainable transport system?
    - And if so, how do we reach a consensus?

4. STUDY AREA – ATTRIDGEVILLE-PRETORIA CBD CORRIDOR

4.1. Introduction

This section outlines the study area. In South Africa, transport planning authorities are engaged in implementing the Integrated Public Transport Networks (IPTN), and the City of Tshwane is one such city (CSP, 2018; City of Tshwane (CoT), 2015 & 2018). The *Comprehensive Integrated Transport Plan* (CITP) of 2015 has identified several corridors for the City of Tshwane, among which the Atteridgeville-Pretoria CBD corridor (CoT, 2015). The Atteridgeville-Pretoria CBD corridor was selected as focus for this case study in order to evaluate the effectiveness of the approaches for selecting a mode of travel to service demand. The reasons for choosing this study area are the following:

- To get insight in the approaches used by South African authorities to allocate modes of travel, especially in their effort at improving access to historically advantaged areas.

To shed light on mode selection approaches, especially as they relate to sustainable transport provision.

Figure 4-1 shows the locality map of the City of Tshwane Metropolitan Municipality in South Africa. The City of Tshwane Metropolitan Municipality encompasses Pretoria (the administrative capital of South Africa). The City of Tshwane Metropolitan Municipality is the largest municipality by land mass in the country (SAG, 2021). According to the 2011 census, there are 2.9 million residents in this municipality. The Municipality is the second greatest contributor to the GDP of the Gauteng Province. The 2011 census also recorded that the population growth rate was 3.1% per annum between 2001 and 2011 while the population density was measured to be 464 persons/km^2. At the time this dissertation was written the South African National Census of 2022 was being performed so that this new data could not be used for the dissertation.

Figure 4-1: City of Tshwane's locality map

(Source: CoT, 2021a)

Figure 4-2 shows the locality map of the Atteridgeville-Pretoria CBD inside the City of Tshwane. The study area is located on the western side of the City of Tshwane and for planning purposes the City of Tshwane has included the study area in Region 3.

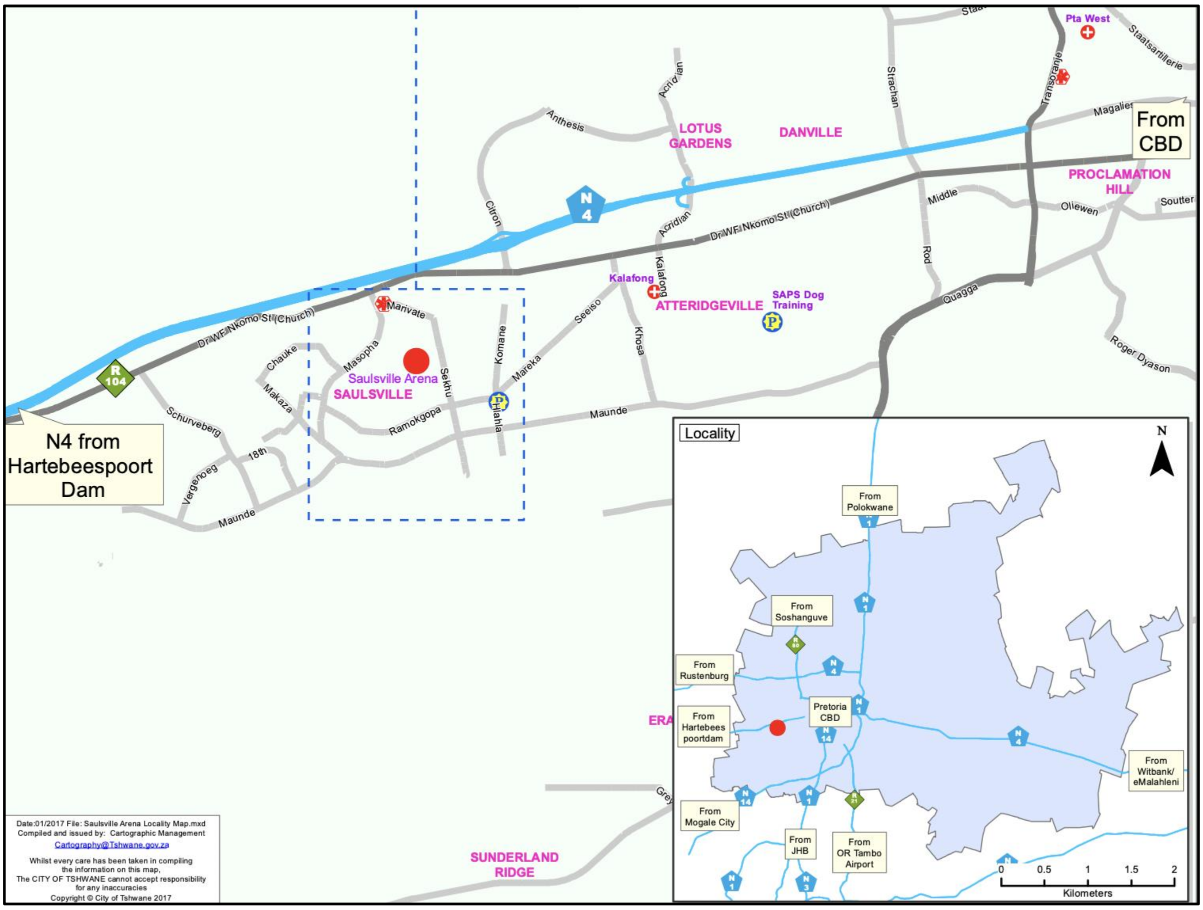


Figure 4-2: Atteridgeville locality map

(Source: CoT, 2021b)

4.2. Socio-economic information

According to the *Gauteng Household Travel Survey* (GHTS) of 2013, there are 83 396 households within the Atteridgeville -Pretoria CBD corridor and the average house sizes range from 2 (in the Pretoria CBD) to 3.4 (in Atteridgeville) persons per household. The mean household income is R5 191 in Atteridgeville and it rises to R9 711 in the Pretoria CBD. Whilst the average household income in Atteridgeville is comparable to that of other townships in the Gauteng Province, it is below the city's average of R7 023.

4.3. Supply road network

Figure 4-3 shows the boundaries of the study area by means of a blue dotted line. The selected corridor boundary is based on the existing databases in Tshwane, such as the traffic analysis zones and sub-regions described in the (GHTS) of 2013. The east to west mobility routes include the R104 (WF Nkomo Road) and the N4 national highway. South to north mobility is ensured through the R55.

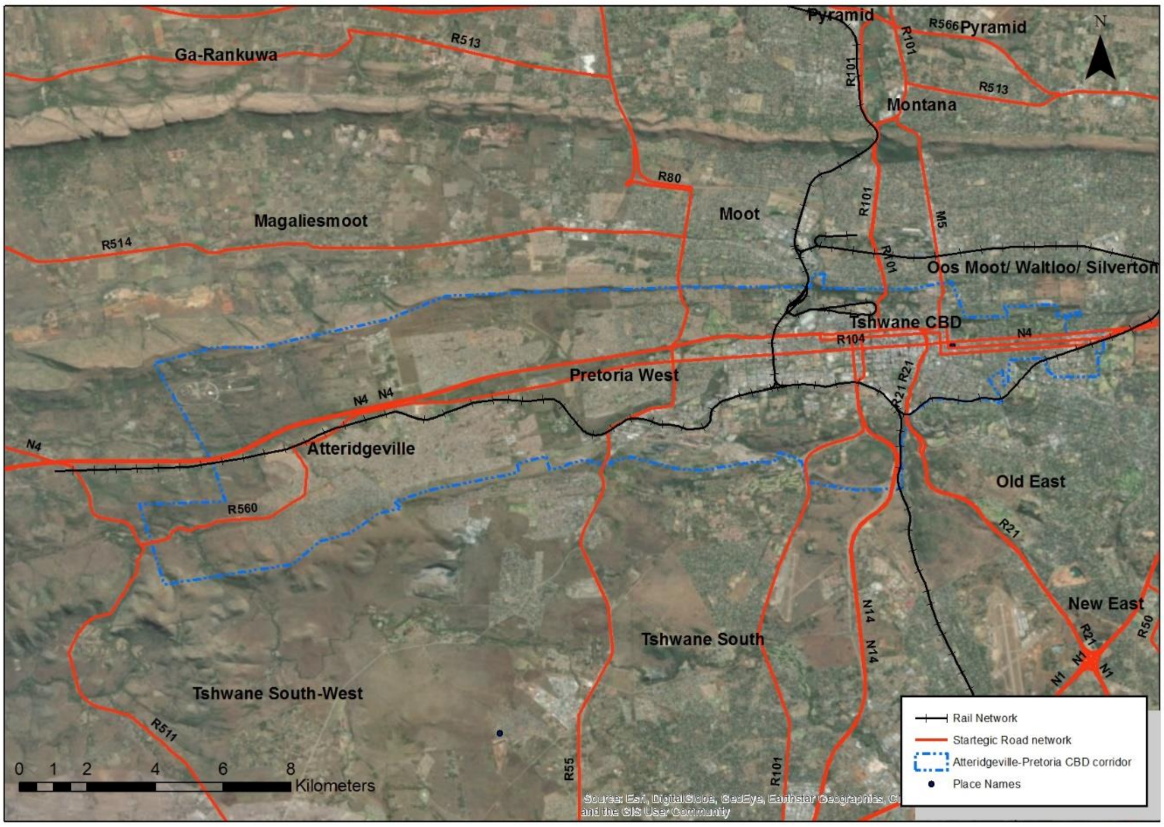


Figure 4-3: Case study area

(Source: Drawn by author from the (DoT, 2016) dataset using ArcMap)

4.4. Land use

Figure 4-4 shows the land use along the Atteridgeville-Pretoria CBD corridor. The displayed land uses are obtained from the *National Transport Master Plan* (NATMAP) of 2016. The land use in the corridor is predominantly residential while a considerable proportion of the land is also used for military purposes. There are also open green areas in and around Atteridgeville.

In terms of traffic flow, the primary activity node is the Pretoria CBD and, therefore, it can be expected that the direction of traffic flow during morning peak periods will be from west to east in the Pretoria CBD.

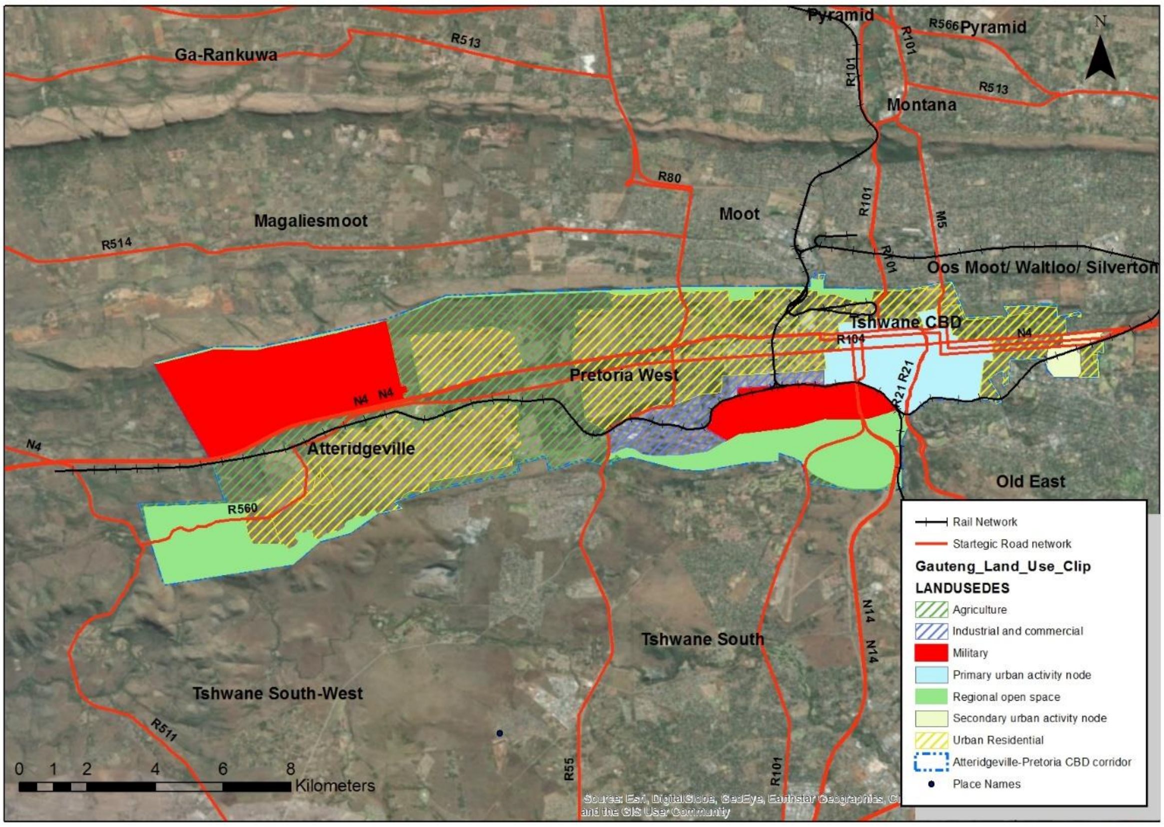


Figure 4-4: Land use along the case study area

(Source: DoT, 2016)

4.5. Proposed public transport plans

In terms of short-term planning, the *Built Environment Performance Plan* (BEPP) of the City of Tshwane (CoT, 2018) was reviewed to identify transport projects earmarked for Region 3. Figure 4-5 shows the areas within the City of Tshwane that are prioritised for capital expenditure. The City of Tshwane identified focus areas in the Municipal Spatial Development Framework (CoT, 2018), and the Atteridgeville-Pretoria CBD corridor was highlighted in this document. The corridor has been earmarked for 11% of the city's budget for spatial transformation in the 2018/19 Medium Term Revenue and Expenditure Framework (CoT, 2018). The *Built Environment Performance Plan* however, does not unpack exactly what is meant by "targeted FOR spatial transformation" (CoT, 2018).

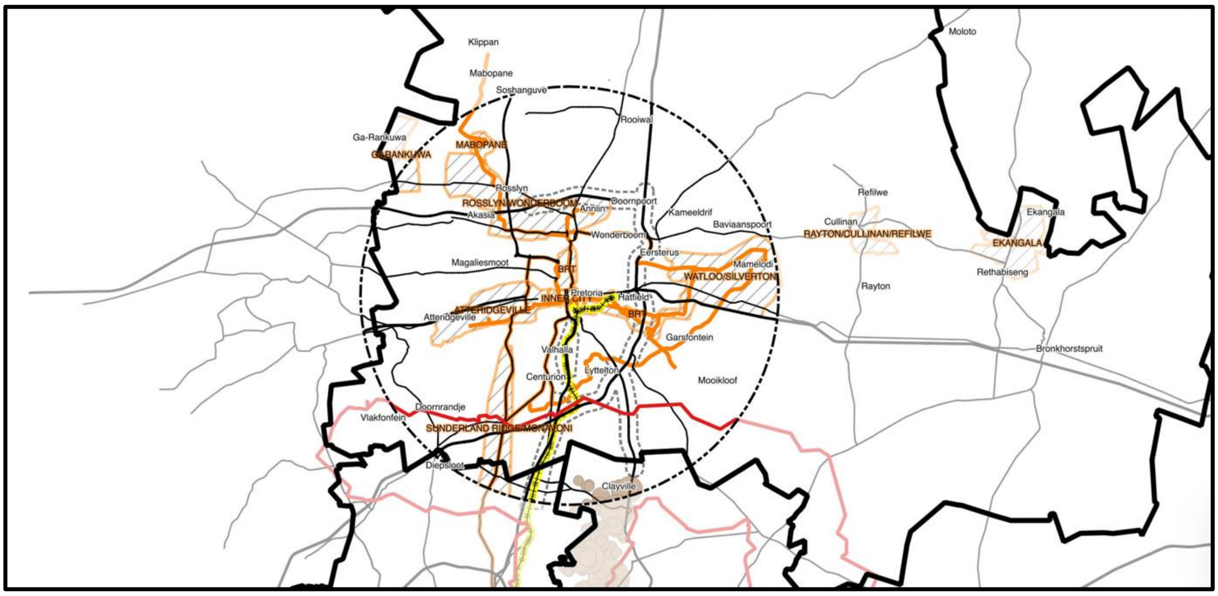


Figure 4-5: 2018/2019 Capital expenditure – Project within 5km of the administrative border

(Source: CoT, 2018)

In terms of long-term planning, there are several corridors that have been earmarked by the City for spatial transformation, which includes refurbishing rail services and introducing the Bus Rapid Transit system. Figure 4-6 shows the City of Tshwane's proposed public transport network in the long term (CoT, 2015). For the Atteridgeville-Pretoria CBD corridor, two route alignment are proposed which are highlighted in blue, viz., Paul Kruger-Maunde Station (Line 2.1) and Quagga Road Saulsville Station (Line 2.2). It is important to note that the Atteridgeville line is supported by PRASA's passenger rail service (Rail Line 5 Saulsville-Rebecca).

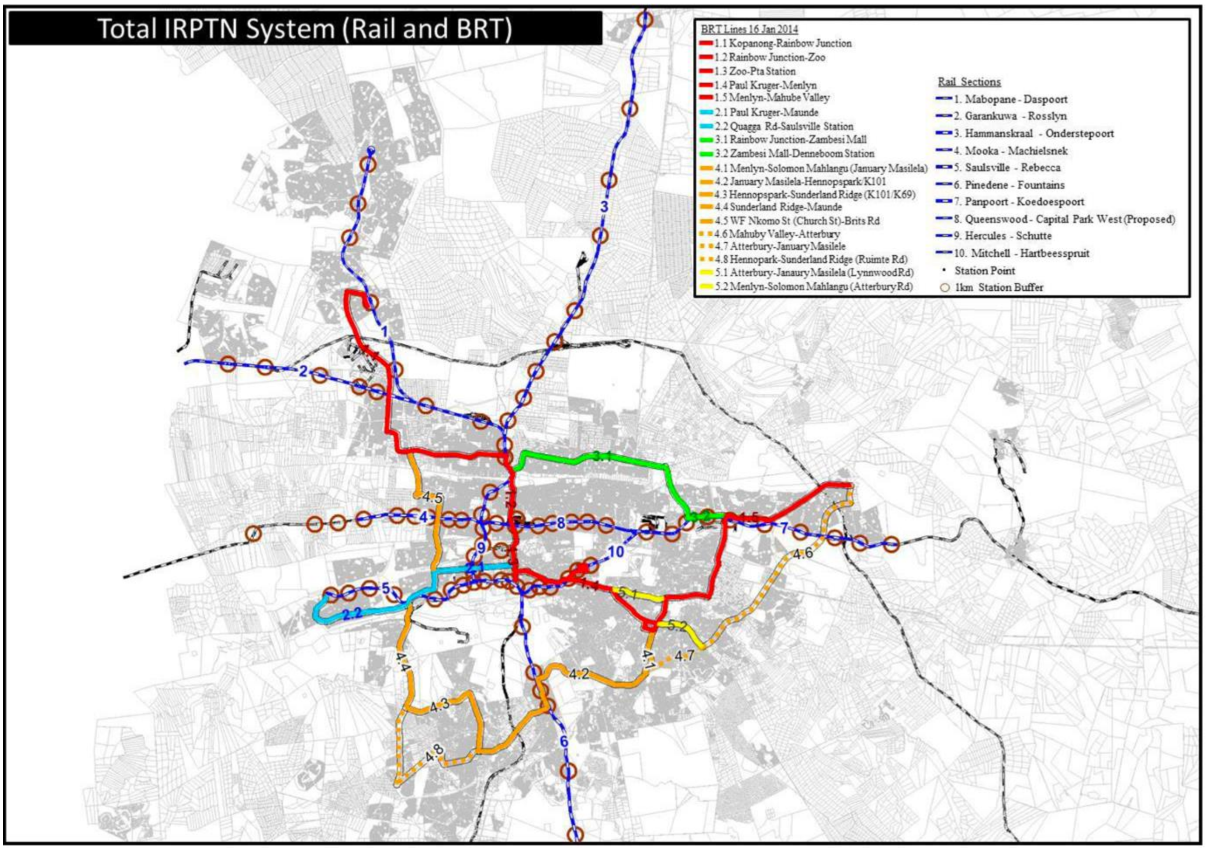


Figure 4-6: Proposed Integrated Public Transport Network for the City of Tshwane

(Source: CoT, 2015)

4.6. Travel patterns

Figure 4-7 shows the main mode of travel in each node in the corridor under question for a typical weekday during the morning peak period (06h00 to 09h00). From this, it is clear that walking all the way and private vehicle usage are the most common modes of travel. Where public transport is concerned, there is a high usage of the minibus taxis and bus services along the corridor. For the Atteridgeville node, the rail services are important as a travel mode.

Whilst focus is limited to the study area, i.e. Atteridgeville-Pretoria CBD corridor, it is recognised that some of the trips that pass through this corridor will be destined for areas lying to the south of the corridor, such as Centurion, Midrand and the Greater Johannesburg region. It is also to be expected that trips will have areas to the north as final destination, such as the Rosslyn industrial node. In addition, the growing strategic importance of the Menlyn node means some of the trips will be destined to the far Pretoria East, outside the corridor selected for this study. The strategic model was used to limit the trips to only those within the Atteridgeville-Pretoria CBD corridor.

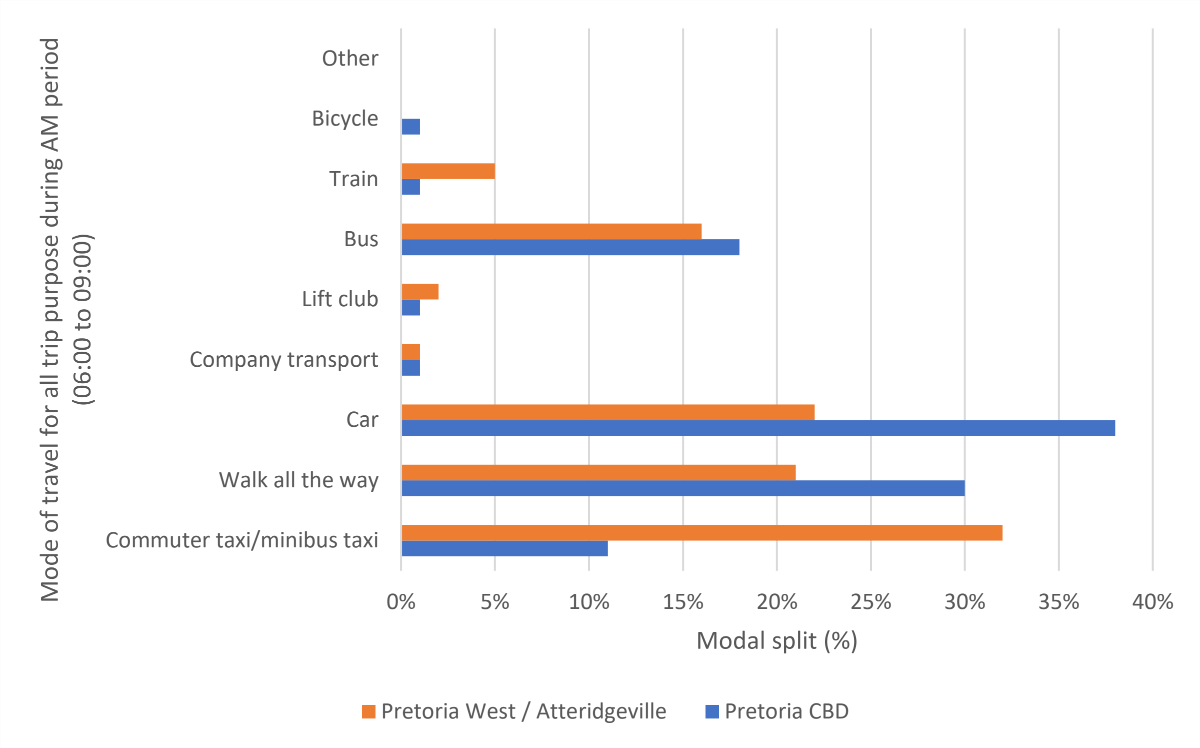


Figure 4-7: Modal split along the corridor at the different nodes

(Source: Drawn by author using *Gauteng Household Travel Survey* (GHTS) of 2013)

Table 4-1 shows the summary of the inputs for the Atteridgeville-Pretoria CBD corridor. Estimated indicators were used as inputs into a computational model. The demand was estimated using the province's ITMP25 transport model, which had been developed on the *EMME*-4 platform (a transport forecasting system). According to the strategic transport model, 30 051 people are moving along this corridor per hour in both directions. The following assumptions were also made:

- 16 528 trips were assumed to be motorised trips along the corridor;
- To represent motorised transportation within the corridor, a modal split of 55% for motorised trips was adopted. The analysis takes into account the lower limit of the public transport modal split between the two nodes. Despite the household travel survey indicating a 70% motorised trip rate, this estimation factors in trips that extend beyond the originating zones while excluding intra-zones as shown in Figure 4-7;
- 80% of the public transport users were assumed to heading towards town and 20% towards Atteridgeville; and
- There were sufficient feeder services for higher capacity modes.

Table 4-1: Atteridgeville-Pretoria CBD corridor

Inputs	Value
Input Demand (1hr person demand)	30 051
Motorised trips (55%)	16 528
public transport split (45% of the motorised trips)	7 437
Public transport split directional split (80:20)	5 950
Length of the corridor (km)	18

(Source: estimating by author using the outputs from Gauteng EMME model and GHTS of 2013)

5. RESEARCH DESIGN AND METHODOLOGY

This section is broken down into sections dealing with the following key elements:

- Conceptual approach
- Model development process
- Modes of travel
- Input data
- Operating environment
- Gaps and uncertainty in the data
- calibrated selection approaches

5.1. Conceptual approach

Figure 5-1 shows the conceptual approach adopted for the study. At a high level, the approach has three sub-stages, viz., the demand sub-stage, the operational statistics sub-stage and the average social cost sub-stage. During the first stage, the total demand within the corridor was estimated using the existing Strategic Road Network for Gauteng (also known as GSRNR 2010), developed on the Emme4 platform. The GSRNR 2010 is a transport model that has informed the ITMP25 study, which has been the master plan responsible for guiding planning transport provision within. The proportion of public transport demand was then estimated using a modal split derived from Gauteng Household Travel Survey (2013).

During the second stage, operational statistics for the various public transport modes, such as, frequency, headway, and service speed were estimated using the estimated public transport demand as an input. Then the estimated service attributes were used to estimate the various components of the total social cost, i.e., user, operator and external costs.

Finally, the total social costs were estimated by adding up the operators, users, and external costs. Then, using the total social costs as an input, the marginal cost and the average social costs were estimated to make it possible to compare approaches. The mode that resulted in society paying the least was then selected as the effective mode to service demand within the Atteridgeville-Pretoria CBD corridor. Each of the elements in the approach is discussed in detail in the following sections.

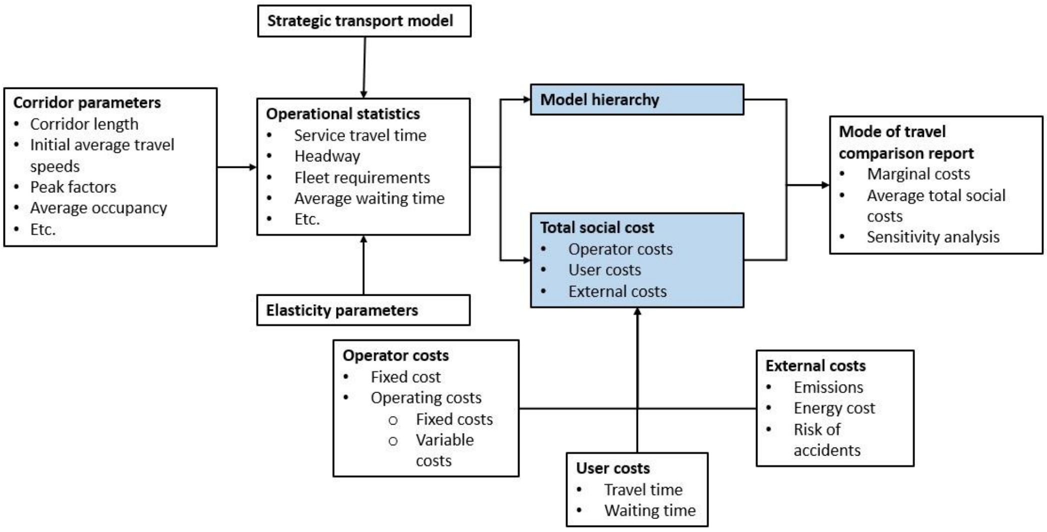


Figure 5-1: Conceptual evaluation approach for the study

(Source: Drawn by author, adapted from work done Li and Preston (2015))

With the selected approach there are various limitations which are discussed in section **5.6**. Suffice to note that among these limitations include estimating public transport splits using reported values from household surveys. However, household travel survey, are the most comprehensive travel surveys to inform planning.

5.2. Model development process and calculations

This section describes the process followed to calibrate the proposed total social cost model for the South African public transport environment. Much of the required default values were informed by the databases in Del Mistro and Bruun (2019) and in Del Mistro and Aucamp (2000).

5.2.1. Average and total social costs

A model was developed on a spreadsheet and the process entailed calibrating the proposed total social cost model for the South African public transport operating environment. First, the exogenous demand levels were user-defined from 1 000 to 200 000 passenger per day per direction. Then, for each of the exogenous demand levels, the total social costs (TSC) and the average social cost (ASC) are estimated as explained here. This is done to make it possible to compare modes.

$$ASC = TSC/\ (\text{passenger-km or passenger trips}) \quad (1)$$

Thus, in Equation (1), ASC is the average social cost, measured in rand per passenger-km or rand per passenger-trips. TSC is the total social cost estimated in rand.

Equation (2) reflects the proposed TSC model, where TSC is the sum of the total operator costs (TOCs), total user costs (TUCs), and total external costs (TECs), measured in South African Rands.

$$\mathrm{TSC} = \mathrm{TOCs} + \mathrm{TUCs} + \mathrm{TECs} \tag{2}$$

5.2.2. Operational statistics or attributes

To estimate the different cost components, i.e., the operator, user, and external costs, first estimates, for each of the exogenous demand levels, the operational statistics or attributes for the various public transport modes (or technologies) were estimated. The operational attributes estimated include the following (units are given in parenthesis):

- Required service frequency [veh/h]
- Average operational speed [km/h]
- Travel time [h]
- Headway [min]
- Waiting time [min]

First, the required service frequency is estimated using equation (3). Inputs to estimating the service frequency includes the seasonality factor ($\propto$), which is used to account for seasonality variations. Li and Preston (2015) recommend using 1.1 as the seasonality factor. Vehicle capacity is taken to include seated and standing capacity. The vehicle capacity and maximum relative load factors are based on the research by Del Mistro and Bruun (2019) as well as by Del Mistro and Aucamp (2000). In this equation, Pax refers to the user defined exogenous demand:

$$F = \frac{\propto * Pax}{VehCap * MaxLF} \tag{3}$$

where:

F	≡	*service frequency*	[veh/h]
$\propto$	≡	*seasonal fluctuations factor*	–
Pax	≡	*demand for the time period in number of passengers per hour*	[/h]
VehCap	≡	*vehicle capacity*	[veh/h]

MaxLF	≡	*maximum relative load factor*	–

Once the service frequency (*F*) has been estimated for a demand segment, the service headway (*h*) is estimated by employing equation (4).

$$h = \left(\frac{60}{F}\right) \tag{4}$$

The operating speed is calculated for two use cases in terms of travel demand level. The first use case refers to conditions when the traffic demand is below the infrastructure capacity requirements. In this case the first condition of equation (5) is used. In the second use case, traffic demand is above the infrastructure requirements and, in this case, second condition of equation (5) is used. V^{ALL} is the average operational speed for various modes, which is as a function of the demand levels. V_0^{NoCap} and V_1^{NoCap} are default user defined speeds for a particular mode (or technology) given the operating environment whilst C_F refers to the capacity of the infrastructure. The default user defined values V_0^{NoCap} and C_F are informed by Del Mistro and Bruun (2019) and also Del Mistro and Aucamp (2000). These variables are used in Equation 5 are given below:

$$\begin{cases} V^{ALL} = V_0^{NoCap} & for \quad F \leq C_F \\ V^{ALL} = \dfrac{V_0^{NoCap} V_1^{NoCap}}{V_1^{NoCap} + V_0^{NoCap}\left(\frac{F}{C_F} - 1\right)} & for \quad F > C_F \end{cases} \tag{5}$$

with:

V^{ALL}	≡	*average operational speed which is read from speed flow curves*	[km/h]
V_0^{NoCap}	≡	*operational speed*	[km/h]
C_F	≡	*critical facility capacity*	[veh/h]
V_1^{NoCap}	≡	*operational speed*	[km/h]

Figure 5-2 shows the calibrated speed curve used to determine the average operational speed at different exogenous demand levels when the mode of travel is minibus taxis. As explained above, the speed curves entail two use cases, first the curves are defined by a situation where the traffic demand is less than infrastructure capacity, which corresponds to the demand between 0 and 14 000 daily exogenous demand per peak direction. Then the second part of the curve entails conditions when the traffic demand is greater than the infrastructure capacity, which corresponds to the demand being greater 14 000.

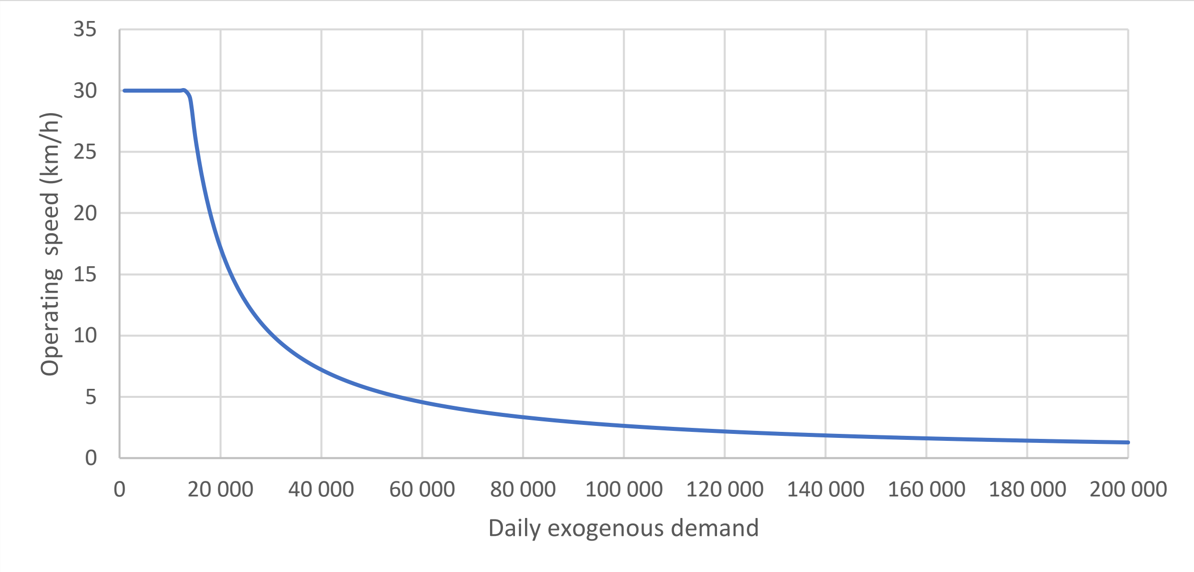


Figure 5-2: Calibrated minibus taxi speed curve

(Source: Drawn by author)

5.2.3. Number of vehicles

To estimate the number of vehicles, the cycle time is estimated first by employing in equation (6). T_0 is the operating time and, in this study, it was taken as equal to the in-vehicle time for the corridor. As explained above, this is estimated using the average operational speed. The user defined turnaround times for the public transport modes are t_{t1} and t_{t2} at the respective terminal points:

$$T' = 2T_0 + t_{t1} + t_{t2} \tag{6}$$

Where:

T'	≡	*estimated cycle time*	[min]
T_0	≡	*operating time*	[min]
t_{t1}, t_{t2}	≡	*terminal times*	[min]

Then, using the estimated cycle time as an input, the number of vehicles is estimated by employing equation (7).

$$N = \left(\frac{T'}{h}\right) \quad (7)$$

Where:

N	≡	number of transit units	[veh/h]

5.2.4. Endogenous demand

Given the set of estimated operational attributes, the model then computes endogenous demand, where endogenous demand is defined as the shift in passenger demand in response to the levels of service for each of the technologies or modes of travel. Endogenous demand is estimated using equation (8), which requires level of service attributes i.e., waiting time and travel times, as inputs.

Q_0 is a user defined exogenous demand level or demand segment, which ranges from 1 000 to 200 000 Pax per day per direction. The associated waiting time to the demand level Q_0 is $T_0^{waiting}$ and it is estimated by dividing the associated headway by 2. JT_0 is the associated journey time to demand level Q_0 and it is estimated by dividing the length of the corridor by the average operational speed at the associated demand level. $T_1^{waiting}$ and $JT_1$are the average waiting times and average operational speeds respectively, and they are fixed for the demand level or demand segment of 10 000 pax per day per direction. E_1 and $E_2$are the elasticity factors for average waiting time and average operational speed respectively. These elasticity factors are defaulted to E_1 = -0,64 and E_2 = -0,4. Though it must be borne in mind that many transport users are captive to the public transport system in South Africa (Cameron & Kingma, 2002). Therefore, elasticity figures might be lower for the South African operating environment. Figures are the subjects of various debates. Such as, the purpose of this study is not to evaluate the merits of the approaches used by other researchers. However, it is to use what is published to address the objectives of this study. To summarise:

$$Q_1 = Q_0\left(\frac{T_1^{waiting}}{T_0^{waiting}}\right)^{E_1} * \left(\frac{JT_1}{JT_0}\right)^{E_2} \quad (8)$$

Where:

Q_1	≡	*endogenous passenger demand*	[/dir]
Q_0	≡	*input exogenous demand level from 1 000 to 200 000*	[/dir]
$T_1^{waiting}$	≡	*waiting time at exogenous demand level of the public transport mode*	[sec]
$T_0^{waiting}$	≡	*average passenger waiting time fixed at a demand level*	[sec]
JT_0	≡	*Journey time at exogenous demand level of the public transport mode*	[sec]
JT_1	≡	*average journey time at a fixed demand level*	[sec]

5.3. Modes of travel

In this study, the analysis was restricted to specific modes of travel or technologies for the purpose of simplification; however, attached in the annexure (section 10.1) is a detailed analysis of the available modes in the South African environment. The technologies are listed together with a brief description (Ryus, Danaher, Walker, Nichols, Carter, Ellis, Cherrington, & Bruzzone, 2013):

- **Minibus taxi**: This technology operates mainly by using low-volume vehicle types, with 14 seats (standing not allowed) being the most common capacity configuration. Although these services operate without a predefined timetable, they mainly operate on fixed routes. These services typically share the road space with general traffic. Compared to other technologies, it is relatively inexpensive.
- **Standard bus**: This technology operates mainly by using medium to high-capacity modes, with the most common mode being the 55-seater (standing not allowed) service for a low floor bus. These services operate on a fixed timetable and typically share the road space with general traffic. The technology has a higher capacity than that of the minibus taxi.
- **Articulated bus**: This technology is similar to standard buses in terms of schedules and routes. However, this technology offers a higher passenger capacity. the most common mode being the 105-seater (standing not allowed) service for a high-floor bus. Because of the size of the articulated bus, it is unsuitable for roads where there is too little turning space.
- **BRT standard bus**: In this study, this refers to technologies that operate on exclusive lanes, that is, the road infrastructure or some lanes are for the exclusive use of this technology. Like standard

buses, these services operate according to fixed schedules and fixed routes. This is an expensive technology as it requires exclusive road infrastructure and stations.

- **Commuter rail**: These services are high-capacity services operating on fixed routes and with fixed schedules. The vehicle capacity per coach is commonly a 170-seater (standing not allowed). These services are provided on grade-separated infrastructure, and, in South Africa, these would be provided by the Passenger Rail Agency of South Africa (or PRASA).

Table 5-1 shows the operational input data used to characterise each of the modes of travel. To estimate the total social cost, this thesis used databases developed by Del Mistro and Bruun (2019) and by Del Mistro and Aucamp (2000) as a departure point. For the commuter rail operational inputs there are detailed datasets in the earlier study (Del Mistro & Aucamp, 2000) but they are omitted from the later study (Del Mistro & Bruun, 2019).

As previously indicated, the approaches in Del Mistro and Bruun (2019), Del Mistro and Aucamp (2000) and Ackerman (2015) were used to estimate capital and operating cost for the various modes of travel considered in this study. The South African Reserve Bank Inflation rates were used to update the operational costs and capital costs. In this study, the 2021 inflation rate of 5.5% was used (South African Reserve Bank (SARB), 2021). However, it must be noted that this inflation rate is lower than rates in other public transport studies. For instance, inflation rates for the MyCiti Business Plan (Transport and Urban Development Authority (TDA), 2015) ranged between 7% and 9% (TDA, 2016).

Each of the operator parameters are explained in detail in Del Mistro and Bruun (2019) as well as in Del Mistro and Aucamp (2000). It must be noted, that cost per vehicle was determined using the inflation rates of the Reserve Bank of South Africa. The interest rates in the Table 5-1 were used to inform the monthly repayment of the different assets required to produce a service. All the cost have been converted into South African Rands (denoted as R) or Rand millions (denoted as Rm).

Table 5-1: Operational inputs

Operational parameter	Minibus taxi	Standard bus	Articulated bus	BRT standard bus	Commuter rail
Travel speed CBD/Commercial in peak (km/h)	30.00	25.00	20.00	35.00	43.00

Operational parameter	Minibus taxi	Standard bus	Articulated bus	BRT standard bus	Commuter rail
Maximum volume/Capacity ratio	0.85	0.85	0.85	0.85	0.85
Vehicle capacity/coach (standing allowed)	14.00	85.00	145.00	85.00	255.00
Vehicle capacity/coach (standing not allowed)	14.00	55.00	105.00	66.00	170.00
Cost per vehicle (Rm)	0.48	1.69	2.97	3.08	25.00
Interest rate (%)	15.00	15.00	15.00	15.00	15.00
Residual value (%)	15.00	15.00	15.00	15.00	10.00
Capacity per lane (Veh/h)	400.00	250.00	200.00	300.00	20.00
Cost of way (Rm/lane-km)	7.00	7.00	7.00	30.00	55.00
Life of way (years)	20.00	20.00	20.00	20.00	40.00
Cost of terminals (Rm/peak hour vehicle)	0.04	0.28	0.30	0.28	–
Cost of terminal (Rm/10 000 peak hour pass.)	0.07	0.20	0.30	0.30	11.56
Life of terminals (years)	30.00	30.00	30.00	30.00	30.00
Interest rate (%)	15.00	15.00	15.00	15.00	15.00
Cost of depot (Rm/coach)	-	0.42	0.48	0.63	2.47
Life of depot(years)	-	30.00	30.00	30.00	30.00
Interest rate (%)	-	15.00	15.00	15.00	15.00
Energy consumption (MJoules/coach-km)	11.30	23.20	32.40	19.40	10.30
Fuel consumption (l/100veh-km)	18.00	40.00	67.00	40.00	–
Non-service vehicle travel (%)	10.00	10.00	10.00	10.00	10.00
Cost of fuel (R/l)	15.00	15.00	15.00	15.00	–

Operational parameter	Minibus taxi	Standard bus	Articulated bus	BRT standard bus	Commuter rail
Cost of energy (R/MJoule) (peak)	–	–	–	–	0.17
Cost/coach/year (Rm)	0.19	1.20	1.20	1.50	10.00
Cost/coach/extended hour (R/extended hour)	49.24	250.00	250.00	330.00	330.00
Cost/lane-km/year (Rm)	0.23	0.25	0.25	0.25	0.58
Cost/terminal/year (% of capital cost)	5.00	5.00	5.00	5.00	5.00
Cost/station or stop/year (Rm)	–	–	–	2.52	2.54
Cost of tyres (R/km)	0.53	1.84	3.23	3.35	27.20
Service and repairs	0.61	2.14	3.76	3.89	31.60

Worth noting that the table presents a range of interest rates that correspond to different assets mentioned in the table, including the Cost per vehicle (Rm), terminals and depot cost. These interest rates are included to reflect the financial considerations associated with the assets listed in the table. It is worth noting that the table's structure has been reproduced to align with Del Mistro and Aucamp (2000) cited, ensuring consistency and accuracy in representing the data. The inclusion of these interest rates allows for a comprehensive analysis of the financial aspects and long-term viability of the assets discussed in the study.

Moreover, additional studies were consulted to inform the input operators costs for the minibus taxi mode. For instance, some of these studies unpacked the minibus taxi operator costs in terms of fixed costs and operating costs (Letebele, Masemola, & Mokonyama, 2009; BusinessTech, 2021).

5.4. Input data

5.4.1. Operator costs

Table 5-2 shows the cost breakdown for those modes of public transport service considered in this study. The operator costs are broken down to operational costs and capital costs (Del Mistro & Bruun, 2019; Del Mistro & Aucamp, 2000). Following Ackerman (2015), operational costs were broken down into three categories, namely, (i) re-payment of capital, (ii) fixed operating costs and (iii) variable costs.

Table 5-2: Capital and operational costs considered in the database

Cost category	Cost items
Capital costs	• Cost of vehicle • Cost of way • Cost of terminals, ranking facilities, bus termini • Cost of stations and stops • Costs of depots
Fixed operating costs	• Vehicle operating costs, which include staff costs, management costs, office rentals, insurance, and marketing • Annual operating costs of staffing and maintenance of road and rail infrastructure • Annual operating costs of staffing and maintenance of depot, terminals, ranking facilities, bus termini
Variable costs	• Cost of energy or fuel • Maintenance • Other

(Sources: Del Mistro & Bruun, 2019; Del Mistro & Aucamp, 2000; Ackerman, 2015))

5.4.2. User costs

Total user costs are time-related costs such as costs related to walking, in-vehicle, and waiting time. Estimated values of time from Hayes and Venter (2017) were used to assign monetary values to travel time related costs. Hayes and Venter (2017) estimated the value of time for various Gauteng municipalities the analysis were segment in terms of trip purpose and income for the different modes. Hayes and Venter (2017) reanalysed the stated preference datasets for the City of Ekurhuleni and City of Tshwane Metropolitan Municipalities. The study focused on a multimodal environment, including private vehicles, buses, BRT buses, travel by rail and minibus taxis as travel technologies. For this dissertation, a value of time saving of R10.81 per hour was used. Figures and approaches are the subjects of various debates. Such as, the purpose of this study is not to evaluate the merits of the approaches used by other researchers. However, it is to use what is published to address the objectives of this study. However, as Quinet (1997) points out, the value of time is actually a spectrum value, that is, it characterised by the personal attributes of users and the purpose of the trip.

5.4.3. External factors

Table 5-3 shows the external cost rates used to estimate the total external costs for this study. The external cost considered in this study are costs related to air pollution, climate change and accidents. The external cost rates used in this study are based on the *Handbook on the external costs of transport* published by the European Commission (EC, 2019). This is a detailed resource on how to estimate direct external costs. The approaches are the subjects of various debates. Such as, the purpose of this study is not to evaluate the merits of the approaches used by other researchers. However, it is to use what is published to address the objectives of this study. It is sufficient to say that the external cost rates for this dissertation were estimated using a top-down approach. In the estimation of costs related to air pollution caused by transport, estimated costs rates included both health and non-health costs. For the climate change cost rate, a cost factor has been used that is based on CO_2 equivalent greenhouse gas (GHG) emissions was used. Accident costs were estimated by looking at human, production, medical, administrative, material and other factors relating to accidents. The *Handbook on external costs of transport* made adjustments for developed and developing countries, for instance the cost of accidents is estimated to be 1% and 2% as a percentage of GDP for developed and developing countries, respectively (WHO, 2015; EC, 2019). To convert the costs reflected from euros to rands, a rate of 1:20 has been used. Each of the external cost components are given in rand per vehicle kilometre.

Table 5-3: External costs rates

Mode of travel	Air pollution [R/veh-km]	Climate change: [R/veh-km]	Accidents [R/veh-km]
Minibus taxi	0.23	0.38	1.44
Single bus	2.84	1.77	3.78
Articulated bus	2.89	1.64	3.78
BRT standard bus	2.84	1.77	3.78
Commuter rail	9.40	4.02	10.44

(Source: Estimated by author using the *Handbook on the external costs of transport of 2019)*

Internationally, research has been done with regard to estimating external costs per vehicle kilometre (Hagedorn & Sieg, 2019; IPCC, 2018; EC, 2019). However, in South Africa, research must still be done to estimate the unit rates for both climate change and emissions at a disaggregate level such as vehicle kilometre for different modes of travel. Similarly for risk of accidents unit cost rates, it is acknowledged that significant work has been done, in South Africa, in terms cost of crashes (RTMC, 2016). However, research still needs to be done to estimate the per kilometre by mode risk unit rate of public transport modes.

The *State of Safety Report 2016/2017* of the Railway Safety Regulator (RSR, 2017) reports on the safety situation of railway passengers and freight. The report includes an assessment of the risk of accidents which is expressed in the number of outcomes per exposure. A comparison is made between the level of risk of rail accidents for European countries and South Africa. During the reporting period of 2015 period, the fatality risk in the European Union was reported to be 0.3 people killed per million train-km. In South Africa, over the same period it was estimated to be 6.12 per million train-km, which is 20 times higher.

5.5. Operating environment

Finally, in the development of the spreadsheet model, the operating environment had to be accounted for. The operating conditions were taken as mixed traffic, which means that public transport services share the road space with general traffic. This is the most common situation for public transport services in South Africa. According to Li and Preston (2015) the infrastructure capacity is 38% of the baseline conditions for mixed traffic conditions.

Additionally, for BRT services, the operating environment was considered. According to Li and Preston (2015), for exclusive lane public transport services (or street median services), the infrastructure capacity is estimated to be 61% of the virtual free flow conditions.

Important to note that reserving road space for public transport is an essential instrument for transport planning and provision. Whilst reserving road space for public transport is essential for other public transport modes such as minibus taxis, in this study, the evaluation is considered outside the scope of this study except when discussed in line with BRT standard bus services.

5.6. Limitations

The databases used in this study have gaps that may have an impact on the accuracy and reliability of the results. Here are some of the areas of concern where data gaps or data uncertainty have been identified.

- **Operator cost data:** There is a lack of datasets about minibus operations or services as it is difficult to collect information about this type of service. This naturally had an impact on the accuracy of the outputs obtained. Where rail technology is concerned, there was limited information available and database information that was available was dated (Del Mistro & Aucamp, 2000).

- **External costs:** International external unit rates on emission, climate change, and cost of accidents were used to estimate the total external costs. Given the much higher risk of accidents and less stringent emissions laws in South Africa when compared to developed countries, the computational model might underestimate the total external costs.

In addition, the dissertation is based on both approaches by Vu and Preston (2020) and Li and Preston (2015) were adopted in this thesis. As such the following assumptions were applied:

- The study is limited to technology selection approaches which support decision making at a strategic planning level.
- A corridor is analysed instead of an entire network.
- Congestion costs are considered internalised through user costs. However, in multi-modal evaluations, the costs would be added as an additional cost to be considered in the calculations that will be explained further down, especially if the calculations also included a comparison between private vehicles and public transport.
- Fare is considered a transfer between the user and the operator. As such, it is not considered in the estimation. This is a limitation especially within the South African operating environment where modes such as the minibus taxis do not have operational subsidies.

5.7. Calibrated selection approaches

In this study two technology selection approaches were assessed for transport sustainability, i.e., a modal hierarchy mode selection approach and a total social cost mode selection approach.

5.7.1. Total social cost computational tool

Based on the described methodology and databases a computational model was developed. Figure 5-3 shows the estimated total social cost curves for road-based modes of travel. The curves display three features, viz., a negative sloping section, which reflects the fixed costs being spread over smaller traffic units, a vertex, which reflects optimal conditions for a mode of travel and a positive sloping section, which reflects sub-optimum conditions for a particular mode with respect to demand for travel.

The findings of this study were consistent with other similar studies. For example, Avenali, Boitani, Catalano, & D'Alfonso (2016) also found a U-shaped relationship between average cost per seat-kilometre.

Firstly, the road-based public transport modes were analysed, as illustrated in Figure 5-3. To summarise the findings for the studied 18 km corridor across varying demand levels, the following measurements of passengers per direction per hour were estimated:

- Minibus taxi: 0 – 2 000
- Standard bus: 2 000 – 4 000
- Articulated bus: 4 000 – 7 000
- BRT standard bus: > 6 500

In comparison, for the studied 18 km corridor the proposed modes as per modal hierarchy as detailed in the *Gauteng 25-year Integrated Transport Master Plan*, are comparable to those estimated recommended using the TSC. The findings of the study are also consistent with the performance-based measures of the City of Cape Town, although, (as discussed in section **3.6.2**), the performance-based measures for the City of Cape Town allow for different modes to be applicable for the same demand level.

Therefore, for the studied 18 km corridor, Atteridgeville to Pretoria CBD corridor, the TSC mode selection approach, given the demand and length of the corridor, recommends the BRT standard bus. On the other hand, the modal hierarchy recommends the articulated bus. For instance, the modal hierarchy for demand levels between 4 000 – 7 500 suggests the articulated bus.

Then, the rail service was include to the road-based public transport service shown in Figure 5-4. As noted in the gaps and uncertainty section that for rail mode at the time of writing the rail service was not operational and that the data related to the rail mode was dated. However, it is also important to note that, at the time of writing, PRASA was busy implementing a modernising and revitalising programme as described in according their 2020-2022 Corporate Plan (PRASA, 2021). The programme aims, among other things, to implement the following programs (PRASA, 2021):

- *Rolling stock fleet renewal* programme
- *120km/h perway improvement*
- *Signaling programme*
- *Depot modernisation*
- *Station modernisation*

The modernisation and revitalisation programme aims to improve the level of service of the rail service in South Africa and may thus have an effect on the results. It must also be mentioned that Avenali et al. (2020) found that rail service outperfomed bus services when capital costs are regarded as sunk costs for both the rail service and the bus service.

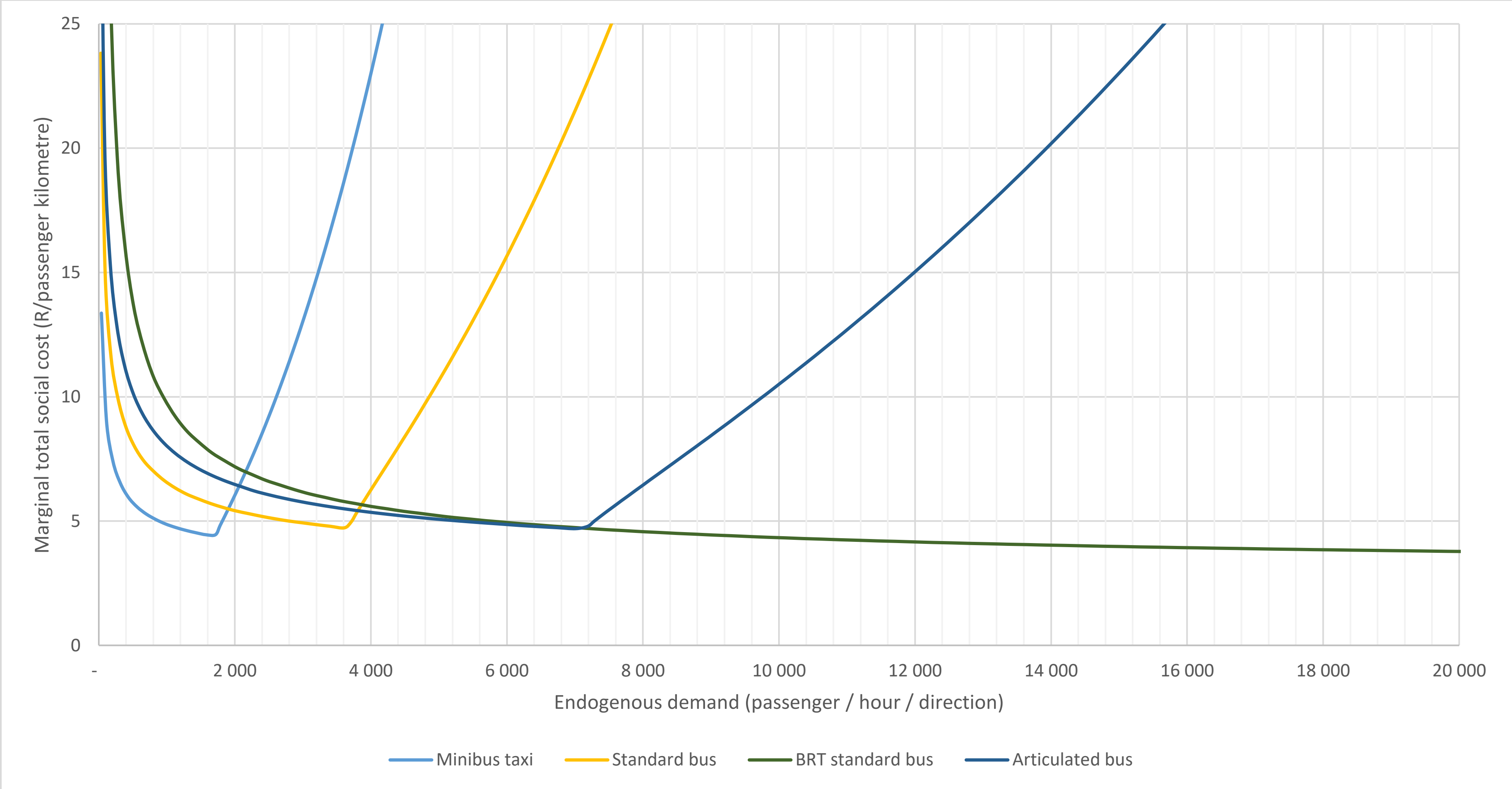


Figure 5-3: Estimated road-based total social cost curves for the 18 km Atteridgeville-Pretoria CBD corridor

(Source: drawn by author using the calibrated spreadsheet model)

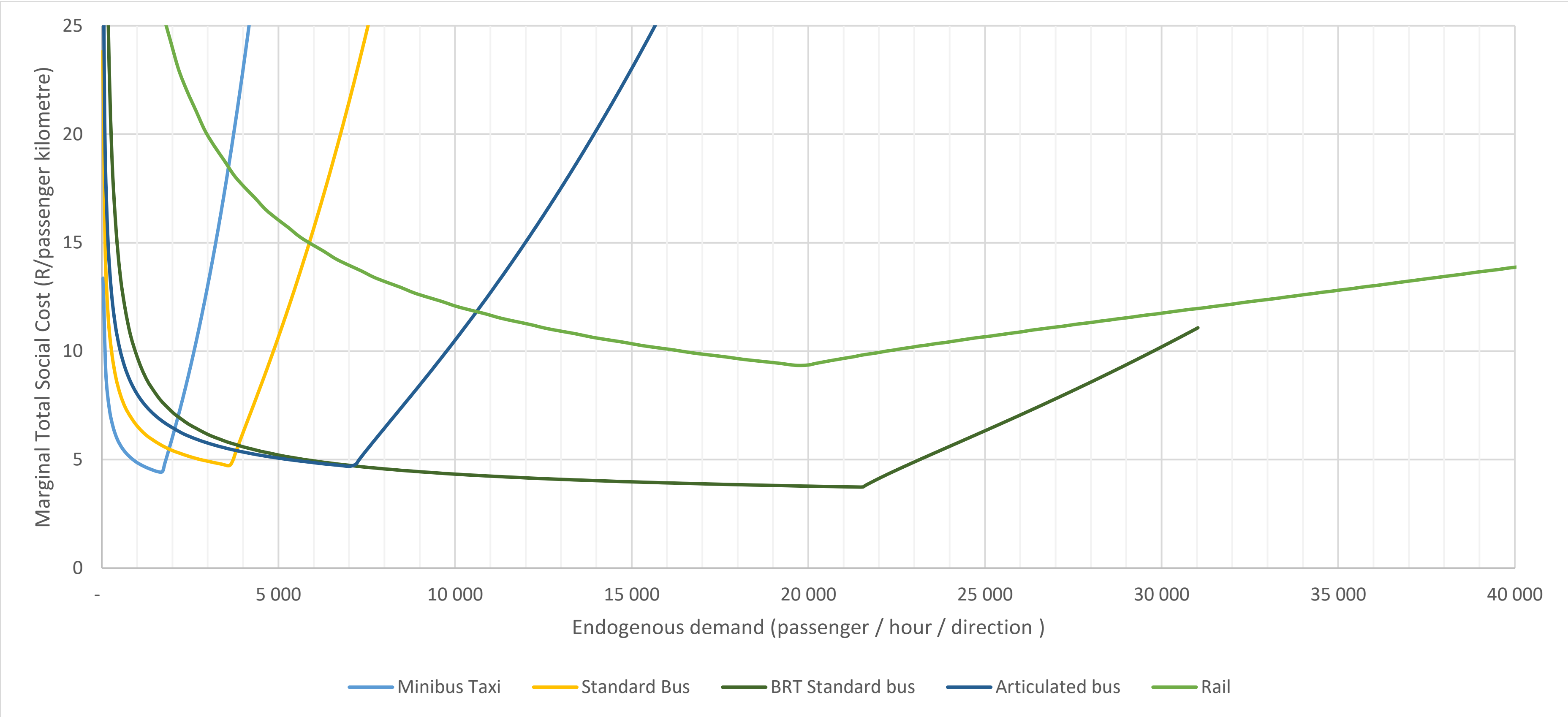


Figure 5-4: Estimated public transport total social cost curves for the 18 km Atteridgeville-Pretoria CBD corridor

(Source: drawn by author using the calibrated spreadsheet model)

5.7.2. Modal hierarchy approach

Transport planning in South Africa follow, among others, a modal hierarchy approach. For this study, the Gauteng provincial modal hierarchy approach as contained in the *25-year Integrated Transport Master Plan* (ITMP25) was selected as a representative approach for modal hierarchy approaches used in South Africa. The reason for this decision is that the corridor that was selected to be studied is found inside Gauteng and is therefore subject to planning as set out in Gauteng transport planning.

Table 5-4 shows the modal hierarchy approach for public transport in Gauteng. It should be pointed out that the Gauteng ITMP25 does not detail how segmentation of demand into the categories of mode of travel is done. The report does note, however, that each technology in the network is planned for on the basis of demand.

Table 5-4: Hierarchy of public transport modes

Technology or mode	Person hour demand per direction
Taxi	0 – 1 000
Minibus taxi	1 001 – 2 000
Bus	2 001 – 4 000
BRT	4 001 – 8 000
Light rail	8 001 – 15 000
Heavy rail	15 001 – 40 000

(Source: GDRT, 2013)

6. RESULTS AND DISCUSSION

The Atteridgeville- Pretoria CBD corridor chosen for this study was evaluated following the methodology explained and within the framework set out in order to determine which mode of travel is appropriate to service the demand along this corridor. The corridor chosen for the study is 18 km long and it was estimated to service 7 400 passengers per hour per direction in the peak direction. The assessment of the findings is as follows:

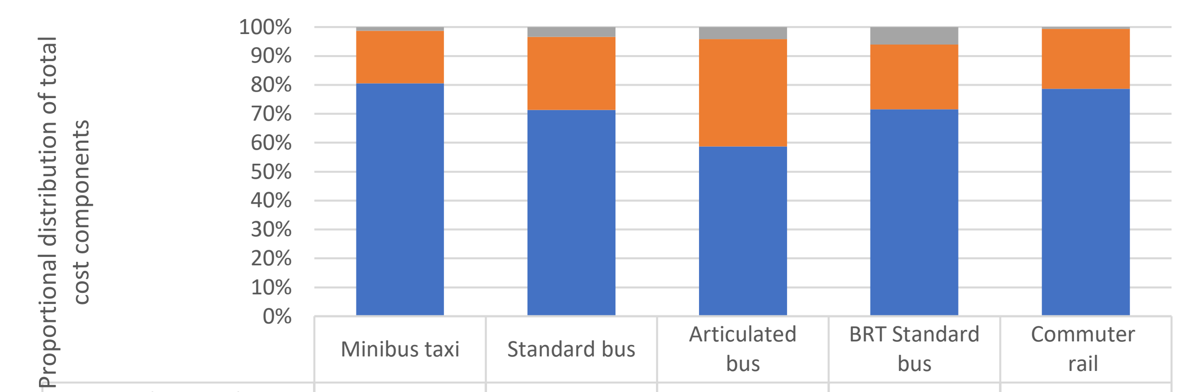
- **Modal hierarchy:** articulated bus is found to be the appropriate mode of travel when a modal hierarchy approach is used for technology selection. This is because the estimated public transport demand along the corridor is between 4 000-8 000 passengers per hour per direction.
- **Total social cost approach:** Table 6-1 summarises the total social cost analysis done in this study for the Atteridgeville-Pretoria CBD. In terms of the estimated total social cost for the corridor, the BRT standard bus technology is the appropriate technology to service the demand along the corridor. Society would pay R4.70 to produce a passenger-kilometre for BRT standard bus services. In terms of marginal operator costs, an articulated bus service would cost the least of all the technologies considered, requiring the operator to pay R3.05 to produce a passenger-kilometre for articulated bus services. However the total social cost of articulated bus would be R5.20.

Table 6-1: Total Social Costs for the Atteridgeville-Pretoria CBD

Mode of travel	Marginal operator costs	Marginal user costs	Marginal external costs	Total social cost
Minibus taxi	69.33	15.59	1.11	86.03
Standard bus	17.19	6.08	0.81	24.08
Articulated bus	3.05	1.93	0.21	5.20
BRT Standard bus	3.36	1.05	0.28	4.70
Commuter rail	10.78	2.84	0.08	13.71

Figure 6-1 shows the percentage distribution of the cost components. On average, the external costs ranged from 0.6 to 6% as a proportion of the total social costs, for the 18 km corridor under consideration. In contrast, Avenali et al. (2020) found that the external costs equalled 8% and 25% of the total social cost for rail and bus services respectively. In the Italian study, however, the external costs included air pollution, congestion, and noise. In addition, in the Italian study, investment costs for the rail and road infrastructure construction were regarded as sunk cost. Avenali et al. (2020) also looked at exogenous demand, that is, the demand assumed to be independent of the mode of travel and the level of service.

The thesis results arrived at estimating rail services to have the lowest external costs for the corridor under consideration, and this is consistent with findings of other studies. For instance, the African Development Bank (AfDB, 2015) found that transport per rail contributed less to external cost than transport per road total contributed to external cost per 1 000 passenger per kilometer (pkm). Moreover, AfDB (2015) noted that external costs may be reduced further through the introduction of an electric rail service.



	Minibus taxi	Standard bus	Articulated bus	BRT Standard bus	Commuter rail
marginal external costs	1%	3%	4%	6%	0.6%
marginal user costs	18%	25%	37%	22%	21%
marginal operator costs	81%	71%	59%	72%	79%

Figure 6-1: Percentage distribution of total cost components

(Source: drawn by author)

Notwithstanding the findings of the thesis, it must be noted that in South Africa, rail deployment would be a brownfield intervention. This is because the rail services are not in operation due to theft, vandalism, and lack of maintenance of the existing infrastructure (PRASA, 2021). As such, the initial capital would be significantly lower (PRASA, 2021). In fact, a review done by AfDB showed that the capital costs for a brownfield development might be 50% of the construction costs of a greenfield two-lane road (AfDB, 2015). In the context of this study, considering the Atteridgeville-Pretoria CBD corridor, the rail would be a brownfield development. Regarding the total social cost, the rail service would most likely be the effective mode with the least total social costs. This is because, for rail technology, a significant proportion of the social costs are comprised of operator costs, especially capital costs. This would be in line with work done by Avenali et al. (2020), which found that rail services outperformed bus services when capital costs are regarded as sunk costs.

Mizutani, Suzuki and Sakai (2011) estimated social costs for private vehicle usage in 111 Japanese cities and this study found that external costs, which are comprised of global warming costs, accounted for between 5 and 11% of social costs. It must be noted, however, that this thesis looked at public transport modes where Mizutani et al. (2011) studied private vehicle usage.

7. CONCLUDING REMARKS

Approaches used to select modes of travel to service the demand along a particular corridor were assessed in this dissertation. A computational spreadsheet model was developed to assess the effectiveness of a total social cost approach for a travel corridor. The research questions were:

- To what extent is a modal hierarchy approach suitable for evaluating the sustainability of public transport mode selection?
    - An assessment was conducted utilising a modal hierarchy and a total costs model. For the Atteridgeville-Pretoria CBD corridor, if the selection of an appropriate mode were solely based on net economic benefits (operators' costs), a different mode would have been chosen, as indicated in the discussion on marginal operator costs. Consequently, society would have incurred higher total social costs. In fact, for the reviewed corridor, the articulated bus emerges as the most suitable mode when employing the modal hierarchy, whereas the BRT system represents the most appropriate mode when using the TSC model.
    - Adopting a welfare theory perspective fosters an awareness that costs have to be internalised for transport systems to be efficient. Through the assessment external and user costs were also estimated. A total social cost approach for transport mode allocation is an important instrument in ensuring that the total costs for each of the modes are internalised. In a modal hierarchy approach, it is unclear to what extent external costs are internalised, which is a limitation in country such as South Africa where public transport has, as pointed out by Kane (2010) an equity and equality dimension.
- To what extent is a total social cost approach effective for evaluating the sustainability of public transport mode selection in the context of a city in South Africa?
    - A total social cost approach was applied to the Atteridgeville-Pretoria CBD corridor and results obtained were compared with the existing approach, which is a modal hierarchy approach. In terms of this particular 18 km corridor, the findings were the following measured passengers per hour per direction:
        - Minibus: 0 – 2000
        - Standard bus: 2000 – 4000
        - Articulated bus: 4000 – 7000
        - BRT standard bus: > 6500
    - It is important to note that, with the total social cost computational tool that was developed, there is flexibility to adjust the length of the corridor and also the demand

being evaluated. Therefore, the analysis may be site specific. In contrast, with a modal hierarchy approach, results are generalised, which may imply that there are some cases where a modal hierarchy approach might be overestimating or underestimating costs.

    - It was found that, for the 18 km corridor under consideration, the total external cost was between 0.6% to 6% as a proportion of the total social costs. In comparison, In Italy, a study by Avenali et al. (2020) did a comparison between the bus and rail services and it was found that the external costs constituted from 8% to 25% as a proportion of the total social cost, for the rail services and bus services respectively.

- To what extent is a TSC framework suitable to support decision making about the mode of travel selection in South Africa as a developing country?
    - A computational spreadsheet model was developed to test the effectiveness of using a TSC for an 18 km corridor which was then used to support decision making in South Africa using a case study. Through the use of the computation tool the demand levels were estimated which would result in society paying for the least cost.
    - It is, however, important to note that operational data is important to have and this was found to be a challenge when drafting an estimated TSC curve for rail services. At the time of writing this thesis, most of the rail lines were not in operation so that the information on rail operations was dated.

Moreover, policy and planning have a significant role in terms of ensuring that the prices charged to the users reflect the external costs associated with the modes of transport that users use. Understanding the external costs that each of these modes imposes is important for planning and for guiding policy development. Whilst the Handbook on the external costs of transport published by the European Commission (EC, 2019) is a useful resource when estimating unit rates for external costs. However, it is limited in capturing the high external cost associated with transport systems in developing countries.

The failure of planning approaches to capture these external costs and user costs might have undesired consequences in the long term. For instance, for the case study of the Atteridgeville-Pretoria CBD corridor, when assessing the based-on operator cost, it was found that the most applicable mode is the articulated bus. However, when assessed for total social costs, it was the BRT standard bus. Total social cost imposed by the articulated bus was a result of high user costs when compared to the BRT standard bus. The study does point to need to refine the currently used approaches.

8. FUTURE RESEARCH

The thesis contributed to the mode of travel efficiency comparison studies, especially to those pertaining to South Africa. It also contribute to assisting decision-makers in appreciating the broader impacts of selecting a mode of travel to service a demand along a corridor. Based on the findings of the study, the following suggestions are proposed for future research.

- Estimation of total external costs using the external rates that are derived from South African databases.
- The future research project may assess the sensitivity of the input variables on the total social cost curves.
- It is recommended further work be done which will include brownfields type interventions. For instance, the rail line already in place appears, however on the basis of the current assess because of the infrastructure costs it is estimated to be costing society more than alternatives.

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ANNEXURE A TRANSPORT OPERATING ENVIRONMENT

Table A-1 shows the operating environment and technologies in a typical city environment in South Africa. In the *Transit Capacity and Quality of Service Manual* (TCQSM), South African public transport technologies are discussed looking at service type, operating environment, vehicle type, and stop spacing (Ryus, Danaher, Walker, Nichols, Carter, Ellis, Cherrington, & Bruzzone, 2013).

Table A-1: Technology and operating environment in South Africa

Themes	Sub-systems	Description
Service type	Scheduled	These refer to services that operate on a fixed timetable, for example, rail and bus services.
	Unscheduled	These services operate without a predefined timetable, but they operate on a fixed route, for example, minibus taxi services.
	Fixed route	These refer to services on dedicated infrastructure or predefined routes, for example, bus and rail services.
	Demand response	The route is determined by the needs of the passenger, both spatially and temporally, for example, e-hailing services and metered taxi services.
Operating environment	Mixed traffic	Public transport services share the road space with general traffic. This is the most common form of public transport in South Africa.
	Semi-mixed traffic	Public transport services have dedicated use during specific times of the day, typically during peak times.
	Exclusive	Exclusive lanes mean that the road infrastructure or part thereof, is strictly reserved for public transport use.
	Grade separated	A grade-separated operating environment entails that a service is operated completely

Themes	Sub-systems	Description
		separated from general traffic on a dedicated infrastructure.
Vehicle types	Rail	Services are provided on grade-separated infrastructure. In South African cities these would be the Gautrain rapid rail service and the passenger rail service provided by PRASA.
	Bus	Typically classified into the following groups: the standard bus, articulated bus, midi-bus and double-decker bus.
	Minibus taxi	Minibus taxis predominantly operate using low-volume vehicle types, with the 14 seaters being the most common.
Stop spacing	Local stops	These services offer the highest level of access with relatively low operating speeds.
	Limited stops	Limited stops are characterised by limited access, high capacity stops and relatively moderate operating service speeds, for example, bus rapid transit stations.
	Express stops	Road-based services with express stops are largely characterised by having one access point at the start of the service and the service would then have a couple of stops towards the end of the termination point of the service.

(Source: Drawn by author using the (Ryus et al., 2013))