UNIVERSITY OF CAPE TOWN

IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

DEPARTMENT OF CIVIL ENGINEERING

CIV5000Z:

MASTERS DISSERTATION (120 CREDITS)

ENHANCING INTEGRATED TRANSPORT PLANNING: A SPATIAL MULTI-CRITERIA ANALYSIS APPROACH TO THE MyCiTi INTEGRATED RAPID TRANSIT SYSTEM, SOUTH AFRICA

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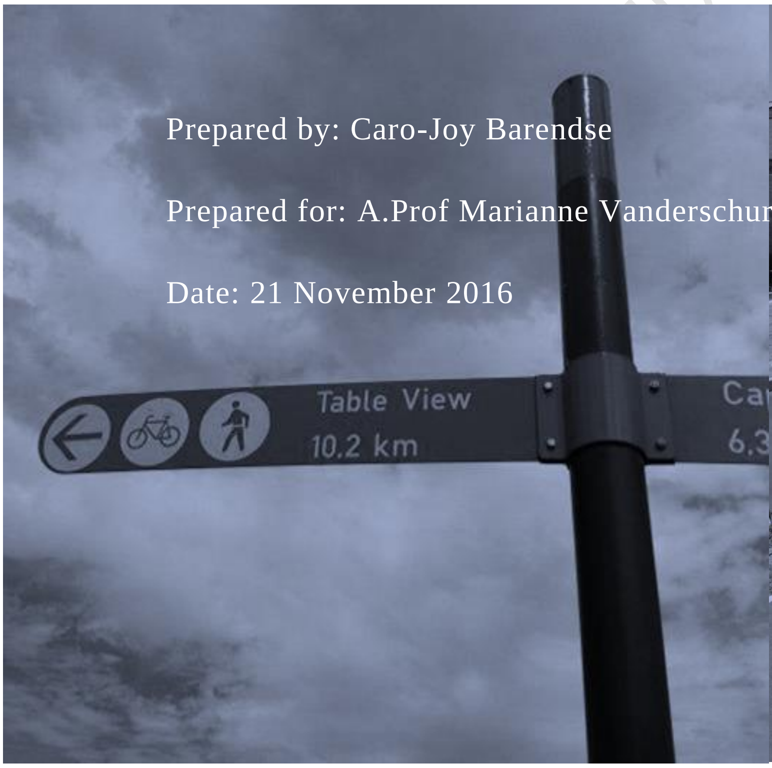
Date: 21 November 2016



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Acknowledgements

I would like to express my heartfelt gratitude to my supervisor, A.Prof Marianne Vanderschuren, whose continued support; enthusiasm and belief in me has aided the successful completion of this study. Her guidance has not only offered value to this research, but to my personal development as a professional.

I would like to extend my sincere gratitude to my close friends and family for their consistent support, understanding and confidence in my ability. I particularly thank my parents for all their sacrifices, support and love that have brought me to this point.

Extremely special gratitude goes to my partner, Justin Plaatjes, for his never-ending encouragement, patience and understanding throughout this thesis. The successful completion of this dissertation would not be possible without his support and unfailing belief in me and my ability to overcome my challenges incurred in conducting my research.

Lastly, I thank my manager, Tessel Severs, for his compassion and support in allowing me leave to complete my studies. The timeous completion of this thesis would not have been possible otherwise.

Abstract

Since the birth of the automobile in 1886, its popularity amongst people has risen dramatically owing to the freedom, comfort, speed, safety and unique designs offered by this mode of transport. 2014 saw approximately 71.15 million units of new vehicle sales globally, showing that private car usage is still on the rise. Rapid degradation of the environment and slumped economic growth can be attributed to the automobile-centric transport system. Raised environmental and social awareness has driven campaigns to promote greener modes of transport instead, such as public and non-motorised transportation. This has seen the introduction of BRT systems in South African cities however; fully integrated transport systems are yet to be achieved. Thus there is a dire need for a design support tool that is adequately capable of processing built environment characteristics in the development of a BRT feeder network that is fully appreciative of the influence of NMT and the urban fabric, and is thus appropriate to the needs of the community it is trying to serve.

This study comprised the application of two Spatial Multi-Criteria based methodologies in which a list of built environment characteristics and public transport demand formed the inputs for the analyses. The analysis produced a composite suitability map for each approach, in which each pixel represented the appropriateness of having a BRT feeder route located in that respective pixel. Routes between O-D pairs identified were solved by carrying out a least cost path assessment based on the mean impedance values along the existing road network. The routes developed were compared to the MyCiTi feeder bus routes using Key Performance Indicators established in this research to determine whether this study was successful in producing an enhanced BRT feeder route planning tool.

Apart from one route, the set of feeder routes developed for each approach were exactly the same with the second method producing lower average impedance values per kilometre thus it was deemed stronger. When compared to the MyCiTi feeder routes, similar operational efficiencies were achieved with respect to average travel time, coverage and directness. However; the study methodologies provided a greater

level of NMT planning inclusion and consideration of environmental factors. Furthermore; it achieved this in a systematic and transparent manner, providing immensely powerful benefits for transportation planners in the public sector.

This study was successful in demonstrating that SMCA combined with the Network Analyst tool in ArcGIS has the ability to enhance the quality and appropriateness of BRT feeder routes, whilst achieving acceptable operational efficiencies. The results could further be improved by incorporating more data on local NMT trends and behaviour. Furthermore; this tool can be applied to solving pedestrian, bicycle and other public transport routing problems.

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List of Abbreviations and Notations

SMCA	Spatial Multi-Criteria Analysis
SMCE	Spatial Multi-Criteria Evaluation
BRT	Bus Rapid Transit
IRT	Integrated Rapid Transit
LWM	Line Weighted Mean
MCA	Multi-Criteria Analysis
TCT	Transport for Cape Town
IRPTS	Integrated Rapid Public Transport System
NMT	Non-Motorised Transport
UTM	Universal Transverse Mercator
KPI	Key Performance Indicator
CBD	Central Business District
O-D	Origin-Destination

Definition of Terms

Geographic Information Systems (GIS)	A software application used to capture, manipulate, analyse and depict all types of spatial data.
Multi-Criteria Analysis (MCA)	A structured methodology used to determine overall preferences among alternative options based on numerous criteria.
Spatial Multi-Criteria Analysis	A decision support tool combining the use of GIS and MCA to assist in the solving of spatial decision problems.
Bus Rapid Transit System	A bus based mass transit system that comprises innovative design measures to provide an affordable, high capacity and speed service.
Integrated Transport Planning	A process of defining future needs of the transport system in a manner that seeks to bring about a seamless multi-modal system.
Non-Motorised Transport	Modes of transport which do not run on a motor.
Built Environment	The human-built space in which people live, work and recreate.
Sustainability	A method of development that meets the needs of the present without comprising the ability of future generations to meet their own needs.

1. Introduction

The birth of the automobile in 1886 can be ascribed to a German mechanical engineer by the name of Karl Benz (Cox, 2013). According to Statista (2015), global new automobile sales for 2014 were reported to be 71.15 million units where in South Africa, 31 201 new units were sold in May of 2015 alone (NAAMSA, 2015). An increasing number of people prefer to use the private car as their main mode of transport which can be attributed to the numerous benefits offered by using this form of transport. The greatest advantage in travelling with the automobile is the freedom and independence gained compared to the fixed routes and schedules characteristic of public transport modes. Furthermore; their comfort, speed, safety and unique designs are very attractive to say the least. However, increasing private car use has resulted in degradation of the environment, due to extensive consumption of fossil fuels, which results in air pollution. Moreover, increasing levels of traffic congestion have resulted in slumped economic growth owing to loss in productivity and lower dispensable income because of climbing fuel prices. Figure 1-1 illustrates the high levels of traffic congestion in the city of Cape Town.

Figure 1-1: Traffic Congestion in Cape Town, South Africa

Source: South African Press Association (2014)

Transport has been identified as one of the leading contributors to environmental and energy crises seen today, through its high consumption of fossil fuels and land, and damage caused to the environment in the form of air, water, ground and noise pollution (Commission of the European Communities, 1992). Even so, Transport remains vital to the efficient functioning of societies through enhancing both economic and social well-being, as it allows people to complete activities and gain access to important services that are spatially separated. The transportation system can either bring communities closer together or divide them; this quality was used as a means to create physical segregation under the Apartheid regime in South Africa. The dependence on the private vehicle by South Africans has been promulgated through the vast majority of citizens being located on the outskirts of cities where they are far away from most job opportunities. Unfortunately, car ownership remains a luxury affordable to the privileged leaving many South Africans still captive to their circumstances.

Raised environmental and social awareness seen around the world has driven campaigns to reduce dependency on the private vehicle, promoting greener modes of transport instead, such as public and non-motorised transportation. This is particularly the case in South Africa, where public transportation has received momentous attention in a range of strategies from the National Development Plan to the State of Nation and Budget Addresses (Pegasys, 2015). In 2007, the National Department of Transport released a Public Transport Strategy and Action Plan, which calls for an Integrated Rapid Public Transport System (IRPTS) to be implemented in 12 cities and at least 6 districts by 2020. The strategy advocates that “IRPTS networks are the mobility wave of the future and are the only viable option that can ensure sustainable, equitable and uncongested mobility in liveable cities and districts”.

In response to the Public Transport Strategy, the City of Cape Town (CoCT) introduced the MyCiTi Integrated Rapid Transit (IRT) system, which comprises mainly Bus Rapid Transit (BRT) trunk and feeder routes supported by pedestrian and cycling facilities. The planning for the BRT service is guided by the principles of quality, equity, security, sustainability and integrity. This translates into design principles of universal access, passenger mobility, accessibility, modal integration, customer convenience, safety and security, sustainable transport, congestion management, optimal use of scarce resources and transport that supports economic development (The City of Cape Town Municipality, 2012).

Despite the efforts of decision-makers, like the CoCT, to create more sustainable transport systems that are multi-modal and wholly integrated, successful implementation of BRT systems in South Africa has proven more difficult due to the unique built environment characteristics brought about by Apartheid planning principles. This is further exacerbated by the lack of formal NMT infrastructure and a deficient understanding of localised NMT patterns which has resulted in the development of BRT feeder routes that are not well-suited to the needs of its potential users. This can be attributed to design support tools that lack the ability to process the unique operational requirements and characteristics of more than one mode at a time. As a result, poorer communities previously excluded by Apartheid are still left isolated from areas where work opportunities and essential services are available

Therefore, the harmful effects on society and the environment associated with fragmented transport systems which are automobile-centric are still imminent, so well designed public transport networks are yet to be achieved in South Africa. Thus there is a dire need for a design support tool that is adequately capable of processing built environment characteristics in the development of a BRT feeder network that is fully appreciative of the influence of NMT and the urban fabric, and is thus appropriate to the needs of the community it is trying to serve.

This beseeching need instigates the motive for finding a design tool that is capable of facilitating improved network development of Bus Rapid Transit systems. One such system is the MyCiTi BRT system considered in this study.

1.1. Background and Justification of Investigation

The planning of the MyCiTi BRT system can be thought of as a spatial decision problem, as it involves a large number of alternatives in the form of various possible routes for trunk, but particularly feeder services, which have multiple, conflicting and disproportionate evaluation criteria. Many spatial problems are best solved through Geographic Information System (GIS)-based Multi-Criteria Decision Analysis (GIS-MCDA). This method was first researched in 1988 by Diamond and Wright who aimed to develop an integrated decision support system which addresses the multi-objective nature of site screening processes. This was followed by studies by Jansen and Rietveld (1990) who applied this tool to agricultural land use decisions in the Netherlands, and Carver (1991), who used this tool to search for suitable sites for the disposal of radioactive waste in the United Kingdom (UK). Since then, this tool has featured in numerous studies, mainly conducted in Europe. Applications tested range from environmental planning/ecology and management, waste management, urban and regional planning to transportation and forestry. Applications within the field of transportation have predominantly been to solve routing problems with a select few employing this tool to analyse land suitability and to perform scenario evaluations (Malczewski, 2006).

This research study stems from the work completed by Keshkamat in 2007, where he applied Spatial Multi-Criteria Analysis in the route development of the Via Baltica Corridor, Poland. This dissertation seeks to extend his work to the realm of integrated rapid transport systems, in an attempt determine whether it can be used to enhance the quality of feeder bus route networks. In testing the viability of using this tool for the aforementioned task, a case study comprising the MyCiTi IRT System, where the modes of BRT, walking and cycling are addressed in the City of Cape Town transport system. Should this tool prove suitable for improving the design of feeder bus routes, an immensely powerful planning technique would present itself as the key towards creating transport systems that are sustainable, efficient and truly equitable – the sole aim of planners, politicians, decision-makers in transportation worldwide.

1.2. Objectives of Study

This research project endeavoured to prove that the use of SMCA in the development of feeder bus routes can enhance the quality of the transportation service provided to communities, with particular application to the MyCiTi IRT system.

In attempting to prove that the above is true, this study aimed to achieve the following:

- Establish Key Performance Indicators for assessing the quality of the feeder bus routes developed in this study.
- Define criteria to be considered in multi-modal transport systems.

- Test whether SMCA can enhance integration in transportation planning of BRT feeder routes.
- Establish a BRT Feeder network, which holistically marries built environment characteristics with passenger demand, and in so doing, supporting Transit Oriented Development (TOD).

1.3. Scope and Limitations of Project

This study was limited by the following:

- Availability of data influenced the level of detail that can be achieved in this research.
- The age of the data obtainable had an impact on how well it reflects the current transport situation.
- The study period was limited to the years 2015 and 2016.

The scope of this research was as follows:

- This study considered MyCiTi buses and facilities, and walking and cycling modes of transportation.
- The area of study was confined to a 500m to 2500m radius around the MyCiTi Woodbridge Island trunk station on the R27 in Cape Town.

1.4. Thesis Outline

This thesis commences with the introduction chapter, which presents the background and justification for this study. A review of literature pertinent to the evolution of transportation planning; measuring integrated transport planning; the MyCiTi IRT system planning and Spatial Multi-Criteria Analysis are documented in *Chapters 2, 3, 4 and 5* respectively. The methodology followed in conducting this research is explained in *Chapter 6*. *Chapter 7* provides a description of the study area and *Chapter 8* goes on to present the results obtained in this study. These results are then discussed in light of the research objectives in *Chapter 9*. Lastly, in *Chapter 10*, this dissertation is concluded and recommendations are made based on the findings of this work.

2. Evolution of Transport Planning

2.1. Introduction

This chapter explores the evolution of transportation planning methods and tools that have given rise to the approach to transportation problems in the modern age.

2.2. Traditional Transportation Planning

Following the invention of the automobile in 1886, the private motor vehicle rapidly rose to become the preferred means for transportation by most people, especially those living in urban cities. By the 1950s highways were already being constructed at an increasing rate, particularly in developed countries, such as the United States of America (USA). In order to plan and prioritise investment in these highways, sophisticated traffic prediction tools were developed to assist in the design of the pavement structure. The development of computers during this time also facilitated the advancement of these planning tools. Kane and Behrens (2002) note that the key method to emerge during this period of rapid development was the 'aggregate four-stage model.' They report that this model was designed, based on the following assumptions:

- It was possible to predict a future land-use pattern independently of changes to the transport system;
- It was possible to predict travel behaviour based on household data averaged over a zone;
- Relationships between household characteristics and travel behaviour would remain steady over time;
- Travel decisions were made principally on the minimisation of travel time and cost;
- Inter-zonal, average weekday, peak hour vehicular trips provided an adequate picture for the purposes of transport system improvements.

Over the years, however, the aggregate four-step model received much flack for being biased, thus leading to the construction of extensive road networks, which by this stage had displaced a number of communities. In response to the criticisms received, three new planning tools were developed.

These are:

- Land-use transport models, which assess the impact of changes in land use on the transport system and vice versa,
- Disaggregate models, which model the travel choices of the individual as opposed to the household, and
- Microsimulation models, which are an improvement of the four-step model, by allowing analysis of travel patterns at vehicle or platoon level.

The commonly used four-step model lacked the ability to assess the travel behaviours of individuals, giving a rather unrealistic reflection of reality. By the early 1980s the approach to transportation planning had shifted towards activity-based models, which consider the activity resulting in an individual making a trip rather than viewing the trip in isolation.

Despite these advancements in transportation planning tools, the traditional planning approach is still significantly critiqued, due to its tendency to create a self-fulfilling prophecy, whereby resources are invested in roadway expansions leaving minimal funding for other modes (Litman, 2014). Kane and Behrens (2002) quote Dimitriou (1990:pp.169) as saying that many of the problems associated with the conventional four-step model can be attributed to the founding assumptions, which perceive the transportation problem as one of overcoming vehicular congestion. Hence, the tool attempts to maximise free flow speeds, reducing travel time and costs; ultimately fostering automobile dependency and reducing modal diversity. As a result, NMT modes, such as walking, cycling, and public transport are often overlooked and treated in an ad-hoc fashion. In developing countries like South Africa, NMT and public transportation are the only affordable means of transportation, so neglect thereof has contributed to maintaining social exclusion of disadvantaged groups (Bickford, 2013).

Further limitations of the conventional four-step model is its inability to consider the tendency of traffic congestion to reach an equilibrium and that traffic is generated in increasing the capacity of a road. In defining the problem as traffic congestion, it also fails to consider needs of non-drivers, accident risks and the hostile effects on communities and the environment to name a few.

2.3. Towards Sustainability

The late 1980s saw the first major leader calling for action against Climate Change, when UK Prime Minister, Margaret Thatcher appealed for the restriction of Greenhouse Gas emissions. Real momentum on this issue was gained in 1992 when Rio de Janeiro hosted the first conference on Climate Change, where the United Nations presented its Framework Convention on Climate Change (Weart, Spencer; American Institute of Physics, 2015). Following this convention, extensive efforts were invested to identify contributing factors to Climate Change where emissions of Carbon Dioxide (CO_2), Methane Gas and aerosols were popular findings; essentially all contributors to air pollution. Transportation is a major role player, due to its consumption of non-renewable fuels and emissions of CO_2, which are exaggerated by traffic congestion as vehicles emit these gases for longer periods of time, due to increased travel times.

The public awareness around Climate Change and its challenges encouraged civilians, decision-makers and politicians to recognise the consequences of our actions, more so, the impact that the modern lifestyle has on the environment. This sparked the debate around sustainability, what it means and how to achieve it. This term applied in the context of the transportation system implies that it should be able to *meet the transportation and other needs of the present without compromising the ability of the future generations to meet their needs* (Transportation Research Board, 2004). Transportation systems are perceived to have significant unsustainable qualities as listed by the Transportation Research Board (2004):

- Non-renewable Fuel Depletion and energy insecurity,
- Greenhouse Gas emissions,
- Local air quality,
- Fatalities and injuries,
- Congestion,
- Noise Pollution,
- Low Mobility,

- Ecosystem damage, and
- Lack of equity.

When considering the above impacts of the transportation system, it is apparent how the traditional transportation planning approach inadvertently fosters promulgation of these effects through creation of vehicle-centric urban cities and communities. Sustainable transport measures therefore encourage the use of NMT and public transportation modes to reduce the Greenhouse Gas emissions per person. This has seen some authorities redefining the transport system hierarchy to place more priority on "greener" modes when allocating road space, funding and pricing. An example of this is illustrated in Figure 2-1.

Green Transportation Hierarchy

1. Pedestrians
2. Bicycles
3. Public transportation
4. Service and freight vehicles
5. Taxis
6. Multiple occupant vehicles (carpools)
7. Single occupant vehicles

The Green Transportation Hierarchy favors more affordable and efficient (in terms of space, energy and other costs) modes.

Figure 2-1: Green Transportation Hierarchy

Source: Litman, 2014

In realising that roadway expansion is not a long term solution for managing congestion, planning methods now try to manage the transport demand, rather than supply, by supporting initiatives, such as ride-sharing or carpooling, congestion charging, intelligent transport systems, etc. Basically, transportation planning methods have to take cognisance of all modes in the system, appreciating the value of each mode and in turn producing transport plans which are address the operational requirements of this multi-modal system in an equitable and rational manner. Furthermore, the planning process should be proactive and translate the impacts listed above into criteria to be achieved.

2.4. Multi-Modal Transport Systems

Multi-modal transport systems reflect the new paradigm of accessibility, as the ultimate goal of the transport system rather than optimum (vehicular) mobility or physical travel (Litman, 2014). Traditional planning tools tend to demine the successful realisation of innovative policies and technologies involving improvements to alternative modes of transport and pricing reforms, according to Hüging et al. (2014), which is what multi-modal planning tries to facilitate (Litman, 2014). This method proves to be challenging in that the decision-maker is forced to consider all transport modes and their interaction. What makes this task even trickier is that each mode and its users has unique characteristics and requirements, which are often conflicting between modes. As a result, the various modes are planned in isolation and implementation of the supporting infrastructure is done on an ad-hoc basis or in conjunction with construction of new roads or upgrades to existing roadways.

Recent policy in South Africa advocates for the promotion of NMT and public transport modes in an effort to create more equitable and socially just transport systems; however planning practices have continued in a business as usual fashion (Bickford, 2013). One crucial contributing factor in this is the continued use of the conventional four-step model is the absence of a tool that can satisfactorily compute all the requirements of modes other than private vehicles. As highlighted in *section 2.2*, the traditional approach is built for the purpose of reducing vehicular congestion and is, therefore, still encouraging domination of vehicle-centric urban forms. This model treats public transport as an accessory to the private vehicle, thereby aiming to optimise vehicle flows and speeds but neglects other characteristics essential for success like passenger waiting times and queues, connectivity to transit points, affordability, passenger comfort and safety. It appears that focus on the user perspective is lacking and quality of the user experience is, therefore, often neglected in conventional planning practices.

Litman (2014) proposed that multi-modal planning include:

- Integrated institutions, networks, stations, user information, and fare payment systems.

- Consideration of a variety of transportation improvement options, including improvements to various modes, and mobility management strategies, such as pricing reforms and smart growth land use policies. Consideration of various combinations of these options, such as public transport improvements plus supportive mobility management strategies.

- Consideration of all significant impacts, including long-term, indirect and non-market impacts such as equity and land use changes. This should at least include:

  - Congestion
  - Roadway costs
  - Parking costs
  - Consumer costs
  - Traffic accidents
  - Quality of access for non-drivers
  - Energy consumption
  - Pollution emissions
  - Equity impacts
  - Physical fitness and health
  - Land use development impacts
  - Community liveability

- Special consideration should be given to transport system connectivity, particularly connections between modes, such as the quality of pedestrian and cycling access to transit stops and stations.

- Special consideration should be given to the quality of mobility options available to people who are physically or economically disadvantaged, taking into account universal design (the ability of transport systems to accommodate people with special needs, such as wheelchair users and people with wheeled luggage) and affordability.

- Use comprehensive transportation models that consider multiple modes, generated traffic impacts (the additional vehicle traffic caused by expansion of congested roadways), and the effects of various mobility management strategies, such as price changes, public transit service quality improvements and land use changes.

2.5. Résumé

Traditional transport planning methods tend to create vehicle-centric communities through the embedded use of the four-step model. This model was built for the purpose of solving vehicular congestion on roadways, in so doing creating a self-fulfilling prophecy, which almost always leads to investment in road projects leaving very little resources available for greener modes, such as NMT and public transport. Awareness around Climate Change and the significant role that transport plays in this challenge has sparked the need to find more sustainable transportation practices. Hence, modes of NMT and public transport have received increased attention and promotion by various policies, policies and decision-makers. Despite these efforts, lack of tools for planning multi-modal transport systems has resulted in the various modes being addressed in isolation and in an ad-hoc manner, to the detriment of the poor and socially disadvantaged, who are reliant on these alternative modes. Social and economic exclusion is still prevalent, particularly in developing countries like South Africa. This reality urgently calls for planning tools and methodologies to be developed, which enable translation of policies into practice, ultimately producing truly multi-modal transport systems. This need supports the topic investigated in this thesis, as it tries to prove that the use of SMCA can enhance the level of integration in transport planning.

3. Measuring Integrated Transport Planning

3.1. Introduction

This chapter introduces the concept of integration in transportation planning and why this modern approach is necessary. As the crux of this study is to demonstrate that spatial multi-criteria analysis can be used to enhance integration in the planning process of BRT feeder routes, and therefore, the final rapid transit system network, a set of key performance indicators will be developed that can be used to measure or assess the performance of BRT feeder routes developed through this method.

3.2. What is Integrated Transport Planning?

As the definition of sustainability within the transportation context has progressed, the use of the term integration has become more and more prominent. This has seen the rolling out of “Integrated Transport Plans” and “Integrated Rapid Transit Systems” across South Africa. “Integration” has indeed become the new trend in the field of transportation. It is, therefore, important to understand what this term means and why it is so important.

Countries around the world are striving towards reducing the number of person-car trips, due to the associated high levels of congestion and pollution. In devising strategies to reduce the preference for travel with the private vehicle, attempts have been made to identify the elements of private car travel that make this mode so attractive. It is believed that, if the same benefits can be provided by alternative modes, such as public transport, then transport policies and strategies are more likely to attract users out of their private vehicles.

Private car travel is appealing to users who can afford to use this mode, as it provides a “seamless” journey, sometimes referred to as “door-to-door” travel (City Transport, 2015), as the user can start and end their trip journey with the car. Public transport in itself commonly forms one or more segments of the trip chain as users have to use another mode, usually non-motorised modes like walking or cycling, to travel to or from a public transport transit point. Therefore, if public transport is to be a competitive alternative to the private car, the entire trip chain needs to be as seamless as possible so that it is nearly as easy, convenient and comfortable to use as the car. Hence, the need for integration of the modes in a trip chain in an effort to create a user-based experience that will attract more people to use alternative modes of transport. May et al. (2006) thus argues that one should be clear on what integration has been designed to deliver rather than seeing it as an end in itself.

Preston (2012) explains that there are a number of definitions of integrated transport depending on the perspective to which it is approached, for example, engineering, microeconomics, management and political science points of view. The microeconomic viewpoint sees integration as the reaction to market failure, whereas the neoclassical perspective is that competition will encourage coordination. The latter view has, however, since changed after the birth of the sustainability paradigm.

A broad definition of integrated transport can be adopted as used by both Preston (2012) and Poorjafari and Poorjafari (2011): "*The organisation process through which elements of the passenger transport system (network and infrastructure, tariffs and ticketing, information and marketing, etc.) are, across modes and operators, brought into closer and more efficient interaction, resulting in an overall positive enhancement to the overall state and quality of the services linked to the individual travel components." Furthermore, it refers to all characteristics of the passenger transport service, including infrastructures, tariff and information systems and especially the authorities and organisations which are involved in planning, managing and running the public transport systems. This definition even goes further than the borders of public transport systems and includes wider integration with other transport modes (e.g. walking, cycling and private cars) and other non-transport services, such as town planning and environmental and social policies. Moreover, this definition clarifies that integration refers to both intermodal and intra-modal issues. That is, it covers not only the interaction between different public transport modes, but also within each mode, by itself.*

Preston (2012) suggests that transport integration can be thought of as steps on a ladder (illustrated in Figure 3-1), where the first four steps represent horizontal integration between the different elements in the transport system, and steps five to seven represent vertical integration between different levels of authority. It is argued that sustainability of the system is achieved at the highest step of the ladder.

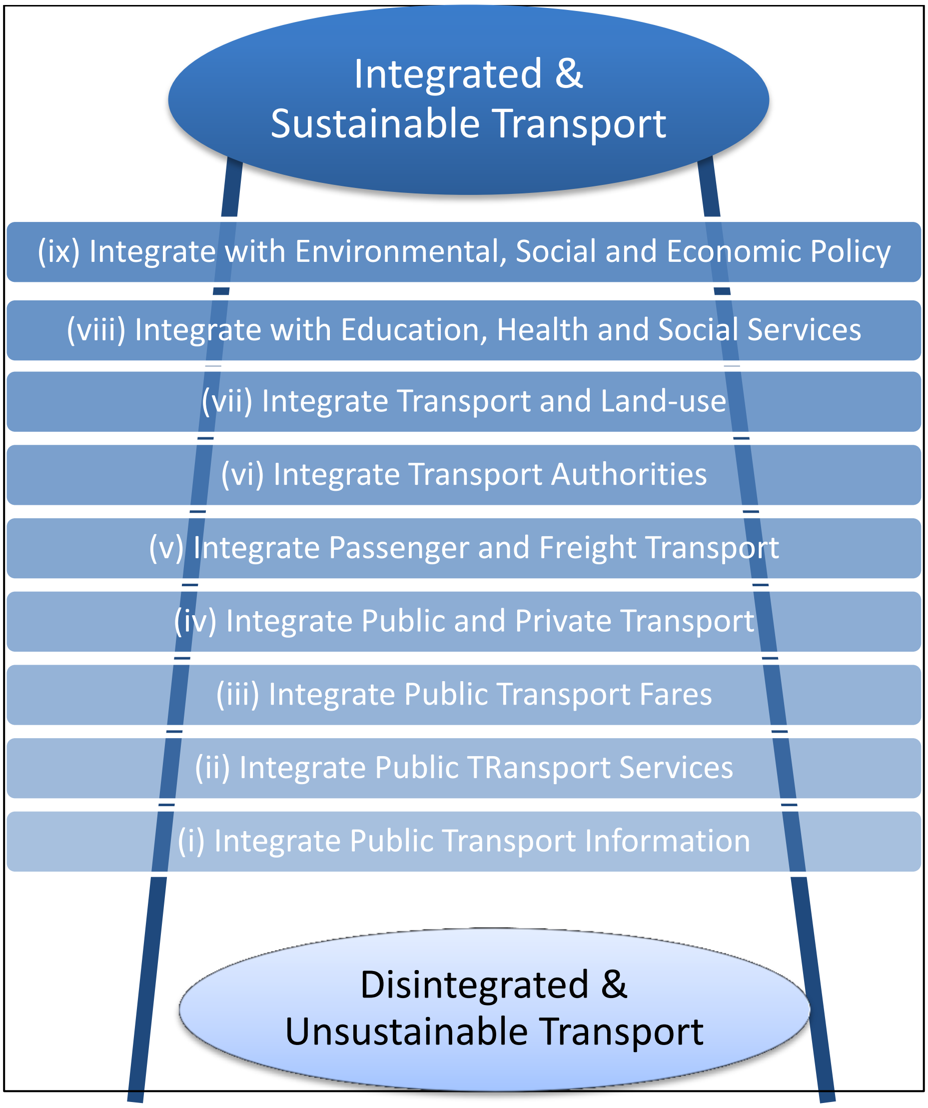

Figure 3-1: Transport Integration Ladder

Source: Adapted from Preston (2012)

As can be seen from Figure 3-1 above, the concept of integrated transport is multi-faceted and rather broad with almost all aspects of the transport system and governance playing an important role in the successful transformation to an integrated system. The various aspects of integration in public transport systems are listed as follows:

- Physical Integration,
- Network Integration,
- Route Network,
- Fare Integration,
- Information Integration, and

- Institutional Integration

There are also numerous tools, strategies and policies that can be applied to each of the above aspects in trying to achieve an integrated transport system; all contributing to the successful realisation of an integrated transport system being so complex. For the purpose of this study, the aspects of physical and network integration will be focused on. Physical and network integration is explained in more detail below.

The transport system comprises many modes and operators, which usually function in silos unless coordination is financially beneficial or regulated. As a result, transfer between modes, or transport services, is often difficult and inconvenient for users. Physical integration is, therefore, necessary to ensure that travel and waiting times are minimised where commuters have to transfer from one mode to the next or from one service to the next. For example, this can be achieved through locating a bus stop at a railway station so walking distance is minimised or providing secure bicycle lock-up facilities at bus stations, so that users can cycle to bus stations to catch a bus, as opposed to walking. Examples, such as these make the use of public transport much more attractive through prioritising the commuters' needs.

One of the most advantageous elements of travelling with a private vehicle is that one can get to any destination one would like to with minimum effort. Network integration, is therefore, necessary to enhance connectivity between numerous destinations, as opposed to offering connection to specific attractions. In this way, more users' transportation needs will be met. An integrated transport network maximises the advantages of each mode in the system thereby extending the reach of the transport network.

3.3. Measuring Integrated Transport Planning

With so many tools and strategies in place to transform the transportation industry into an integrated (and sustainable) system, it is essential to be able to measure the success or impact of each tool to gauge what the overall progress has been. As mentioned in *Section 3.1*, this study focuses on the aspects of physical and network integration. This section will present key performance indicators, which will be used to measure the performance of the BRT feeder routes that have been developed through the SMCA methodology in which various built environment and transport characteristics have been considered.

3.3.1. Key Performance Indicators

Based on the literature review conducted for this thesis, a list of Key Performance Indicators (KPIs) was developed and used to evaluate the final BRT feeder bus network produced as part of this research. The KPIs were also used as a guide to compare the feeder bus routes developed through this study to the existing MyCiTi feeder bus network in the study area. The KPIs identified are listed in Table 3-1 along with the evaluation approach.

Table 3-1: List of KPIs

Key Performance Indicator (KPI)	Units	Method
Average Travel Time	In minutes per feeder bus	Quantitative
Coverage	No of attractions within a 500m distance per route	Quantitative
Directness	Metres/ metres	Quantitative
Consideration of Environmental Factors	Degree of consideration	Qualitative
Level NMT Planning Inclusion	Degree of consideration	Qualitative

BRT planning guidelines, such as Institute for Transportation & Development Policy (2007), explain the importance of minimising average travel time whilst maximising the coverage and directness of BRT feeder routes. Furthermore, these system goals were also quoted by the Transport for Cape Town Planning Officials as important objectives in developing the MyCiTi BRT feeder bus routes, hence these have been included as KPIs in this study. In addition to these three KPIs, the inclusion of NMT planning in the BRT feeder route design is also cited as a critical objective due to the enhanced benefits offered to the potential ridership numbers for the BRT system.

Unlike the aforementioned KPIs, consideration of environmental factors in the BRT feeder route development was not identified in the BRT planning guides reviewed or by the Transport for Cape Town Planning Officials. However; BRT systems are being implemented in South Africa based on the premises that it supports sustainability, thus it was viewed as an imperative KPI.

4. Review of MyCiTi IRT System Planning

4.1. Introduction

The purpose of this chapter is to provide an introduction to the MyCiTi IRT System, as originally envisaged, and to describe the system planning approach that was followed during the implementation of Phase 1 of the IRT system. Furthermore; challenges that were faced during this implementation phase are also highlighted in this chapter.

4.2. Description of the MyCiTi IRT System

4.2.1. Background

In 2007, the National Department of Transport released a Public Transport Strategy and Action Plan, which calls for an Integrated Rapid Public Transport System (IRPTS) to be implemented in 12 cities and at least 6 districts by 2020. The strategy advocates that “IRPTS networks are the mobility wave of the future and are the only viable option that can ensure sustainable, equitable and uncongested mobility in liveable cities and districts”. The long term vision is to place 85% of a metropolitan city’s population within 1 kilometre of an IRPTN trunk (road and rail) with a fine-grained feeder system of smaller buses, taxis, bicycles, pedestrian access, as well as metered taxis and park and ride facilities. Public transport, walking and cycling will be prioritised over private car travel and road space will be demarcated accordingly. The overarching strategic approach is to create a mass rapid public transport system, which integrates routes of various modes and maximises accessibility, particularly to those with special needs (Pillay and Seedat, 2007).

In response to the Public Transport Strategy, the City of Cape Town (2008) identified the improvement of public transport as one of the key strategic focus areas for future development in its Integrated Development Plan (IDP) (2012 – 2017). This has given rise to the MyCiTi Integrated Rapid Transit (IRT) system, which comprises mainly Bus Rapid Transit (BRT) and Non-Motorised Transport (NMT). The planning for the

BRT service is guided by the principles of quality, equity, security, sustainability and integrity.

In an interview conducted with the Manager: System Planning & Modelling for Transport for Cape Town (TCT), he described the Adderley Station as an epitome of the original vision for the MyCiTi IRT System. This vision was based on the creation of a multimodal public transport system where passengers can board and alight quickly and seamlessly transfer from one mode to another. There should be no clear division or boundary between the modes, therefore, no difference in ticketing systems and levels of service. The transfer process should also be universally accessible, so that passengers with special needs can also transfer between modes with ease. The system should also include opportunities for trade and business creation, so that passengers have the option to buy necessities or coffee, while waiting for the next service should they wish to.

In an interview with the Manager: MyCiTi Infrastructure for TCT, it was explained that when the initial planning of the MyCiTi system was started, the goal was to raise the image of public transport ad to transform it into a system that provides equal opportunities for all Capetonians, including special needs passengers and those excluded through the Apartheid regime. The rail service is often overcrowded, unsafe and dirty and the GABS buses are noisy, uncomfortable and inaccessible for people with special needs, likewise for rail. The MyCiTi BRT system was, therefore, planned to replace GABS and minibus taxis. However, given that the system rollout will only be completed in 2030, it is questionable whether removing these operators from the transport system will allow sufficient capacity to be able to meet the growing transport demand in Cape Town.

4.2.2. System Components

As the MyCiTi IRT System is multimodal, a number of modes were included at the planning and implementation levels. The planning of the system considered all existing modes of public transport available in Cape Town, namely, Prasa rail services, Golden Arrow Bus Services, minibus taxi services and NMT. However, when it came to infrastructure provision, MyCiTi Trunk and Feeder Bus services and NMT were included. The reason for this is that the MyCiTi Bus service was intended to complement the rail service, which is still considered as the backbone of public transport in Cape Town, rather than compete with it, and to replace the GABS and minibus taxi services for the reasons mentioned in the section before.

The system planners were faced with three Bus Rapid Transit (BRT) service options which they could implement; namely, 1) Trunk-Feeder services, 2) Direct Services and 3) Mix of Trunk-Feeder and Direct services. The characteristics of each are described below:

1) Trunk – feeder services:
    a. Use of larger vehicles along high density corridors and smaller ones in lower density areas;
    b. Trunk services operate as a closed system with segregated busways which are predominantly in the median of the roadway;
    c. Stations are closed with pre-boarding;
    d. The trunks facilitates higher speeds and carrying capacities;
    e. The trunks are supported by feeder routes which distribute and collect passengers to or from the main trunk stations along trunk routes;
    f. Feeder services operate in mixed traffic lanes with kerbside stops;
    g. Fare verification is on-board therefore feeder stops are open.

2) Direct Services
    a. Passengers are transported directly from origin to destination, without the need of transfers from feeders;
    b. BRT Trunk vehicles may only operate along an exclusive busway for one portion of the route;
    c. The busways are only segregated in areas of high demand; otherwise the busses operate in mixed traffic.

3) Mix of Trunk-Feeder and direct service
    a. Mix of trunk-feeder and direct services;
    b. This can be used where the local circumstances vary from high to low density. Direct services are better suited to high densities and trunk-feeder services are more suitable to lower densities.

The final decision was to implement the Trunk-Feeder service option and include Trunk extensions where deemed necessary.

4.3. Description of the Network

In 2008, the initial MyCiTi BRT network plan was developed, during which the existing public transport supply and demand were analysed to provide cues as to where Trunk and Feeder services should be provided in Cape Town. Therefore, bus, minibus taxi, and rail routes, passenger origin and destination and passenger demand were assessed to identify the most feasible BRT Trunk and Feeder services.

From this analysis, it was established that most public transport users live in the suburbs of Khayelitsha, Mitchells Plain, Blue Downs and Nyanga. The main commercial and industrial attractors are in Claremont, Rosebank, Milnerton, Maitland, Parrow, Bellville, Salt River and Cape Town Central Business District (CBD).

Using EMME/3 software, the traditional four step model was used to project the passenger demand for each route developed. This model showed that the N2 is the main public transport route, transporting commuters from the metro-south east to the inner city areas. Other important routes are Lansdowne Road and Vanguard Drive.

The original system plan developed identified the following transport corridors on which Trunk services should be provided:

- R27 West Coast Corridor,
- Koeberg Corridor,
- Airport Link (via Nigeria Way),
- Klipfontein,
- Lansdowne,
- Vanguard Drive, and
- Symphony Way.

The MyCiTi Planning team concluded that, due to the high volume of existing public transport services, particularly minibus taxi operators, more time would be necessary to implement the MyCiTi services along the Lansdowne and Klipfontein Road Corridors. Some road segments also had encroachments by informal housing, which would need to be relocated and this process would also be time intensive. In light of these limitation identified, it was decided that the first phase to be implemented would include the West Coast Corridor, the inner city and a few airport services, as these had the joint benefit of satisfying the 2010 FIFA World Cup requirements. Furthermore, it was noted that the West Coast Corridor did not have any rail services at the time so an improved and competitive public transport alternative would be provided.

Phase 1 of the MyCiTi System thus included the following areas:

- Innercity;
- West coast including R27 and Koeberg Road;
- Feeder services to Hout Bay, Camps Bay, Sea Point, Blaauwberg, Milnerton, Du Noon and Atlantis.

Due to a lack of time and budget, the City opted to implement a smaller version of Phase 1 referred to as Phase 1a with Phase 1b to be implemented at a later stage. Phase 1a consisted of one Trunk route along the West Coast to the CBD, one airport service to the CBD and thirteen feeder routes serving the trunk corridor and the inner city area. Areas covered included the R27 from Atlantis to the CBD, Cape Town International Airport, Hout Bay, Camps Bay, Sea Point and Du Noon, all connecting to the CBD. Phase 1a would be extended by 2011 to Montagu Gardens and Maitland Rail Station via a second Trunk Corridor (Koeberg Road) along with various airport services.

4.4. How the Network was planned

It was mentioned, in the preceding section, that the MyCiTi BRT network was developed using two main steps. The first was to analyse the existing public transport system in Cape Town, to identify the main commuter corridors, origins and destinations. These routes were modelled using EMME/3 software to project the future passenger demand for public transport, including that for the MyCiTi services. A 20% shift from private vehicles to the MyCiTi service was also incorporated into the model, in line with the long term vision for Cape Town. However, it is unclear what the basis of this assumption was, and whether the percentage applied was realistic.

As a Trunk-Feeder technique was followed in developing the routing structure, Trunk Services were assigned to high demand corridors and locations whilst Feeder services were allocated to serve the lower demand areas.

The criteria applied to develop the routes for Trunk, Feeder and NMT are explained in more detail below.

4.4.1. MyCiTi Trunk Services

The ultimate aim of a Trunk service is to optimise average travel speeds between origins and destinations following the most direct route. This implies certain criteria for selecting routes for Trunk Services to operate on:

1. Sufficient road reserve: This allows the installation of dedicated rights of way for the BRT to operate on which will enable the achievement of higher average travel speeds.
2. Station Spacing: The spacing between consecutive stations impacts the distance available to be able to achieve and continue at higher average travel speeds thereby also increasing travel times.

In meeting these two criteria, certain classes of road become more suitable, such as class 2 and 3 (Primary and Secondary Arterials respectively), leaving only a few options available between a given origin and destination pair. If one takes the Blaauwberg/Atlantis to Cape Town CBD pair as an example, there are three alternatives available:

1. R27 (Marine Drive),
2. Koeberg Road, and
3. N7, N1.

After assessing these three options, it becomes apparent that the R27 is indeed the most suitable, as implementing the Trunk Service along Koeberg Road would require the closing of a number of intersections to facilitate the right of way for the buses so this would divide the existing activities along Koeberg Road as crossing opportunities for pedestrians and vehicles alike would decrease. Using the N7, N1 option would not provide enough attractors and opportunity to collect passengers, as these are mobility routes where access is very limited.

Once the route had been determined, the station locations were assigned based on the surrounding land use, spacing of about 900 metres to 1000 metres, sufficient boarding and alighting opportunities and coverage (based on an assumed 500 metre walking distance). It should be noted, however, that Hitge and Vanderschuren (2015) found that MyCiTi commuters were walking an average distance of 1.3 kilometres. This is more than double the assumed average walking distance applied in the MyCiTi BRT planning and implementation. The decision on the location of stations was done manually and was not informed by a modelling procedure.

4.4.2. MyCiTi Feeder Services

The purpose of the MyCiTi Feeder Bus Service is to collect and/or distribute MyCiTi commuters from attractors and destinations and transport them to a Trunk station from which they will continue the main stretch of their journey before transferring to another Feeder service, be it via NMT or MyCiTi. In order to fulfil this function, siting of MyCiTi Feeder Bus routes requires the application of a slightly different set of criteria compared to that for Trunk Services. The criteria applied include:

1. Coverage: This needs to be maximised in order to collect or distribute the highest number of passengers per route.
2. Directness of Routing: The more direct the route, the shorter the travel distance and therefore the more convenient for the commuters.
3. Land Use: The Feeder Service should be able to transport the passengers to where they need to be in order to access certain services, such as places of employment, shopping centres, medical services, police stations, etc. Likewise, the Feeder Services should also be able to collect the commuters as close to their place of residence as possible so that trip times are decreased for passengers.
4. NMT Access: Pedestrian and bicycle desire lines should be served so that commuters have the option to walk or cycle to reach the MyCiTi Feeder Service along the most convenient and safe NMT routes.
5. Traffic Congestion along the Route: As the Feeder Buses operate in mixed traffic conditions, congested roads do not offer a more attractive alternative to the private vehicle if the bus has to sit in the same traffic as the general traffic. Should there be congested roads along the route, there should be sufficient road

width to allow infrastructure to be implemented that will provide travel time savings for the feeder buses, such as queue jump lanes.

The City of Cape Town had developed an NMT Master Plan, which was used as a basis for informing the NMT connectivity to the potential route. However; it was later revealed that the siting of the feeder routes was a more volatile, complex and sensitive exercise as originally thought. The difficulties experienced in siting feeder bus routes are explained in more detail in *Section 4.4.3*.

4.4.3. NMT Infrastructure

The City of Cape Town realised the important role that NMT has to play in the transportation system, before the concept of BRT was introduced in South Africa's transport strategies and plans. The NMT Policy and Strategy, Volume 1: Status Quo Assessment, carried out by Pendulum Transportation Planning & Engineering Consultants in 2005, cited the lack of an integrated planning approach as the most significant contributor to the poor NMT environment present in Cape Town at the time. This strategy stressed the importance of designing public transport infrastructure, as an environment to be used by people, rather than purely for the vehicles but it failed to mention the necessity of planning public transport routes around NMT activities.

Despite this, the City of Cape Town Integrated Rapid Transit System Operational Plan Phase 1 Report (2008) identified the need to integrate modes of transport in order to maximise the potential customer base, particularly with NMT. It also highlighted as one of its essential components, the need to design supporting NMT infrastructure with Special Needs Passengers in mind. This then gave rise to the Integrated Rapid Transit System Operations Plan – Non-Motorised Transport Plan: Phase 1 Corridor (2009), which aimed to improve the NMT infrastructure in support of the proposed MyCiTi BRT services.

The City of Cape Town identified the following guiding principles as part of its Public Transport Implementation Framework:

- Access for all to the PT system,
- Accessibility for Special Needs People in the PT system,
- Priority treatment of cyclists and pedestrians in the PT system, and

- Provision for NMT as a feeder to public transport.

Further strategies were developed as part of the NMT Plan for the Phase 1 Corridor:

- Pedestrian access at stations by improving access, identifying hazardous locations for cyclists and pedestrians, promote at grade pedestrians crossings and consider pedestrians with special needs,
- Cycleway integration by developing cycle ways along busways and along feeder routes to IRT stations,
- Bicycle parking should be provided at all stations,
- Bicycle distribution groups, and
- Promote the use of pedicabs as a feeder mode.

The City of Cape Town decided that a 500 metre walking distance around each IRT station and along each route would be treated as an NMT Feeder Zone in which improvements to the NMT infrastructure had to be made, to make it easier and more comfortable for commuters to reach the MyCiTi Bus service, thereby encouraging the use of NMT as a feeder mode and improving its potential commuter base. This treatment was extended to 1000 metres around modal interchanges.

The plan explained that bicycle facilities should be provided along IRT busways and along NMT feeder routes where appropriate. A minimum cycle lane width of 1.5 metres to 1.8 metres was recommended for one-way cycling and 3 metres for two-way facilities by Pendulum Transportation Planning & Engineering Consultants (2009). Bicycles would also be permitted on the MyCiTi Buses during off-peak periods otherwise bicycles could be parked outside IRT stations in a bicycle parking facility to be provided during the IRT implementation phase.

This plan also explained the importance of locating stations along pedestrian desire lines and should be closely located to passenger attractions. It was noted, as the trunk stations were to be located in the median, pedestrians would have to cross the road to get to the station putting them at risk of being knocked by a vehicle. Therefore, it was strongly suggested that stations be positioned at signalised pedestrian crossings with the station access on the side closest to the crossing.

During implementation, existing and local area NMT plans were reviewed for the 500 metre treatment radius around the MyCiTi Bus stops and stations where these were available. The NMT Network Plan for Cape Town was revised to include the Phase 1 routes and stations.

The following criteria were used to decide on sites where NMT infrastructure would be provided:

- Where NMT would be acting as a feeder to public transport services,
- NMT integration with IRT services,
- Major attractions,
- Improve walkability of the CBD,
- Availability of space,
- Proximity to a pedestrian desire line,
- Safety of pedestrian access,
- Proximity to IRT service, and
- Public transport facilities.

The final implementation of Phase 1a comprised of a 3 metre wide shared bicycle and pedestrian facility, which runs along the entire 16km length of the R27 Corridor. A secondary network of paths and cycle ways was been designed for 500 metres along all the intersecting roads with the Trunk Route. The class of NMT facility to provide was determined by looking at the available road reserve, so either no demarcated cycle lane was provided, or a cycle lane was provided within the road through paint marking demarcation. No road widening was made to add cycle facilities. This level of infrastructure provision for cyclists is minimal and demonstrates little appreciation of the importance of cycling as a mode within the MyCiTi IRT system.

Traffic calming was implemented in the form of reducing speed limits, such as on the R27 from 70km/hr to 60km/hr. Other measures, such as speed humps and roundabouts were not implemented, due to negative impact these have on travel speeds for the MyCiTi Buses and discomfort to passengers on board the bus when going over speed humps. Priority for pedestrians at intersections where stations are located was provided through block crossings. Overall, it appears that a greater effort could have been invested in improving the pedestrian environment for MyCiTi commuters.

An attempt was made to improve the environment in the station precincts, by involving urban designers so that people were made aware that they are in a mixed use zone. This was done through changing the paving at these intersections and implementing tactile paving to warn the cyclists that they need to give priority to the pedestrians. Outside of the precinct, limited attention was given to improving the environment for NMT users and passengers.

4.5. Challenges Faced

During the planning and implementation of Phase 1a of the MyCiTi IRT System, a number of challenges were faced that are still not completely resolved today. These difficulties were mainly linked to the routing of the MyCiTi Feeder Bus routes and the achievement of universal access of the system.

The latter challenge is mainly due to the lack of guidance and funding related to the provision of universally accessible infrastructure. It is imperative to ensure that the whole trip chain is accessible for SNPs and not just a part of it as then the entire trip chain breaks down. In hindsight, the 500 metre treatment zone may not have been sufficient to facilitate the increased usage by SNPs, or other users either, however, this is all that the budget allowed at the time. A significant number of infrastructures provided, at the time were also done incorrectly, resulting in the facility losing its purpose. As a result, the value of the infrastructure expenditure, specifically related to universal access, has not been fully realised yet due to the limited increase in usage by Special Needs Passengers.

Regarding the Feeder Service routing, a large number of complaints were received from the Atlantis community according to planning officials at TCT, due to safety and security concerns arising from gang wars in the area. Other issues included congestion levels and the impact of the taxi industry, as it was assumed that existing minibus taxi routes operated at the time would be removed completely, however, these continued to operate along the MyCiTi feeder routes. The approach that ensued was to use temporary bus stops as a trial for the feeder bus route, before constructing the final infrastructure. A more community-centred approach was also followed where a number of workshops were hosted with the community, to identify where they would prefer to have the bus stops and routes. This approach provided better guarantee that the community would use the MyCiTi services.

In hindsight, the planning team for the MyCiTi BRT system at TCT have found that the current planning approach in siting the Feeder Bus routes can be improved to better appreciate the local characteristics that make up an area, in particular the existing NMT travel patterns and the influences thereon as this will ultimately impact whether the route developed will best serve its potential customers.

5. Spatial Multi-Criteria Analysis

5.1. Introduction

This chapter describes the tool, Spatial Multi-Criteria Analysis (SMCA), proposed in this dissertation to have the ability of enhancing integrated transport planning. The origins of this method are explained, followed by a description of Multi-Criteria Analysis (MCA), the tool from which SMCA evolved. An overview of the SMCA methodology, as well as examples of where this method has been applied in the past, is provided.

5.2. Background

Although the use of this method is limited in South Africa, there is a vast collection of literature on Spatial Multi-Criteria Analysis and the application thereof worldwide. Literature can be found dating back to as early as 1988 (e.g. Diamond and Wright, 1988, and Janssen and Rietveld, 1990). A literature review conducted by Malczewski (2006) revealed that publishing of SMCA- related articles has increased exponentially post-1995, with modest developments between 1990 and 1995. The high level of compatibility and synergy between MCA and Geographic Information Systems has been noted as the main reason for the increasing popularity of utilising SMCA as a decision support tool. Additionally, GIS software became more readily available to practitioners and the public as the costs fell and technology became more accessible (Dempsey, 2012).

5.3. Multi-Criteria Analysis

The development of multi-modal transport systems involves the assimilation of various modes, each with their own set of requirements for optimal performance and operation. The process of integrating individual modes, into a greater transport system, can be thought of as a decision-making process, whereby the networks of the various modes are developed, determining the routes of operation and locations for infrastructure investment. A number of decision support systems have been developed to assist decision-makers and key role-players in the process of making decisions concerning complex problems. One such tool is the Multi-Criteria Analysis (MCA) tool.

The main purpose of MCA is to provide a means of handling large amounts of multifaceted information in a consistent way, when faced with having to decide between several alternatives. This method can be used to identify a single most preferred option, to rank options, to short-list a limited number of options or to distinguish between acceptable and unacceptable possibilities (Department for Communities and Local Government, 2009).

The MCA analysis method aims to establish preferences, between a given set of alternatives, based on a pre-defined list of explicit objectives for which criteria have been agreed upon amongst the decision-makers involved. The criteria and sub-criteria are measures of performance used to assess the degree to which individual objectives have been attained for each option. A fundamental characteristic of this method is the vital role played by the decision-making body, in determining objectives and associated criteria, fixing a weighting to each criterion and rating the performance of every option against the set of criteria. This tool, therefore, presents a significant level of subjectivity, which can be mitigated through the use of measurable criteria, rather than qualitative criteria, to reduce the influence of subjective opinions on the overall result of the analysis.

MCA is valued by decision-makers, due to its ability to handle complex problems in a transparent manner. The set of criteria and related weightings can be changed, to test the influence on the final results by performing a sensitivity analysis, thereby providing flexibility to the method. The scores and weights are developed using established techniques and information and can be cross-referenced to check the validity of the assessment hence an audit trail is available. This tool also allows the use of qualitative criteria, which is beneficial for assessing problems involving social and environmental impacts.

The Department for Communities and Local Government (2009) explains that a standard feature of MCA is a performance matrix or consequence table, where each row describes an option and each column describes the performance of the options against each criterion. The performance of every alternative is predominantly expressed as a numerical term (quantitative) but can alternatively be represented by "bullet point scores," colour coding, binary terms or qualitative terms (as illustrated in Figure 5-1). Basic forms of MCA use this performance matrix as the final product of the analysis, where assessors conclude the process by utilising this matrix to justify the extent to which the objectives have been achieved by the entries in the table. More advanced methods follow a process of standardising the matrix to even out the comparison of performance by each alternative.

Table 4.1 Performance matrix

Options	Price	Reheat setting	Warming rack	Adjustable slot width	Evenness of toasting	Number of drawbacks
Boots 2-slice	£18				☆	3
Kenwood TT350	£27	✓	✓	✓	☆	3
Marks & Spencer 2235	£25	✓	✓		★	3
Morphy Richards Coolstyle	£22				☆	2
Philips HD4807	£22	✓			★	2
Kenwood TT825	£30				☆	2
Tefal Thick'n'Thin 8780	£20	✓		✓	★	5

Figure 5-1: Example of a typical Performance Matrix

Source: Department for Communities and Local Government, 2009

Most MCA techniques adopt a two-step process of numerically analysing the performance matrix (Department for Communities and Local Government, 2009):

1. **Scoring:** Numerical scores are assigned to each option which depicts the expected consequence or performance of that option against all the criteria using strength of performance scale. Scales of 0 to 100 are typically used where the highest performing option will score higher than lower performing options when assessing each criterion.
2. **Weighting:** Numerical weights are assigned to reflect the relative preferences of the decision-maker/s between the individual criterions.

Mathematical routines are then used to process these two components to provide an overall assessment of each alternative being evaluated in the performance matrix. Most MCA methods differ in how this step is approached and the nature of the assessment will dictate what method is most appropriate.

The first type of approach is to directly analyse the performance matrix to identify whether any option is dominant in its performance over the others. This quick and easy method may be used to simply help the decision makers to eliminate alternatives in a systematic way. It is important when using this method to question whether it is acceptable for there to be trade-offs between the criteria, so that one area of performance can compensate for another of lower performance. If this is deemed unacceptable, *non-compensatory MCA* techniques may be used.

The next approach stems from the work of Von Neumann and Morgenstern (1947) and of Savage (1954) on the Multi-Attribute Utility Theory, which aims to establish a model on how individuals should make multi-criteria decisions. Whilst this method provided valuable insight, it offered limited assistance in complex decision tasks. Research by Keeney and Raiffa (1976), however, was exceptionally powerful in the advancement of this theory. They established a collection of methodologies, which allows a more practical approach to the evaluation of multi-criteria options. Their method involves ascertaining whether criteria are independent of one another or not. Thereafter an index, *U*, is established which represents the opinion of the evaluator's preference of each option based on its performance against the individual criterions. This function is used to convert the attributes of individual options into a real score. The alternative with the highest score is considered the preferred solution.

Further methods include Linear Additive models and the Analytic Hierarchy Process (AHP). The first is adopted when it can be rationally presumed that the criteria are independent of one another. In this case the value scores for each criterion can simply be multiplied by the relative weighting, and then the weighted scores can be summed to obtain a final score for that option. The option with the highest score is considered best. The latter method applies another form of linear addition; however, weights and scores are determined using pairwise comparisons of criteria between options (Department for Communities and Local Government, 2009).

Lastly, is the Outranking method where the performance between options for each criterion is compared and the weighting of the respective criterion is assigned to the option, which outperforms its competitors for that specific criterion. The alternative that significantly outranks the other options is deemed preferred (Department for Communities and Local Government, 2009).

As outlined above, there are numerous MCA techniques available to support decision-makers in their tasks. It is, therefore, imperative that a suitable method is selected for a particular problem. A sensitivity analysis should always be conducted to test the influence of either the weighting or rating of a particular criterion on the overall result, as the final decision often carries dire consequences if it is not suitable. The general MCA process can be summarised as shown in Figure 5-2.

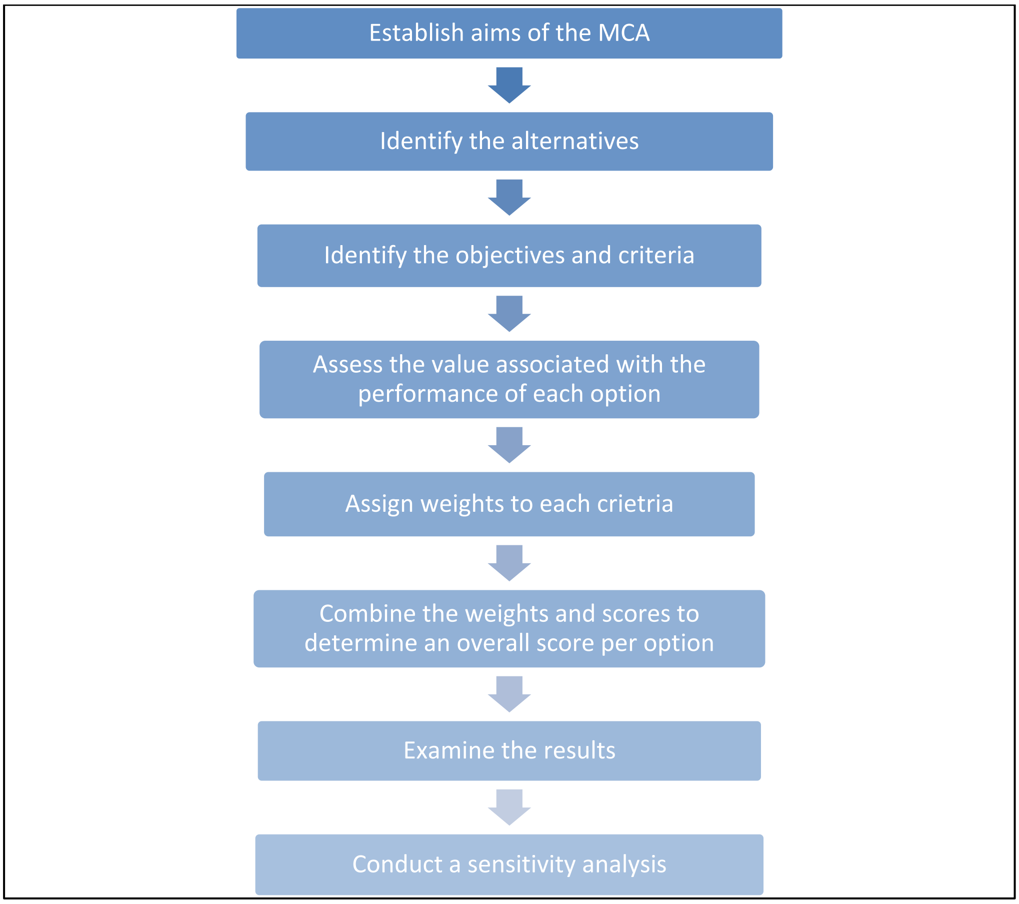

Figure 5-2: Summary of MCA Process

Source: Adapted from Department for Communities and Local Government, 2009

5.4. Past Applications of Spatial Multi-Criteria Analysis

Even though this method is not used extensively in South Africa and is in fact relatively unknown in industry, Spatial Multi-Criteria Analysis (SMCA) has been applied to solve a number of spatial decision problems across various industries around the world. A few examples of how this method has been used elsewhere are presented in this section.

In a literature review conducted by Malczewski (2006) he noted that major application areas include:

- Environmental planning/ecology and management;
- Transportation;
- Urban and regional planning;
- Waste management;
- Hydrology and water resource;
- Agriculture and forestry.

The above applications accounted for 72.4% of the applications reviewed. The remainder of the applications were in areas like natural hazard management, recreation and tourism management, geology and geomorphology, industrial facility management and cartography. Interestingly, all of the above applications involved solving site suitability problems. This method has also been applied to plan/scenario evaluation problems.

The study completed by Zucca, et al. (2008) provides a good example of how this method can be applied to site suitability problems where they used this method to select a site for a local park in Bergamo, Italy. This study adopted a value focused approach using the framework of carrying out the assessment in three phases i.e. Intelligence, Design and Choice phases. Two rounds of SMCA were performed using different criteria trees developed with various stakeholders. The first round was used to produce level of suitability maps from which the alternative sites could be selected. Thereafter, the alternative sites were developed by designing the alternative park layouts. The second round of SMCA was then used to select the most appropriate site based on the designed alternatives.

The application of SMCA to solve transportation problems is being used increasingly as well. Sharifi, et al. (2006) used SMCA to evaluate alternative rail networks developed. The evaluation technique used an additive utility function to select the preferred rail network design. Keshkamat (2007) used SMCA to produce and evaluate various road routings for the proposed Via Baltica Corridor in Poland. Four themes were developed, which represented different policy visions for the Via Baltica Corridor. Using SMCA, four level of suitability maps were produced, one for each policy vision. A network analysis was then performed using these suitability maps in

ArcGIS to generate optimal routings for the corridor by determining the path of least impedance in each map. The route which offered the least overall impedance and, therefore, cost, was selected as the preferred alternative routing for the corridor.

Beukes, et al. (2011, 2012) provided a unique take on SMCA by combining this method with cluster analysis to prioritise Transport Infrastructure projects. Unlike other SMCA applications in which the alternatives assessed were either sites or routes, this study determined the most suitable mode of transport to use a predetermined route. His argument was that certain characteristics such as land use, densities, etc. define the local context of a specific route and these characteristics are more suitable to particular modes of transport than others. He, therefore, argues that this should be considered when prioritising infrastructure investment projects. In previous applications a single accumulated map is produced that combines the standardised criterion maps, whereas he develops suitability maps for each mode of transport. These maps indicate the relative suitability of a mode of transport to a specific location.

The above examples of how SMCA have been applied in previous studies provides evidence to show that this tool could in fact be used in a number of ways, to solve a number of different types of problems, particularly in the field of transportation, where it has been used most creatively. This provides reason to believe that this tool could in fact be used to enhance the level of integration in transportation planning in South Africa.

5.5. Overview of SMCA

This section provides an overview of SMCA, starting with an explanation of what SMCA is followed by how it is used and ending off with a comparison of the weaknesses and strengths of this method.

5.5.1. What is SMCA?

Spatial decision problems typically involve a number of potential alternatives and multiple, conflicting and numerous evaluation criteria. The alternatives have to be evaluated by a number of decision-makers and experts who often have opposing views on the relative importance of the criteria involved in selecting the preferred alternative or solution (Malczewski, 2006). Chakhar and Mousseau (2007) explain that a spatial decision alternative comprises two attributes; that of what to do and where to do it. The decision alternative can either have an explicit or implicit spatial element, in which case the latter case applies when the consequences of a given alternative has spatial implications.

Due to the spatial nature of the problems, Geographic Information Systems (GIS) are an obvious choice for assisting decision-makers in assessing the possible alternatives. Beukes, et al. (2012) describes GIS as being well-suited for analysing large and disparate sources of information. Despite this unique ability, GIS in itself is incapable of recommending suitable sites based on specific planning objectives when multiple and conflicting criteria and objectives are present; this responsibility therefore remains with the decision-makers (Diamond & Wright, 1988).

MCA on the other hand, provides an established set of methodologies for structuring decision problems and for designing, evaluating and prioritising suitable alternatives based on the defined objectives or criteria of the decision-makers involved (Beukes, 2011). This makes the integration of GIS and MCA, known as Spatial Multi-Criteria Analysis, extremely valuable for solving and assisting decision-makers with spatial decision problems. In SMCA the role of GIS is to provide the base information to the decision model. For multi-objective spatial problems, the GIS is used to generate a set of composite maps illustrating the relative suitability of any given parcel of land in achieving a particular objective (Diamond and Wright, 1988). The use of these two integrated tools, in the form of SMCA, has been increasing since the 1990s as the use of GIS has gained popularity (Power, 2003).

5.5.2. How Does SMCA Work?

Malczewski (2006) suggests that decision problems can be split into two categories, namely multi-attribute and multi-objective decision problems. He explains that the first type assumes a limited number of predetermined alternatives where the problem solving involved is more of a selection process as opposed to a design process, which is the case with the latter type. Multi-objective problems are said to be continuous in the sense that the best solution may be found anywhere within the region of feasible solutions. These two types of decision problems are sometimes referred to as discrete and continuous problems, respectively.

Zucca, et al. (2008) explains that Keeney (1992) distinguishes between two main approaches to solving decision problems. The first being an alternative-focused approach, which starts with developing the alternatives followed by the specification of objectives and criteria, ending off with the evaluation and recommendation of an alternative. The second type is the value-focused approach, which considers the objectives as the basis of the analysis. So it first specifies the values and then develops potential alternatives based on these values. These alternatives are evaluated based on the identified criteria. Drawing from Keeney's description, this approach is similar to that described by Malczewski (2006).

The value-focused approach, or multi-objective approach, is concentrated on in the remainder of this section as the methodology used in this thesis is more aligned to this type of approach.

Sharifi, et al. (2006) is quoted by Zucca, et al. (2008) in explaining that a spatial decision problem can be visualised as a "table of maps," or a "map of tables," which has to be transformed into one final ranking of alternatives. This can be illustrated by Figure 5-3.

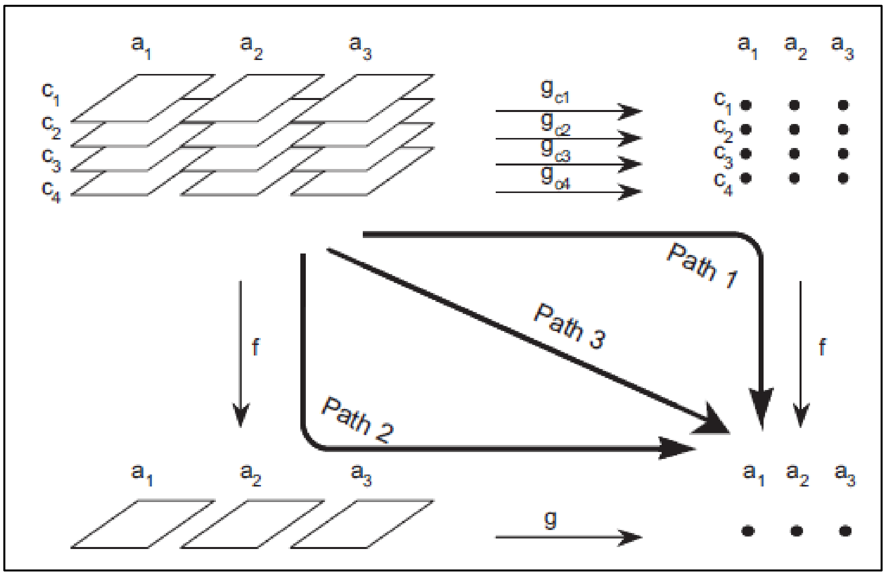

Figure 5-3: Decision Paths available in Solving Spatial Decision Problems

Source: Zucca, et al., 2008

The most direct approach is shown by *Path 3* where all the information is processed by the decision-maker and transformed into a ranking. If *Path 1* is followed, then the starting point is to aggregate the spatial information into non-spatial values for each individual theme. Thereafter, the conventional MCA can be applied to determine the suitability or performance of each alternative. On the other hand, if *Path 2* is followed, suitability maps for each alternative are produced through applying MCA techniques to aggregate the theme maps; thereafter, each map is aggregated to a single non-spatial value. This approach provides visual illustration of the performance of each alternative across the geographical space. This approach also allows the decision-maker to include both spatial and non-spatial criteria in the MCA, without losing the spatial element.

On a high-level, the approach to decision-making can be broken down into three steps as alluded to by Karnatak, et al. (2007) and Zucca, et al. (2008). They classify these phases as the intelligence, design and choice phases. The intelligence phase comprises the tasks of data collection, processing and evaluation. The project goals and criteria would also be established in this phase, after which the information collected would be assessed in GIS to develop the set of alternatives during the design phase. Lastly, the choice phase involves performing the evaluation and ranking of the alternatives through the selected decision rule.

Figure 6-4 illustrates the decision flow chart for Spatial Multi-Criteria Analysis in more detail; where it can be seen how the various steps fit within the framework put forward by Karnatak, et al. (2007) and Zucca, et al. (2008).

From Figure 5-4 it can be seen that the first step is to define the spatial decision problem by setting out the objectives of the analysis. Thereafter, all existing data can be collected and pre-processed using GIS in the form of a screening exercise to gain a better understanding of the physical characteristics of the site or problem.

Together with the stakeholders and experts, the assessment criteria can be established and weights assigned to reflect the perceived importance of each criterion. A criterion can be defined as a standard by which the alternatives will be judged and evaluated according to their desirability. Once again, criteria may be either explicit or implicit. An explicit spatial criterion for example, is a physical characteristic such as shape or area whereas implicitly spatial criteria require some spatial input in order to compute the level of achievement of the criterion (Malczewski, 2006).

Furthermore, the criteria need be categorised as a benefit, cost or constraint. A beneficial criterion is one that adds to the suitability or utility of the alternative, whereas a cost detracts from it. A constraint is a hard criterion that represents a natural or artificial restriction on the potential alternatives, such as environmentally sensitive areas (Chakhar & Mousseau, 2007). Unlike the influence of constraints that cannot be counterweighted, the effect of a cost criterion on the suitability of an alternative can be compensated by a benefit criterion. The criteria are structured into what is termed a *criteria tree*, where the individual criteria represent the branches of the tree.

The aforementioned process of establishing criteria and associated weights is akin to the initial steps followed when conducting MCA. However, when conducting SMCA, each criterion in the criteria tree is represented by a map. These maps are attached and positioned according to the criteria tree structure in a SMCA enabled GIS software, such as ILWIS. Once these maps are in place, standardisation of the criteria is necessary to ensure that the performance of each alternative is measured using the same scale for each criterion in the analysis. Standardisation involves normalising of all the input maps where utility values between 0 (not suitable) and 1 (highly suitable) are assigned to each map (Keshkamat, 2007).

After performing the SMCA, a map is produced for each alternative that illustrates the composite suitability or utility of the alternative over space. Each pixel in the map represents the suitability of the respective alternative at a specific location. In order to allow comparison of the alternatives, the pixel values need to be aggregated using methods, such as the average sum of the pixel values (Zucca, et al., 2008). This is done in the network/site analysis step of the assessment.

A sensitivity and/or uncertainty analysis is necessary to identify the presence and influence of any bias in the assessment. This can be done by applying different sets of weightings to the criteria tree and assessing the impact on the final results.

On conclusion of the sensitivity analysis, recommendations can be made on the most suitable alternative.

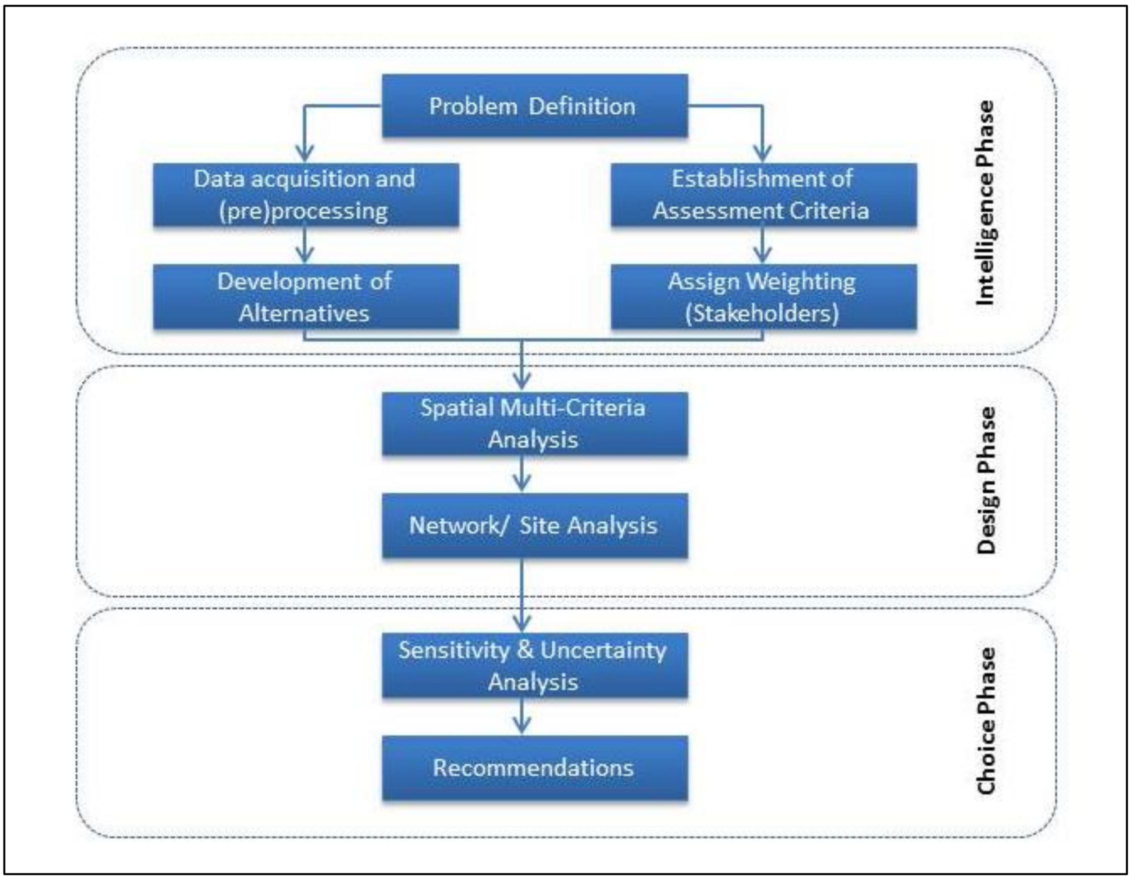

Figure 5-4: Decision Flow Chart for SMCA

5.5.3. Strengths and Weaknesses of SMCA

In considering the strengths and weaknesses of the SMCA method, the appropriateness to assessing particular spatial decision problems can be determined. That said, the strengths of this method make it applicable to solving most spatial problems, as the weaknesses can be managed.

The biggest and most commonly cited strength of the SMCA technique is that it allows a structured and streamlined approach by providing explicit trade-off information to assist decision-makers when faced with complex spatial problems, where there are a large number of alternatives, and where there are multiple and conflicting planning objectives. In these cases, one site may be optimal in terms of cost but may not be the most suitable in meeting the operational requirements of the given facility, whilst another site may be more costly to develop, but will best suit the operational requirements of the facility under question. In these situations there is no single most favourable solution (Diamond and Wright, 1988; Carver, 1991; Karnatak, et al., 2007; Zucca, et al., 2008).

SMCA is also a very transparent approach in the manner in which goals, criteria and weightings are selected and incorporated into the evaluation of the alternatives, as a trail of evidence is available on how the final decision is made. This strengthens the accountability and reliability of the decision-making process as opposed to the majority of decision-making methods which often leave stakeholders and the public dissatisfied with the manner in which decisions were made (Diamond & Wright, 1988; Carver, 1991; Zucca, et al., 2008). Additionally, in using site specific information in the assessment, more insight is provided to the decision-makers and stakeholders, enabling better informed decisions to be made (Carver, 1991).

Furthermore, Keshkamat (2007) reasons that the ability of this technique to handle multiple and conflicting criteria, both qualitative and quantitative, makes this tool suitable in integrating various policies, regulations and important functional requirements, therefore, making it advantageous to transportation planning. Beukes, et al. (2012) goes further to propose that this tool is capable of appreciating multi-modal attributes of the transport system and surrounding land uses, enabling integration of the two.

Despite all the strengths of SMCA, there are also a few weaknesses. One of biggest challenges of using this method is that it is quite complicated in nature and requires an adequate understanding of how to use it in terms of the evaluation and standardisation techniques available. This factor can lead to incorrect implementation of the method, which could have significant consequences, such as unfruitful expenditure or reduced operational efficiencies of the new facility. It also results in the limited use of this method in industry. Furthermore, the stakeholders and decision-makers involved highly influence the results through their perceived importance of the evaluation criteria resulting in a significant level of inherent bias in the decision-making process. Different techniques or stakeholders will inevitably produce different results when applied to the same evaluation criteria thus must be considered in the application of this technique (Carver, 1991).

The use of data in the SMCA procedure is also very extensive, thus the availability and quality of data included in the analysis can impede on the value of the final results. Furthermore; the choice of pixel size in the evaluation may lead to loss of information, making this decision crucial to the reliability of the outcomes.

6. Method Description

6.1. Introduction

The methodology followed in conducting this research is set out and described in detail in this chapter. An overview of the process followed is illustrated in Figure 6-1 below, where it can be seen that two approaches were followed in this study. A more detailed work flowchart can be found in *Section 6.12* and is illustrated in Figure 6-5.

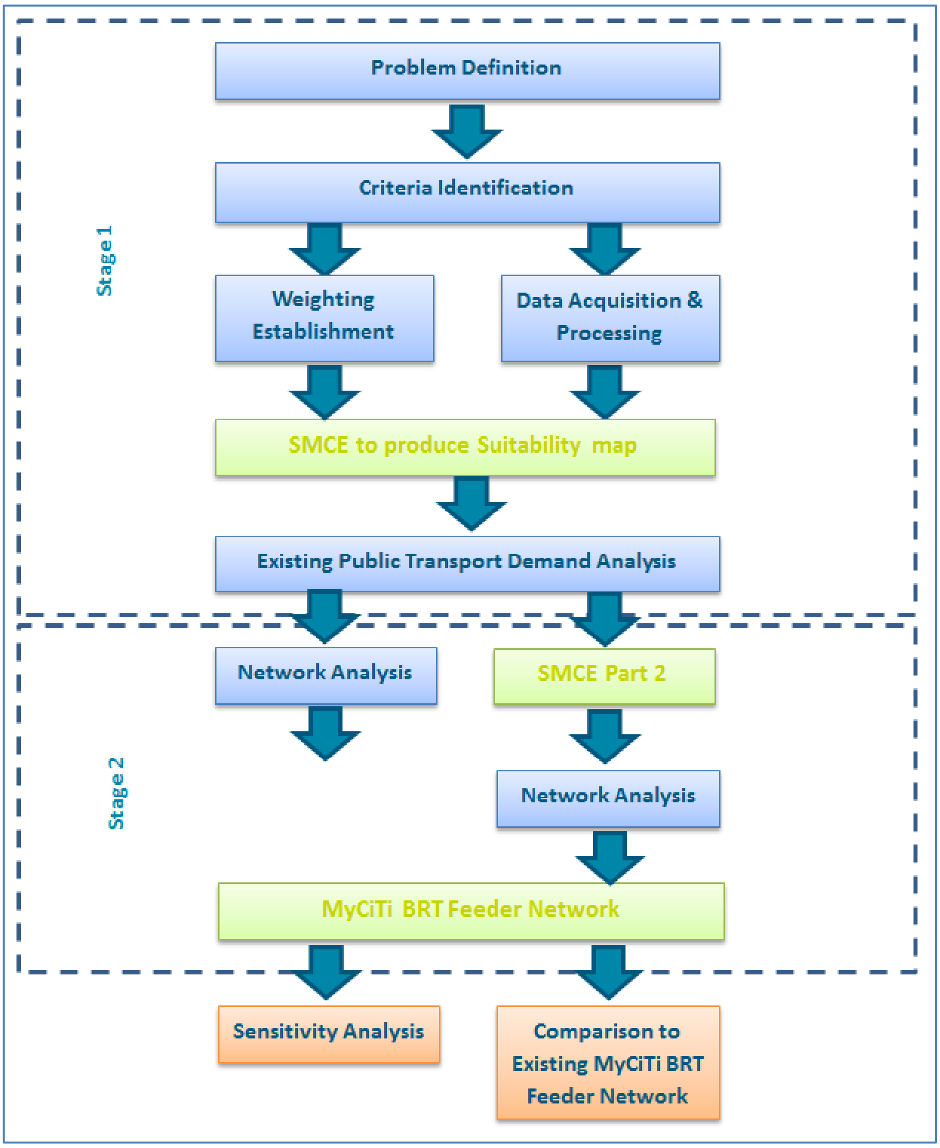

Figure 6-1: High Level Method Flow Chart

6.2. Identification of Modes to be Included

The first step taken was to identify and decide on which transportation modes to be included in this study. Initially the following modes were identified:

- MyCiTi Bus Rapid Transit (Trunk and Feeder services),
- Pedestrians,
- Cyclists,
- Special Needs Passengers, and
- Private motor vehicles.

The users for whom infrastructure was provided, as part of Phase 1, in the rollout of the MyCiTi IRT System were used as a base to start from as this study aims to improve the planning approach followed in developing that system. However; it was concluded that catering for Special Needs Passengers (SNP) involves a form of infrastructure provided for both pedestrians and cyclists, and it was assumed that no additional road infrastructure would be provided solely for the use of private motor vehicles. Hence the modes included in this study were as follows:

- MyCiTi Bus Rapid Transit (Trunk and Feeder Services),
- Pedestrians, and
- Cyclists.

6.3. Identification of Assessment Criteria

The criteria identified for this study was based on transportation planning principles, particularly for BRT feeder systems, and the experience of the author. The criteria were grouped into five themes; land use, socio-economic, environmental, transportation and Non-Motorised Transport (NMT). It was opted to have NMT as a separate theme from transportation, to allow more emphasis and influence on the final results rather than having NMT as a sub-component of the transportation theme. The assessment criteria established along with an explanation justifying the inclusion of each criterion are shown in Table 6-1. Each criterion listed in this table was represented by a criterion map in the Spatial Multi-Criteria Analysis (SMCA). Therefore, the choice of criteria inclusion was, unfortunately, also influenced by the data available in order to develop these maps; so elements, such as quality of NMT infrastructure or demand for NMT facilities could not be included, despite the important role these factors have on BRT routing.

Once the criteria had been identified, each criterion had to be classified as either a spatial factor or constraint. The spatial factors were then further defined as either a spatial benefit or cost. Each classification can be explained as follows (ILWIS 3.31 Academic , 2007):

- **Spatial Constraint:** This is a criterion that determines which areas should not be considered as suitable in the analysis results and will receive a value of zero in the final output. Poor performance of a spatial constraint cannot be substituted by good performance of a spatial factor.
- **Spatial Benefit:** A spatial benefit is a factor which should be optimised in the analysis. In other words, the higher the value, or the more thereof, the better this is for the final suitability. Values on the higher end of this factor will receive a value of 1 in the final suitability computation.
- **Spatial Cost:** A spatial cost is a factor which should be minimised in the analysis. The lower the value, or the less thereof, the better this is for the final suitability. Values on the lower end of this factor will receive a value of 1 in the final suitability computation. Poor performance of a spatial cost can be substituted by good performance of a spatial benefit for the same pixel in the suitability analysis.

The classification assigned to each criterion used in this analysis is also included in Table 6-1. The choice of what classification to assign to each criterion was based on how the attributes were labelled in the rasterisation process.

Table 6-1: Assessment Criteria

Category	Criteria	Explanation
Land Use	Land Use cost	A higher mix in the land use is better suited for TOD
	Building Density (floor area ratio) benefit	Higher densities support PT and NMT modes.
Socio-Economic	Average Annual Household Income cost	Average Household Income indicates likely choice of private motorised modes over PT modes.
	Residential Density benefit	Higher population densities support PT and NMT modes.
	Employment Opportunities benefit	Employment opportunities indicate desired destinations and are better suited to PT and NMT modes.
	Presence of vulnerable road users benefit	PT should be encouraged where there is a higher representation of vulnerable road users such as the elderly, children and disabled.
Environmental	Proximity to Environmentally sensitive areas cost	Environmentally sensitive areas should be avoided in provision of transport infrastructure, including PT.
	Proximity to Heritage Sites benefit	NMT access to heritage sites should be maximised whilst motorised modes should avoid heritage sites.
	Proximity to Landscape Parks and Recreational Facilities benefit	NMT and PT access to these facilities should be maximised and motorised modes should avoid these sites.
	Water Courses and Lakes constraint	Provides a barrier to NMT modes specifically and less so to motorised modes.
Transportation	Private Car Ownership cost	The higher the private car ownership, the more incentive to promote PT and NMT travel.
	Proximity to Destinations benefit	Higher proximity to destinations indicates the travel needs of commuters will be better satisfied.
	Proximity to other PT Facilities benefit	Presence of other PT facilities (taxis, GABS, etc.) indicates a PT demand therefore NMT access should be improved and routes prioritised for MyCiTi.
	Hazardous Locations cost	High Accident zones should be avoided by PT and NMT modes.
Non-Motorised Transport	Presence of Pedestrian Infrastructure cost	Presence of pedestrian infrastructure indicates good access opportunities for pedestrians to use PT.
	Presence of Bicycle Infrastructure benefit	Presence of bicycle infrastructure indicates good access opportunities for cyclists to use PT.

6.4. Data Acquisition and Processing

6.4.1. Data Acquisition

The data required for the development of the criteria maps was acquired from a number of sources. Most of the data was readily available, whilst a few criterion maps had to be built from scratch. Table 6-2 lists all the criteria and the source of each dataset.

Table 6-2: List of Data

Criteria	Source of Data
Land Use	City of Cape Town Municipality
Building Density (floor area ratio)	City of Cape Town Municipality
Average Annual Household Income	Census 2011
Residential Density	Census 2011
Employment Opportunities	City of Cape Town Municipality
Presence of vulnerable road users	City of Cape Town Municipality
Proximity to Environmentally sensitive areas	City of Cape Town Municipality
Proximity to Heritage Sites	City of Cape Town Municipality
Proximity to landscape parks and recreational facilities	City of Cape Town Municipality
Water courses and lakes	City of Cape Town Municipality
Private Car Ownership	Census 2011
Proximity to Destinations	City of Cape Town Municipality
Proximity to other PT Facilities	City of Cape Town Municipality
Hazardous Locations	Western Cape Government
Presence of Pedestrian Infrastructure	Google Earth
Presence of Bicycle Infrastructure	Google Earth

6.4.2. Data Processing

Once the data had been received it had to be cleared up in preparation for use in building the individual criterion maps. ILWIS 3.3 was used to perform the Spatial Multi-Criteria Analysis. It was, therefore, necessary for all maps to be prepared as raster files for input into the SMCE Criteria Tree in ILWIS. As all the data was received as vector shape files, apart from the NMT infrastructure which was created in Google Earth, each shape file was converted into a raster format using ArcGIS. ArcGIS was used for the rasterisation process as it was found that, when this operation was done using QGIS, pixels in which there were no data values were left unpopulated and could not be read by ILWIS. In ArcGIS, these pixels are assigned a value of zero and thus could be read in ILWIS.

An overview of the processing procedure followed for each criterion is provided in Table 6-3.

Table 6-3: Processing Procedures Followed

Criteria	Processing Procedure
Land Use	Land use classes were grouped into five categories using QGIS: business, residential, industry, community facilities and unpopulated. The shape file was then rasterised using ArcGIS before being imported into ILWIS.
Building Density (floor area ratio)	Shape file was rasterised in ArcGIS based on the floor area ratio attribute, and was then imported into ILWIS.
Average Annual Household Income	The highest average household income recorded in the study area was R840 000 per annum. The average annual household income attribute was then classified into 7 income bands, before the arithmetic average annual household income was computed for each ward. This was then used as the basis for the rasterization in ArcGIS, before being imported into ILWIS.

Criteria	Processing Procedure
Residential Density	The residential density map was computed as the number of dwelling units per ward. This was the basis for the rasterization in ArcGIS, before being imported into ILWIS.
Employment Opportunities	Employment opportunities were mapped as business and industrial land use classes. This was used as the basis for the rasterization process in ArcGIS. The final raster was then imported into ILWIS.
Presence of Vulnerable Road Users	Vulnerable road users were mapped as land use classes comprising medical facilities such as hospitals and clinics, and schools. This shape file was then rasterized in ArcGIS.
Proximity to Environmentally Sensitive Areas	Environmentally sensitive areas were mapped as those having been classified as Core 1 and Buffer 1 areas in the Cape Town Spatial Development Framework. This shape file was rasterized in ArcGIS before being imported into ILWIS where a “Distance Calculation” operation was performed.
Proximity to Heritage Sites	The shape file containing the heritage sites was rasterized in ArcGIS based on the “heritage” attribute. The raster was then imported into ILWIS.
Proximity to Landscape Parks and Recreational Facilities	Landscape parks were mapped as nature reserves and recreational facilities were mapped as public swimming pools, sports fields and facilities, places of interest such as sports clubs, city buildings and beaches. This map was converted into a raster file in ArcGIS and imported into ILWIS. A “distance calculation” operation was performed on this raster in ILWIS.

Criteria	Processing Procedure
Water Courses and Lakes	Water courses and lakes were mapped as natural water features, such as rivers, canals, lagoons and lakes. This polygon map was then converted into a raster in ArcGIS and imported into ILWIS.
Private Car Ownership	The number of households per ward in which at least one car was owned was mapped as a percentage of the total households in that specific ward. This vector map was then converted into a raster map in ArcGIS and imported into ILWIS.
Proximity to Destinations	Destinations were mapped as places of interest that people go to complete daily activities or to access essential services. These included entertainment, hospitals, clinics, museums, post offices, police stations, libraries, town halls, shopping centres and places of worship. This point file was then rasterized in ArcGIS and imported into ILWIS.
Proximity to other PT Facilities	Other public transport facilities were mapped as GABS bus stops, taxi ranks, railway stations and public transport interchanges. This file was rasterized in ArcGIS and imported into ILWIS.
Hazardous Locations	Accident data obtained from the Western Cape Government was analysed to pick out accidents involving pedestrians or cyclists in the study area. Roads on which such accidents occurred frequently were mapped in Google Earth and exported as a kml file. The kml file was imported into QGIS and converted into a shape file having the same projection as the other maps. This shape file was rasterized in ArcGIS before being imported into ILWIS.

Criteria	Processing Procedure
Presence of Pedestrian Infrastructure	Google Earth Street View was used to map whether a given road had a formal sidewalk on one side of the road, both sides of the road or no formal sidewalk at all. These kml files were imported into QGIS and merged to form one vector layer. This vector file was rasterized in ArcGIS and imported into ILWIS.
Presence of Bicycle Infrastructure	Google Earth Street View was used to map where cycle lanes had been provided. This kml file was imported into QGIS where it was converted to a vector layer. The vector file was rasterized in ArcGIS and imported into ILWIS.

In order to perform the SMCE operation in ILWIS, all input raster maps need to have the same pixel size and geo-reference, so that all the raster maps are perfectly aligned to one another.

The choice of what pixel size to use was guided by the resolution of the data used in this analysis therefore the effects related to the Modifiable Areal Unity Problem (MAUP) come into play, as a different pixel size may result in a slightly different suitability map. The other factor considered is that influences from outside the rectangular area of the pixel do not affect the area inside that specific pixel; this is another reason why the choice of pixel size is so important. It was decided that a pixel size of 50 metres would be used for the following two reasons:

1) A pixel size larger than 50 metres resulted in the loss of information, when the vector files were converted into raster files.
2) A pixel sixe of 50 metres also allows the impacts of the areas adjacent to the road network to be incorporated into the suitability computation, resulting in a “corridor” which is 100 metres wide.

A geo-referenced file based on the UTM Zone 34S coordinate system projection was created in ILWIS and was assigned to each criterion's raster file. The following corners were specified for the georeferenced file created:

Minimum X ; Y: (265 342.29 ; 624 3076.27)
Maximum X ; Y: (272 266.36 ; 625 4286.81)

6.5. Criteria Weighting

Two sets of weighting were applied for the purpose of facilitating comparison of the resulting suitability maps, and consequently, the resulting BRT feeder network. This was also done to demonstrate the influence, and therefore, the importance of carefully selecting the weighting scheme to be applied. The first weighting set was simply equal weights applied to avoid the influence of bias on the results. The second weighting set was informed by interviews held with the Transport for Cape Town Planning officials for the MyCiTi system, thus reflecting their perceived importance of each theme with respect to the others.

Weightings were applied first at a theme level and then at a criterion level (referred to as group level and factor respectively in ILWIS SMCE). The two weighting schemes applied were done so using the "Direct Method" in ILWIS where the weighting is manually entered as opposed to using a formula. The weighting used was as follows:

1) **<u>Equal Weighting Scheme:</u>**

Theme	Weighting
Land Use	0.2
Socio-Economic	0.2
Environmental	0.2
Transportation	0.2
Non-Motorised Transportation	0.2

2) **Expert-Influenced Weighting Scheme:**

Theme	Weighting
Land Use	0.25
Socio-Economic	0.25
Environmental	0.1
Transportation	0.15
Non-Motorised Transportation	0.25

6.6. Public Transport Demand Analysis

In determining the original MyCiTi BRT feeder routes, the existing morning road-based public transport demand was used as a basis for establishing the potential demand for the MyCiTi bus service, as this would ultimately replace the Golden Arrow Bus Services (GABS) and minibus taxis operating on the selected routes. The same approach was used by Transport for Cape Town in developing the MyCiTi BRT network; therefore, the Origin-Destination (O-D) Matrices utilised by the Transport for Cape Town Planning officials were obtained and analysed to extract the high demand public transport O-D pairs within the study area. It should however be noted that newly designed and implemented feeder bus routes may have generated more demand, and this demand has not been looked at in this study.

The study area consists of 118 Transport Analysis Zones (TAZ) as shown in Figure 6-2. The O-D matrices for minibus taxis and GABS were merged and analysed in conjunction, to identify four O-D pairs with the highest public transport demand in the study area. It was opted to use four O-D pairs as maximum, due to the size and scale of the study area. Should more O-D pairs have been used, more resultant routes would be developed resulting in too many feeder routes than what is practical for a study area of this size. The following four pairs were identified (Table 6-4), and the associated public transport demand is reported in morning peak hour trips.

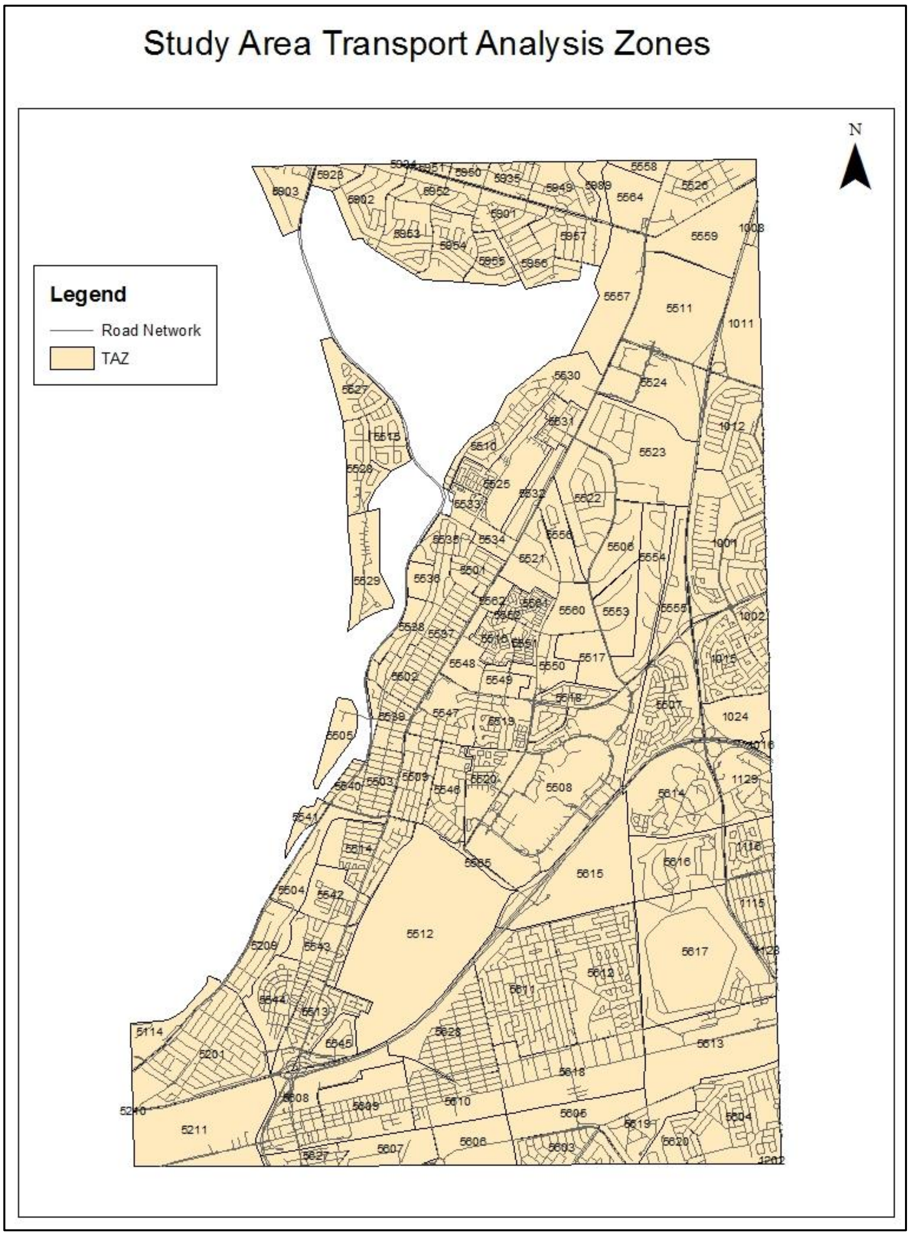

Figure 6-2: Study Area Transport Analysis Zones

Table 6-4: Public Transport OD Pairs

O/D	5508	5523	5561	5612
5508	0	1	0	0
5523	0	0	0	0
5561	7	13	0	4
5612	36	4	0	0

As shown in Figure 6-1, two BRT feeder route development approaches were investigated in this research. When following the first approach, the O-D analysis was used simply to identify four O-D pairs with the highest public transport demand, and the associated demand was used to prioritise the routes developed – this is explained further in *Section 6.8.3*. When following the second approach however, the results of the O-D analysis were used to produce an associated public transport demand map for input into a second round of SMCA with the built environment composite suitability map. In so doing, the public transport demand has a direct influence on the development of the routes, as opposed to only being used for prioritisation of routes as applied in the first approach.

6.7. Spatial Multi-Criteria Analysis

Two approaches were adopted in this study, of which the first approach involved only one round of SMCA, whilst the second approach also included a second round of SMCA. Both rounds of SMCA conducted are explained below.

6.7.1. Built Environment Approach (SMCA Part 1)

Once all the raster files representing each criterion had been prepared in ArcGIS, imported into ILWIS and correctly georeferenced, the SMCE operation could commence. The first step in this procedure was to build a Criteria Tree in ILWIS and load the raster file to be used for the respective criterions in the assessment. This is all done in the “Problem Definition” mode of ILWIS SMCE.

After all the maps are in place, the “Multi-criteria Analysis” mode is switched to for the remainder of the assessment. In this mode, the weightings developed for the specific weighting scheme being tested were assigned using the “Direct Method.” This was first done for all the themes or groups before applying to the set of criteria or factors within each theme.

Thereafter, each criterion was designated as a benefit, cost or combination of the two and the standardisation technique was assigned. The technique for standardising was either maximum, interval, goal, concave or convex depending on how the raster file was structured. The criteria tree built for the Equal Weighting Scheme along with the standardisation technique selected for each criterion map is depicted in Figure 6-3.

Once the Criteria Tree was complete, the analysis could be run and the final composite suitability map could be produced. Each pixel in this map represents the suitability or utility of that pixel in relation to the overall goal of the analysis, which in this case was for BRT feeder service routing. Suitability values range from 0, being least suitable, to 1, being most suitable. This suitability map was then exported as an .asc file before being converted to a raster file in ArcGIS for use in the network analysis step of the investigation.

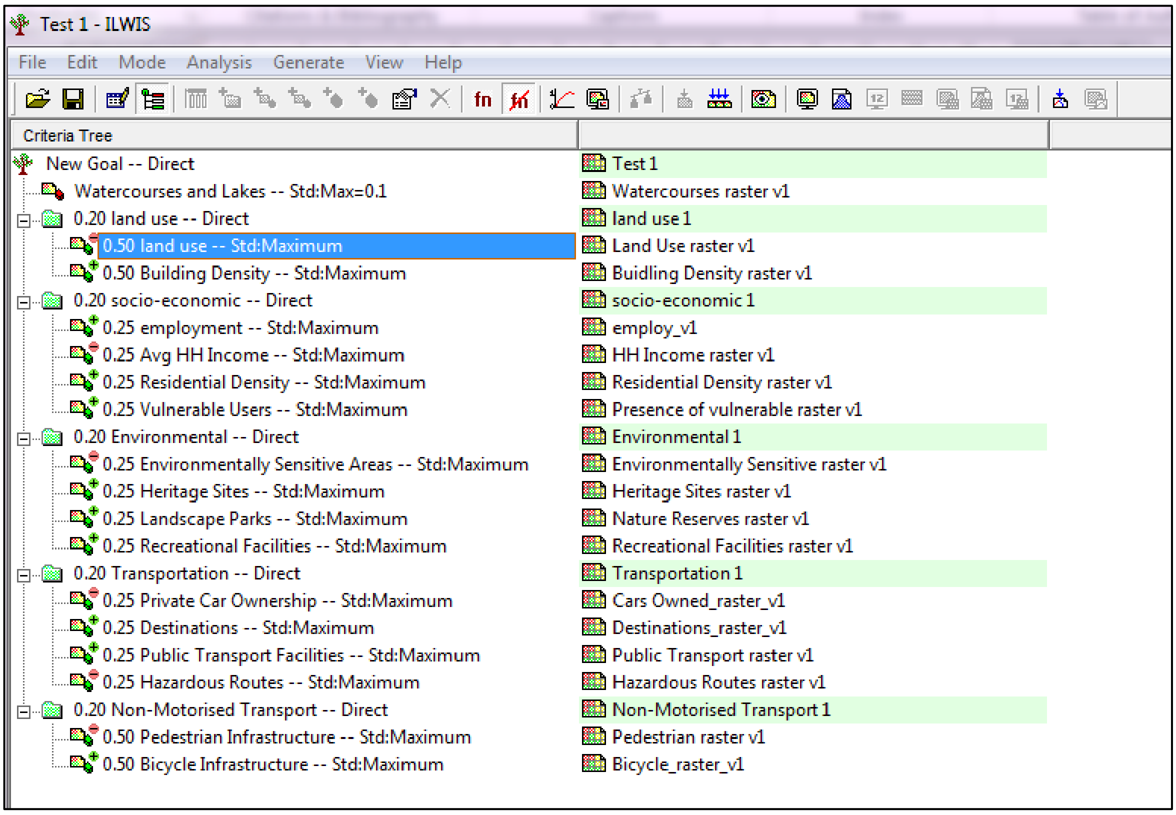

Figure 6-3: Equal Weighting Scheme Criteria Tree

6.7.2. Transit-Oriented Approach (SMCA Part 2)

In following the second approach, a second round of SMCA was carried out which comprised of two criterion maps; namely the built environment composite suitability map discussed in *Section 6.7.1*, and the associated public transport demand map discussed in *Section 6.6*. As there were only two criterion maps involved in this round of SMCA, each map was assigned a weighting of 50% and standardised following the same procedure explained in *Section 6.7.1*.

6.8. Network Analysis

6.8.1. Road Network Impedance

On completion of the SMCA, for both part 1 and 2, a Line Weighted Mean calculation was performed whereby the average suitability values along each road segment were extracted. This was done using the Geospatial Modelling Environment[1] programme to perform the calculation. The function “isectlinerst” was used to determine the Line Weighted Mean (LWM) of suitability scores along the road network. After running this calculation, the LWM values were automatically added as a feature attribute in the road network layer.

Line Weighted Mean can be described by equation (1):

$$\text{Line Weighted Mean } (LWM) = \frac{\sum_{i=l}^{n}(l_i.v_i)}{L} \qquad (1)$$

Where:

l_i = length of segment i,

v_i = suitability value of the pixel underlying the segment i,

L = total polyline (road) length of which the segment forms a part.

Figure 6-4 shows a snippet of the isectlinerst window in which the LWM function was performed.

[1] GME was used as the Hawth’s tool extension in ArcGIS, as previously used by Keshkamat (2007), is no longer available.

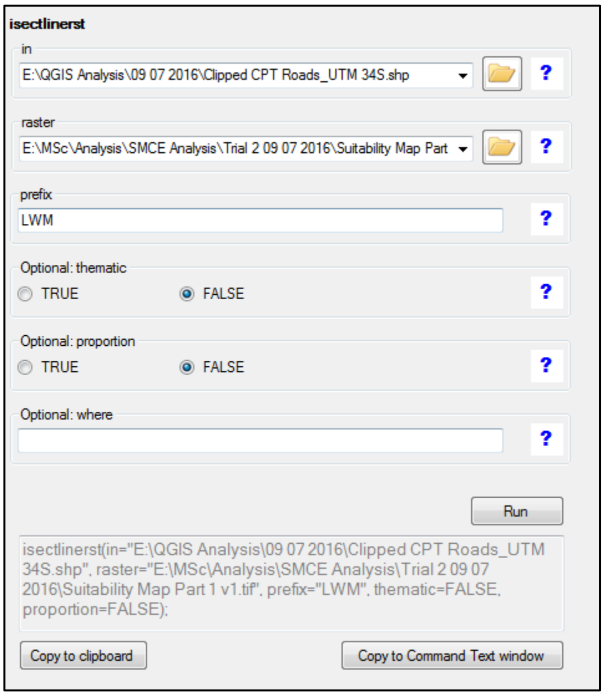

Figure 6-4: Line Weighted Mean Calculation

The Network Analyst tool in ArcGIS, used for the route design, determines the route based on the least cost path, which in this case is the least impedance path. Therefore; the LWM suitability values extracted had to be inverted to obtain the mean impedance values for each road segment as follows:

$$\theta_i = \frac{1}{LWM_i} \; for \; \forall i \qquad (2)$$

Where:

θ_i = Mean impedance value of a segment i,

LWM_i = Line Weighted Mean value of a segment i.

6.8.2. Least Cost Path Analysis

Once the Impedance values per road segment and the public transport O-D pairs for the study area were known, a Least Cost Path Analysis was executed in order to determine the potential feeder bus routes along the existing road network. This part of the analysis was performed using the Network Analyst extension in ArcGIS.

The first step was to add a Network Analyst Dataset layer to ArcGIS, which comprised the existing road network shape file, containing the Impedance values calculated in *Section 6.8.1*. In the Network Dataset Properties dialog box, Turns, Connectivity and Elevation were set to the default settings. The Attributes tab in this dialog box automatically loaded "Length" and "Minutes" as attributes, so an additional two attributes were added; namely, "Impedance" and "Speed Limit." Using the "Evaluators" button, the program was set to use the Impedance field from the road network attribute table for basing the calculation of the routes. Lastly, the travel mode was set to automobile for the analysis. On completion of configuring the network properties, the road network could be "built" using the "Build Network Dataset" button in the Network Analyst Toolbar. "Building" the network means that the road network is ready to be utilised for performing Network Analyst functions.

After the network had been built, a "New Route" function was selected, which adds a new network analysis layer to the project. Network Analysis Objects then had to be added to the network analysis layer, which in this case were the Origin (starting point) and Destination (ending point) for each pair. Before the analysis was executed, the Layer Properties Dialog Box was opened to configure "Analysis Settings" and "Accumulation" tabs. The analysis was set to use the Road Network Impedance values in determining the least cost path between the origin and destination for each pair, and it was set to accumulate the Length and Impedance attributes for each route. The network was then "solved" to produce the least cost path or route, which contains the lowest accumulated impedance values out of all possible options. The total route impedance can be expressed by the following mathematical equation:

$$\theta_R = \sum_{j=1}^{m} \theta_j \; for \; r \in \{1, \dots, R\} \quad (3)$$

Where:

θ_R = Route impedance of a route, R

Θ_j = Impedance of a segment, j, and

M = Total number of segments making up the route, R.

This procedure was carried out for each O-D pair resulting in twelve potential feeder bus routes for each approach.

6.8.3. Prioritisation of Routes

In deciding which feeder bus routes should ultimately be implemented for both approaches 1 and 2, the potential routes developed had to be prioritised. This was done by using the average Impedance per kilometre to determine which route is most favourable, i.e. which route offers the lowest average Impedance per kilometre, and thus the highest benefits. The average impedance per kilometre was computed using the following equation:

$$\theta_d = \frac{\theta_R}{L_R} \qquad (4)$$

Where:

Θ_d = Impedance per unit distance

Θ_R = Total route impedance for a route *R*, and

L_R = Length in kilometres of a route *R*.

The public transport demand was used thereafter to weigh each route in prioritising what should be implemented, so the routes which obtained lower weighted impedance values were deemed the most advantageous. The weighted impedance values were calculated using Equation (5):

$$\theta_W = \frac{\overline{\theta_R}}{D_R} \qquad (5)$$

Where:

$\overline{\boldsymbol{\theta}_R}$ = Average impedance per kilometre of a route *R*, and

D_R = Public transport demand of a route *R*.

6.9. Comparison with Existing MyCiTi Feeder Bus Routes

In order to enable fair comparison of the routes obtained using approaches 1 and 2, both with each other and with the existing MyCiTi feeder bus routes implemented, a set of key performance indicators (KPI) had to defined. Apart from allowing comparison on equal grounds; measuring the routes obtained for approaches 1 and 2 allowed evaluation of the degree to which the outcomes of each approach meets the objectives of this study.

Chapter 3.3 identifies the list of KPIs used and *Chapter 8.7* documents the use of these KPIs in evaluating the outcomes of each methodology, including the comparison with the existing MyCiTi feeder bus routes in the study area.

6.10. Sensitivity Analysis

By applying a second set of weighting, the sensitivity of the results to the weighting schemes chosen could be tested. This in itself is a form of sensitivity analysis. Therefore, no additional sensitivity testing was conducted.

6.11. Software Used

A number of different software packages were used throughout this study and are listed below.

1) **Criteria Maps Creation and Preparation:**
    - QGIS
    - ArcGIS Map 10.3
    - Microsoft Excel
    - SuperCross
    - Google Earth©
2) **Performing SMCA**
    - ILWIS 3.3 Academic
3) **Performing Network Analysis**
    - ArcGIS Map 10.3
    - R version 3.3.1 (statistical computation platform)

- Geospatial Modelling Environment

6.12. Comprehensive Work Flowchart

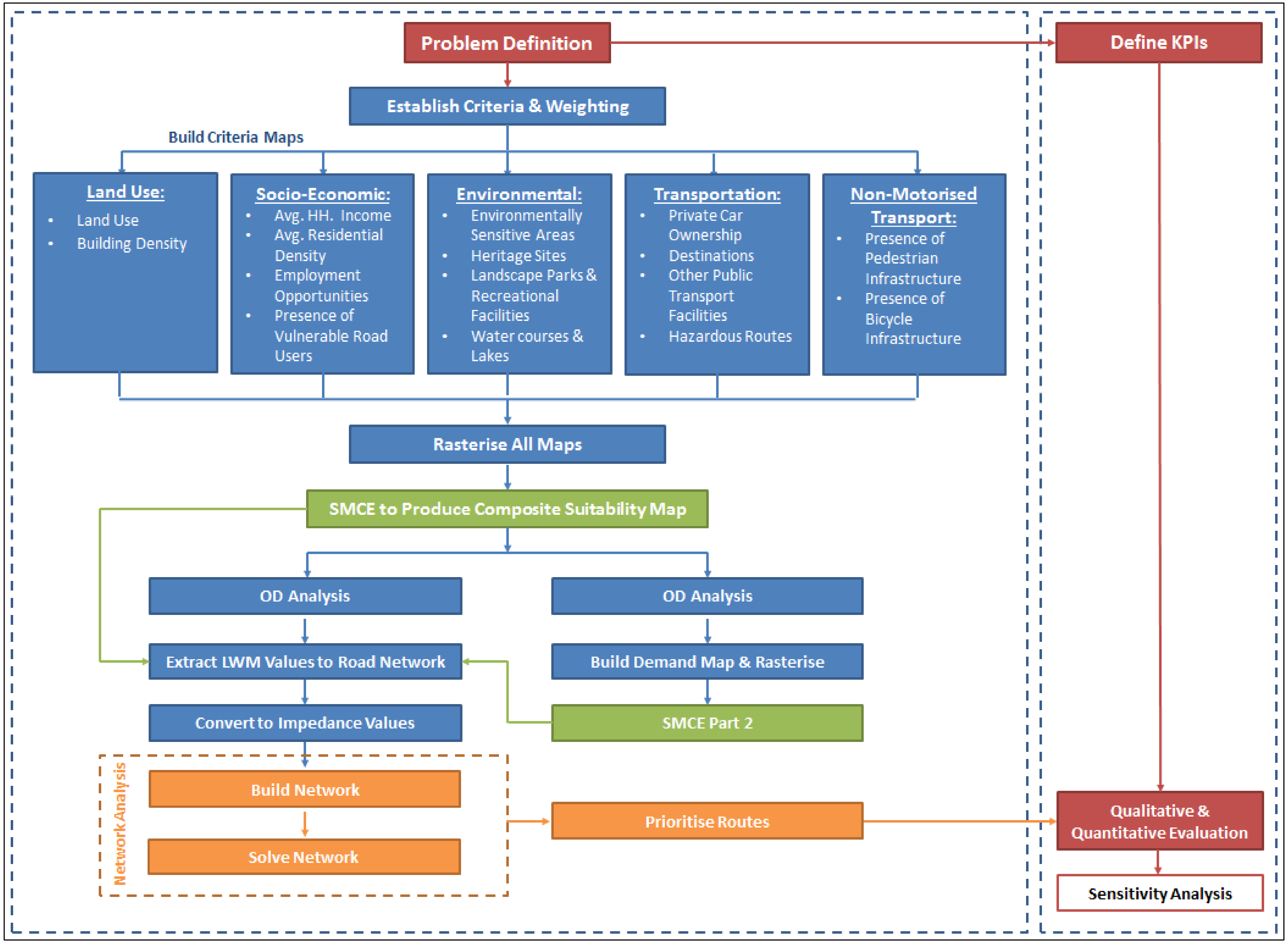

Figure 6-5: Comprehensive Workflow Diagra

7. Description of Study Area

7.1. Introduction

The intent of this chapter is to describe the built environment characteristics of the study area in terms of the criteria established in *Section 6.3*. This is done through the presentation of the individual criterion maps that were produced as input for the SMCA conducted.

7.2. Background

The study area for this thesis is located in Millerton, a suburb of Cape Town, South Africa. The suburb of Millerton has coordinates 33° 52' S; 18° 30' E. Figure 7-1 below indicates the location of Cape Town and the surrounding towns of Malmesbury, Stellenbosch, Somerset West (not shown), Strand, Paarl and Grabouw, all in the province of the Western Cape.

Figure 7-1: Cape Town, South Africa
Source: Google Earth, 2016

A closer view of the selected study area is shown in Figure 7-2 and forms part of the first phase of the roll out of the MyCiTi IRT System, Phase 1A. This site has been selected as the focus area for this study, as it is centred around the intersection of the existing BRT trunk route along Marine Drive (R27) and the planned feeder BRT route along Koeberg Road (M5), which intersect on Loxton Road at the Woodbridge Island Station. This area contains a mix of high order roads, watercourses, residential housing and commercial developments, making it an interesting landscape to analyse for the purpose of this research. As this was the first implementation of the BRT infrastructure in Cape Town, the planning and implementation as seen here is thought to best encapsulate the original vision of the system.

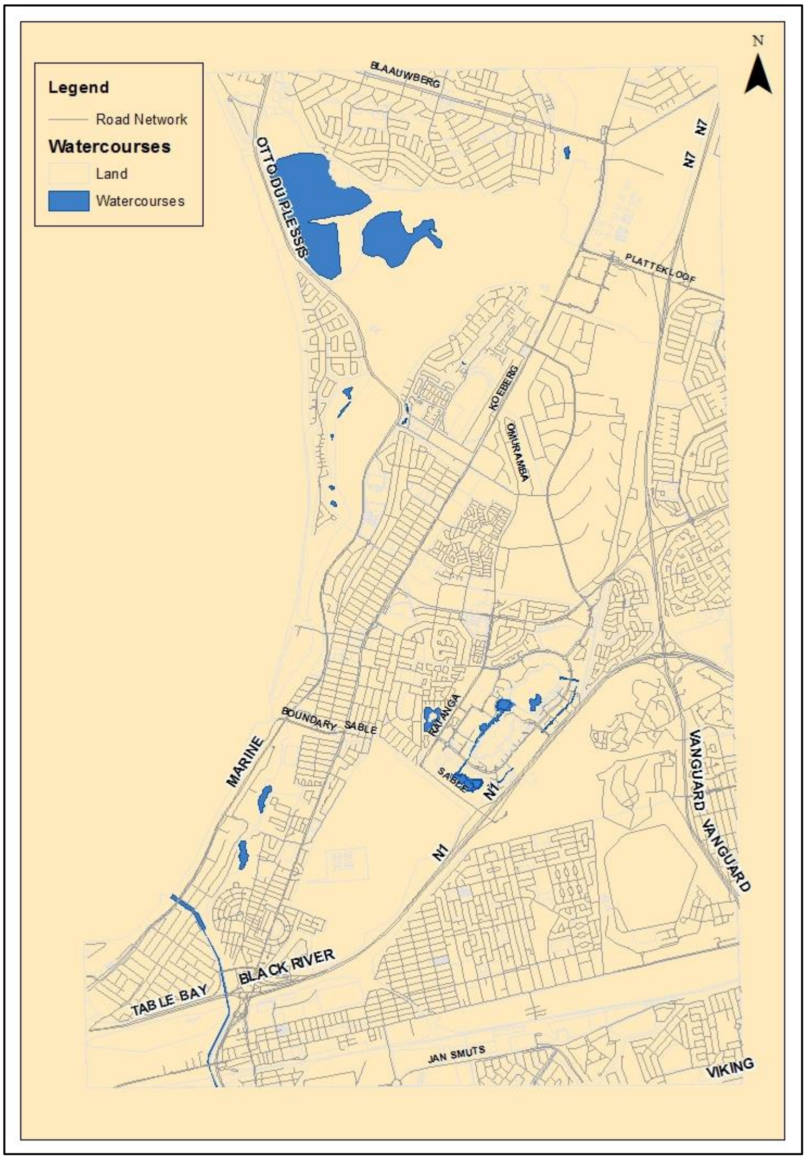

Figure 7-2: Study Area Map

A radius of about 5000 m with centre point at the intersection of Marine Drive and Loxton Road was analysed in this thesis, as it provides a satisfactory overview to gain an in depth understanding of the fabric that makes up this area and of how the various transit elements can affect the routing of the BRT feeder network at a local scale.

7.3. Land Use Theme

7.3.1. Land Use

As alluded to earlier, there is a great mix of land uses in the study area. Referring to Figure 7-3, which shows the land use types and mix, it can be seen that there is a range of business, residential, industrial, community facilities and uninhabited land. Looking at Koeberg Road, the southern end is surrounded mostly by a combination of residential and community facilities, with a few businesses in between. Once past Bosmansdam Road, the presence of industrial and business activities increases.

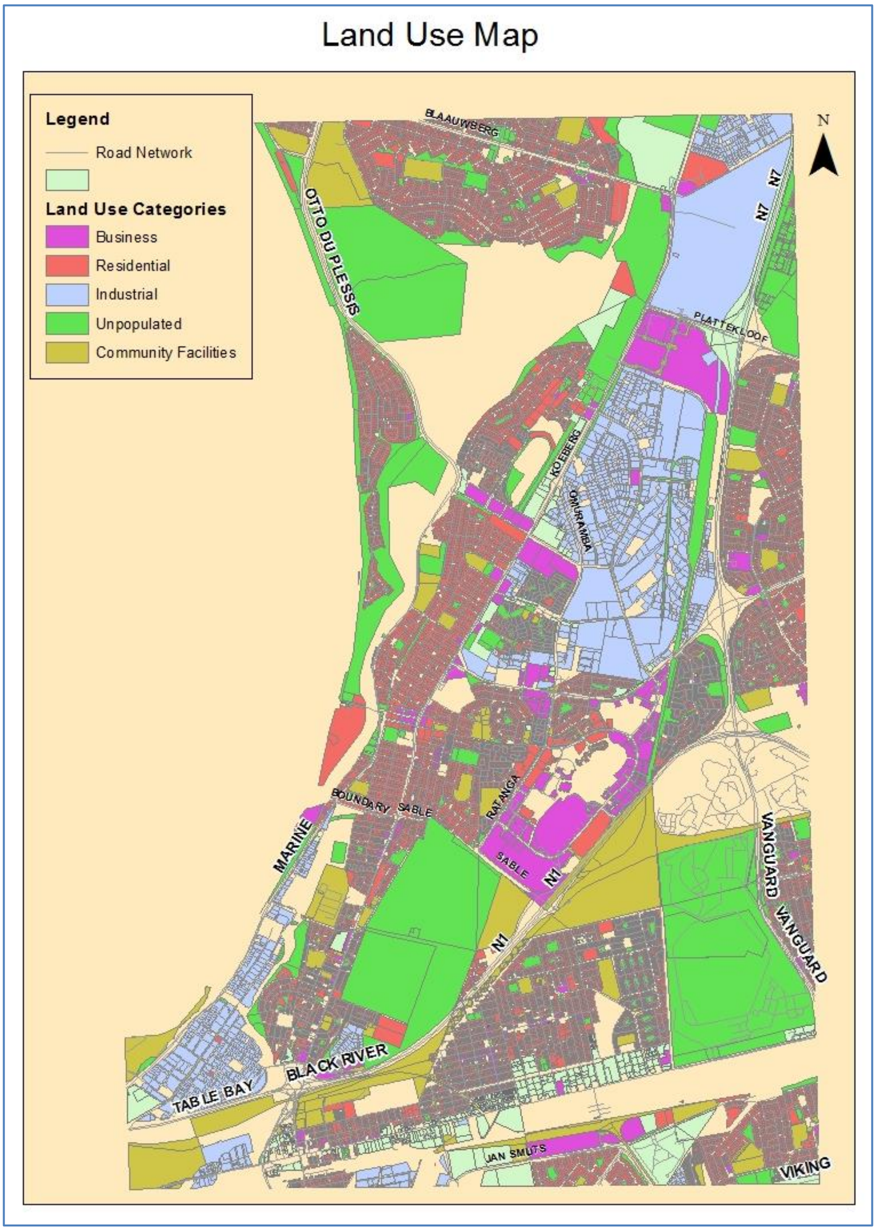

Figure 7-3: Land Use Map
Source: Map created from City of Cape Town Municipality's GIS database

7.3.2. Building Density

The building density reflects how well a parcel of land utilised through analysis of the floor area to footprint ratio. Figure 7-4 depicts the floor area ratio for each plot, from which it can be seen that the building densities are relatively low for most of the area, with spots of higher building densities. This means that few medium to high rise buildings are located in this area.

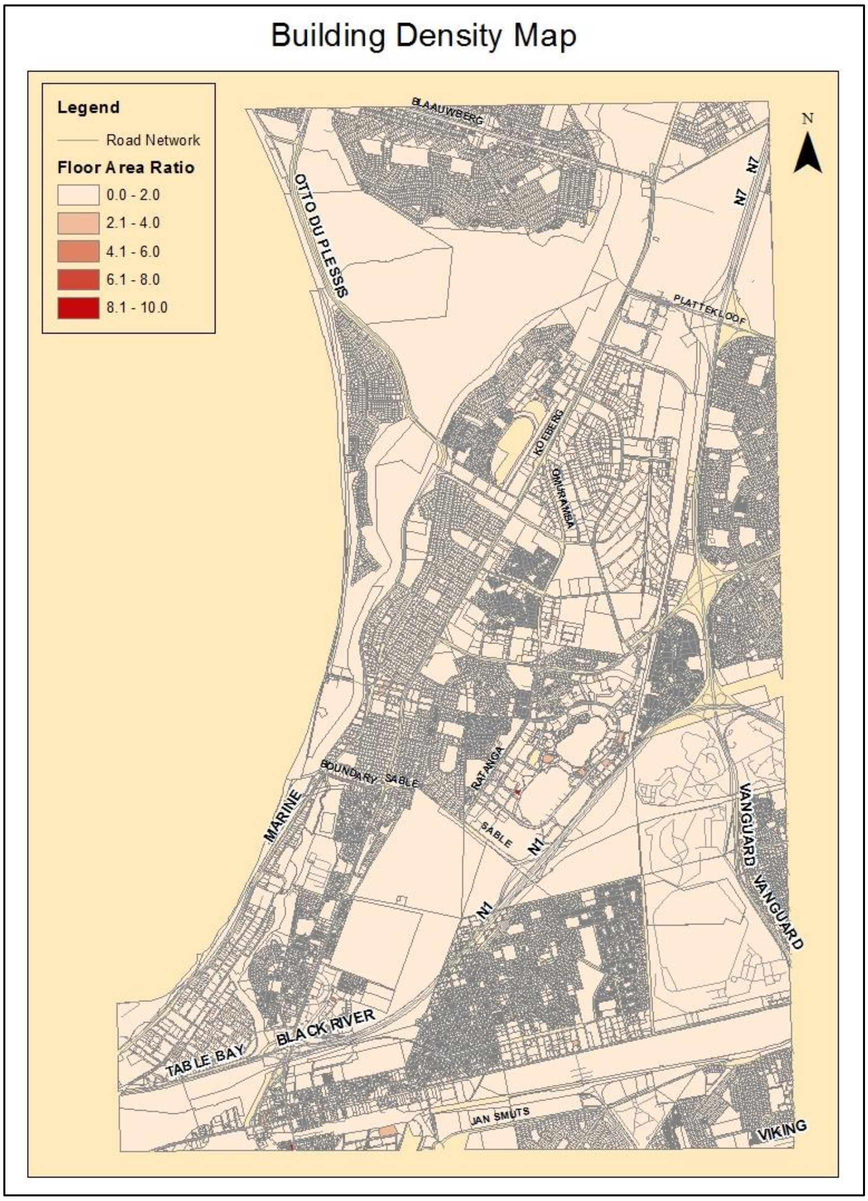

Figure 7-4: Building Density Map
Source: Map created from City of Cape Town Municipality's GIS database

7.4. Socio-Economic Theme

7.4.1. Average Annual Household Income

Figure 7-5 illustrates the spread of the average annual household income across the study area, where lower average household income levels are found along the southern end of Koeberg Road, which gradually increases towards the northern end. There is also a very wealthy area to the west of Otto Du Plesis Drive, known as Sunset Beach, which stands out against the rest of the study area.

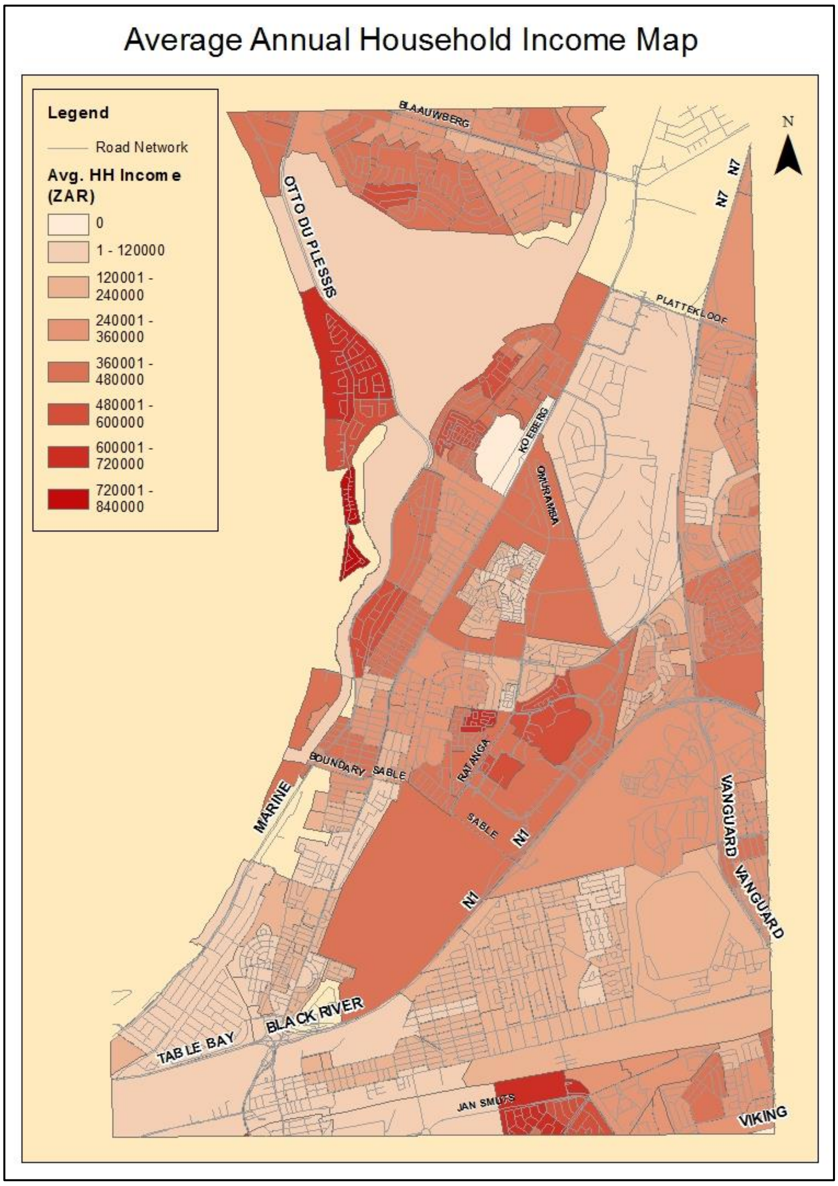

Figure 7-5: Average Annual Household Income Map
Source: Map created from National Census 2011 database

7.4.2. Residential Density

Figure 7-6 depicts the range of the residential density in terms of number of dwelling units per square kilometer. Other than the building density map, this map reflects how many households (generally occupied by one family each) there are per square kilometer. Similar to the building density map, this area has a relatively low residential density.

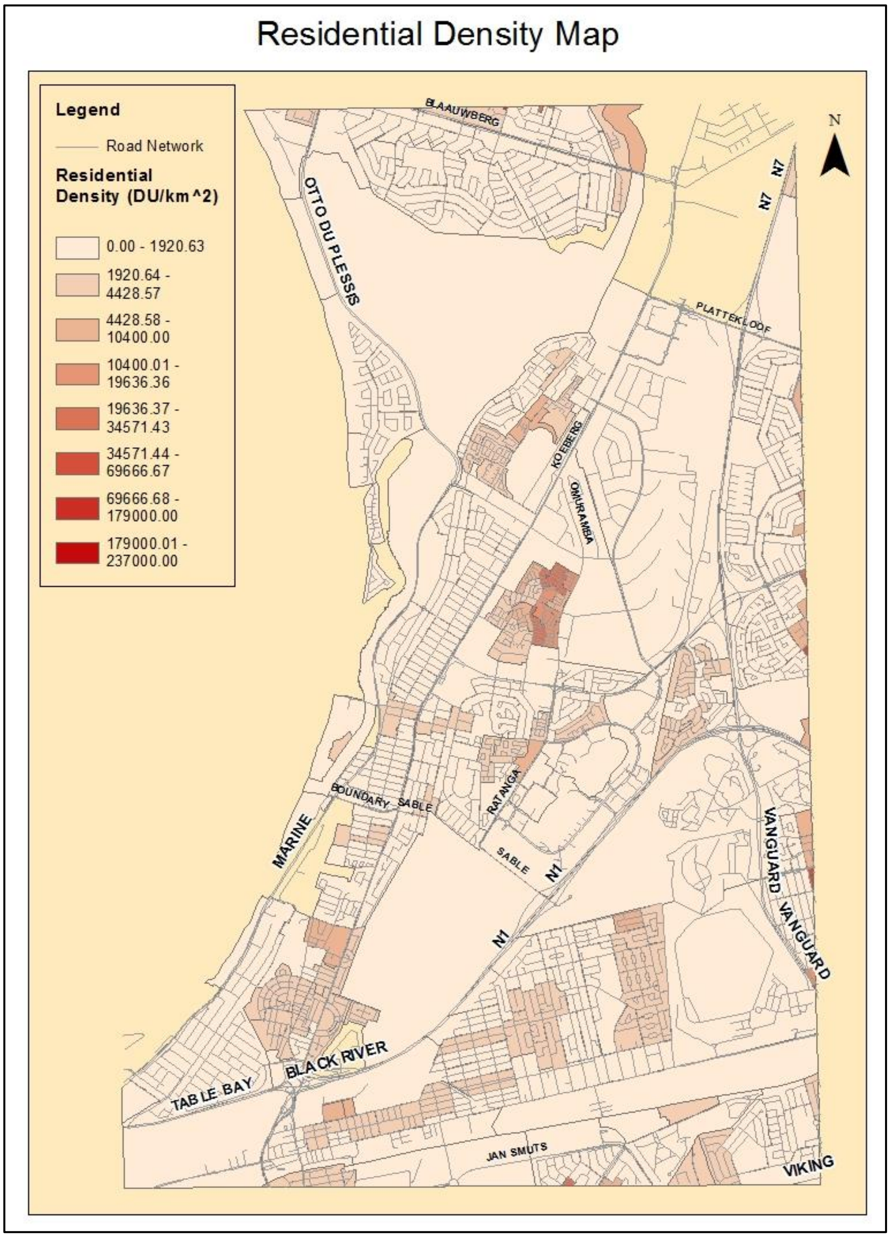

Figure 7-6: Residential Density Map
Source: Map created from National Census 2011 database

7.4.3. Employment Opportunities

Figure 7-7 provides an overview of the extent of employment opportunities available in the study area. As can be seen there is a near balance between the employments and non-employment opportunities in this area, indicating a slightly higher level of attraction for transport users to this area.

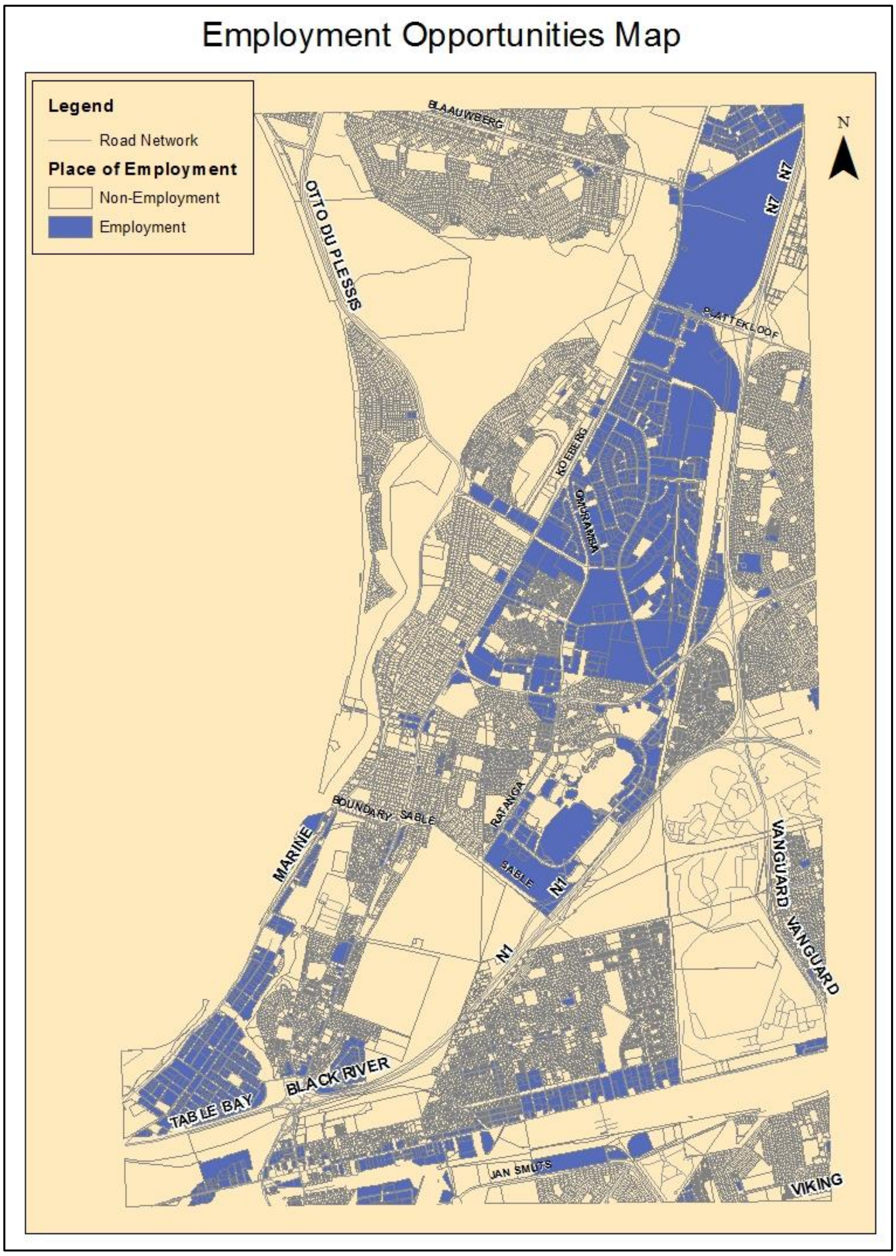

Figure 7-7: Employment Opportunities Map
Source: Map created from City of Cape Town Municipality's GIS database

7.4.4. Presence of Vulnerable Road Users

The presence of schools and health care facilities implies a higher proportion of children, elderly and sickly who are vulnerable road users, due to a decreased level of senses to danger. Figure 7-8 shows that there are a significant number of locations where vulnerable road users can be expected.

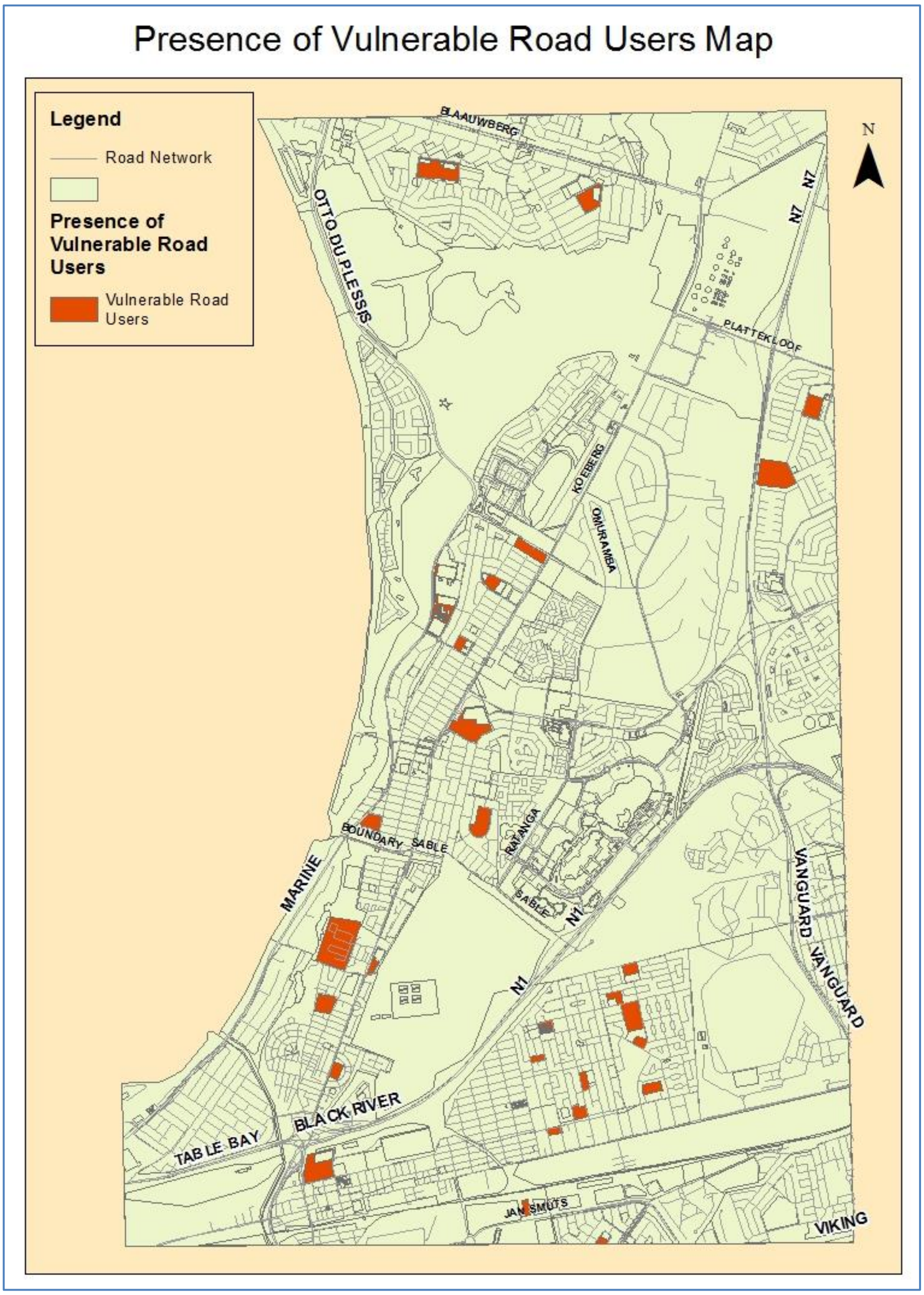

Figure 7-8: Presence of Vulnerable Road Users
Source: Map created from City of Cape Town Municipality's GIS database

7.5. Environmental Theme

7.5.1. Proximity to Environmentally Sensitive Areas

The Cape Town Spatial Development Framework (SDF) distinguishes between Intensive Agriculture/Settlement, Buffer 1 and Core 1 areas with the last two referring to environmentally sensitive areas. Buffer 1 areas are described as "Natural vegetation in Endangered, Vulnerable and Least Concern in good or restorable condition," and Core 1 areas are described as "Critically Endangered vegetation of High & Medium quality; needed for national targets. Any loss is a permanent & irrevocable loss." Figure 7-9, therefore, maps the location and proximity to environmentally sensitive areas.

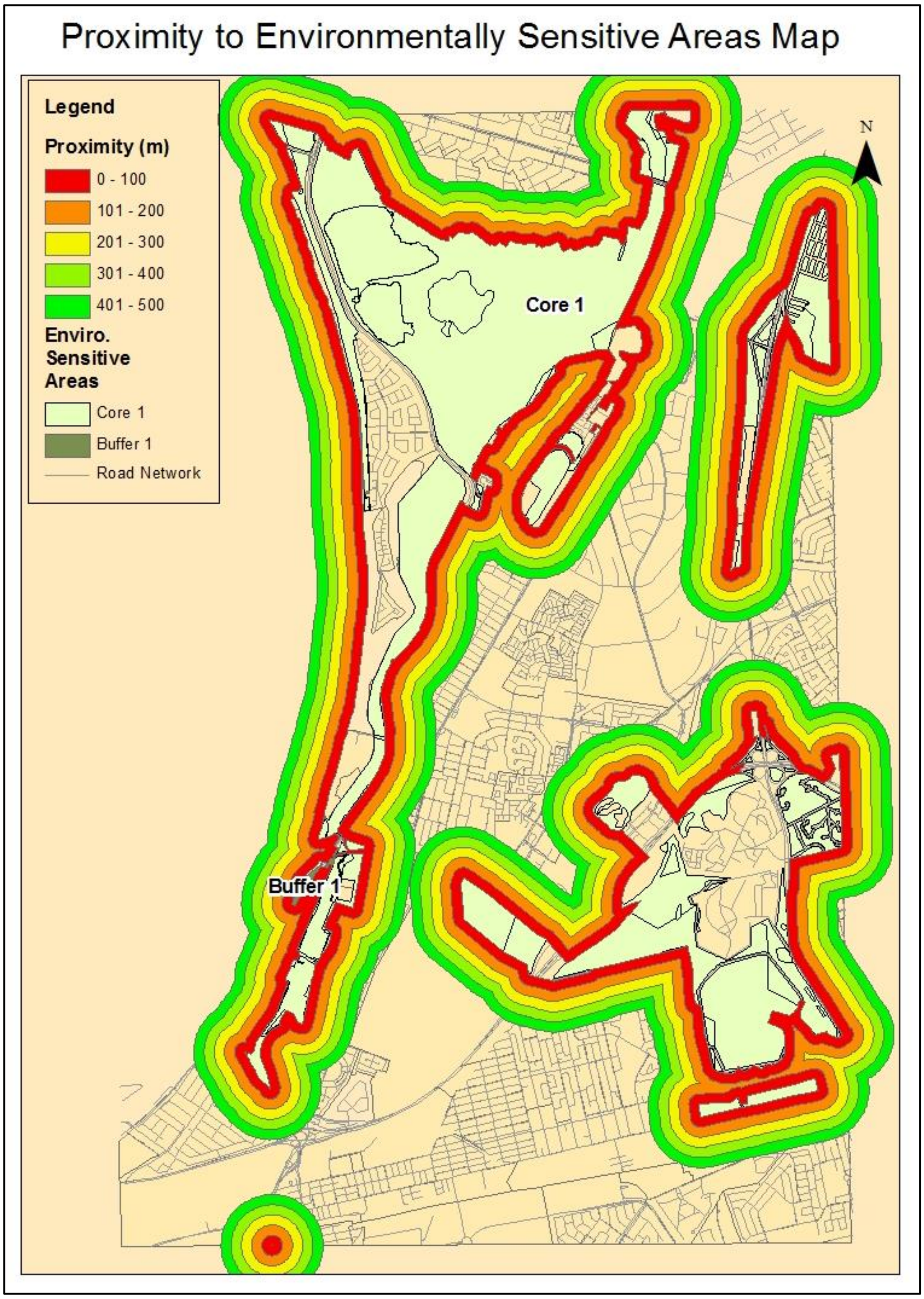

Figure 7-9: Proximity to Environmentally Sensitive Areas Map
Source: Map created from City of Cape Town Municipality's GIS database

7.5.2. Proximity to Heritage Sites

Heritage sites indicate features that need to be preserved and may also serve as potential tourist attractions. Figure 7-10 shows the locations of any heritage sites and the proximity to these sites for the study area.

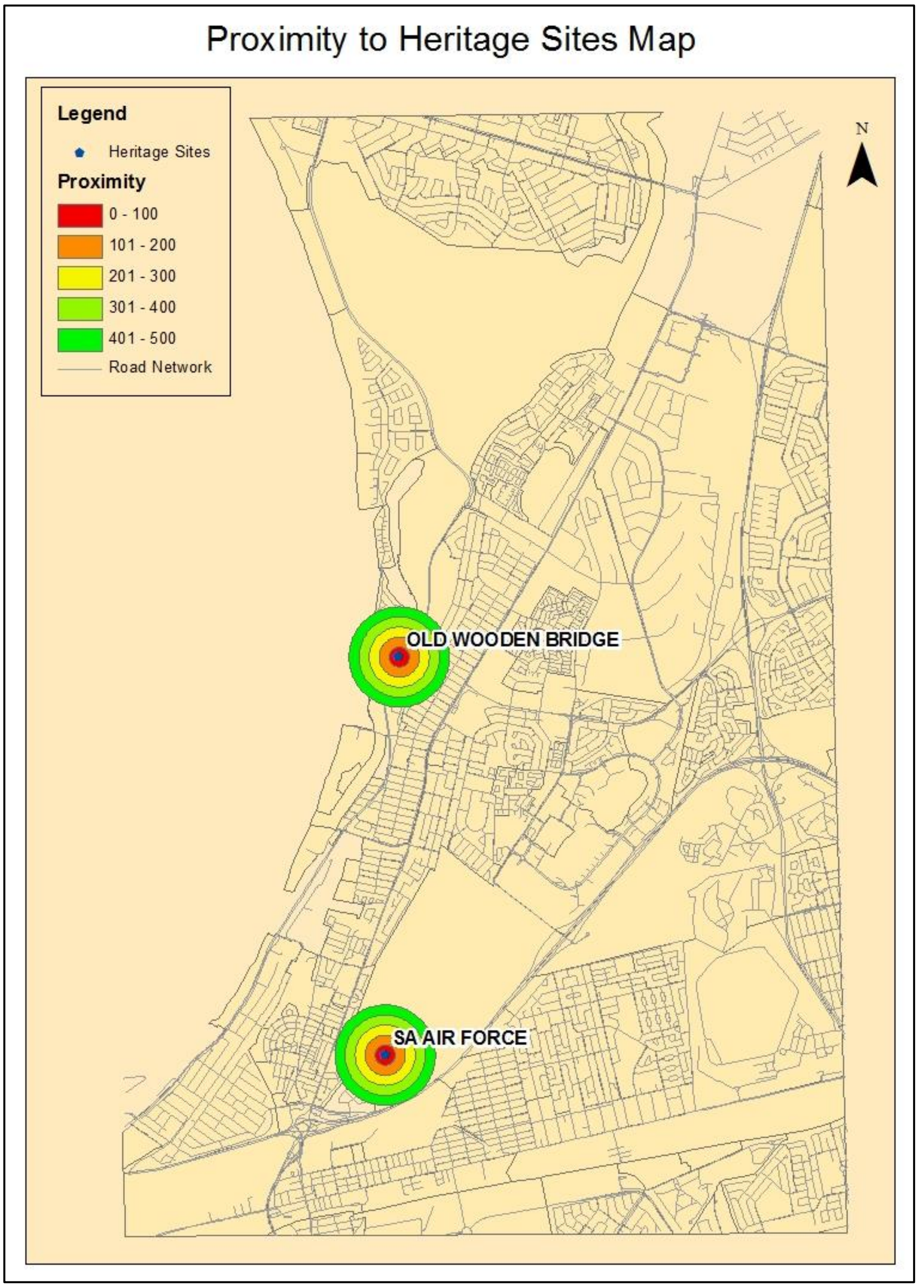

Figure 7-10: Proximity to Heritage Sites Map
Source: Map created from City of Cape Town Municipality's GIS database

7.5.3. Proximity to Landscape Parks and Recreational Facilities

Figure 7-11 depicts the location and proximity to landscape parks and recreational facilities in the study area. As can be seen there is a relatively high presence of reactional attractions where people can partake in leisure activities implying a travel demand to these locations on weekends, public holidays and school holidays.

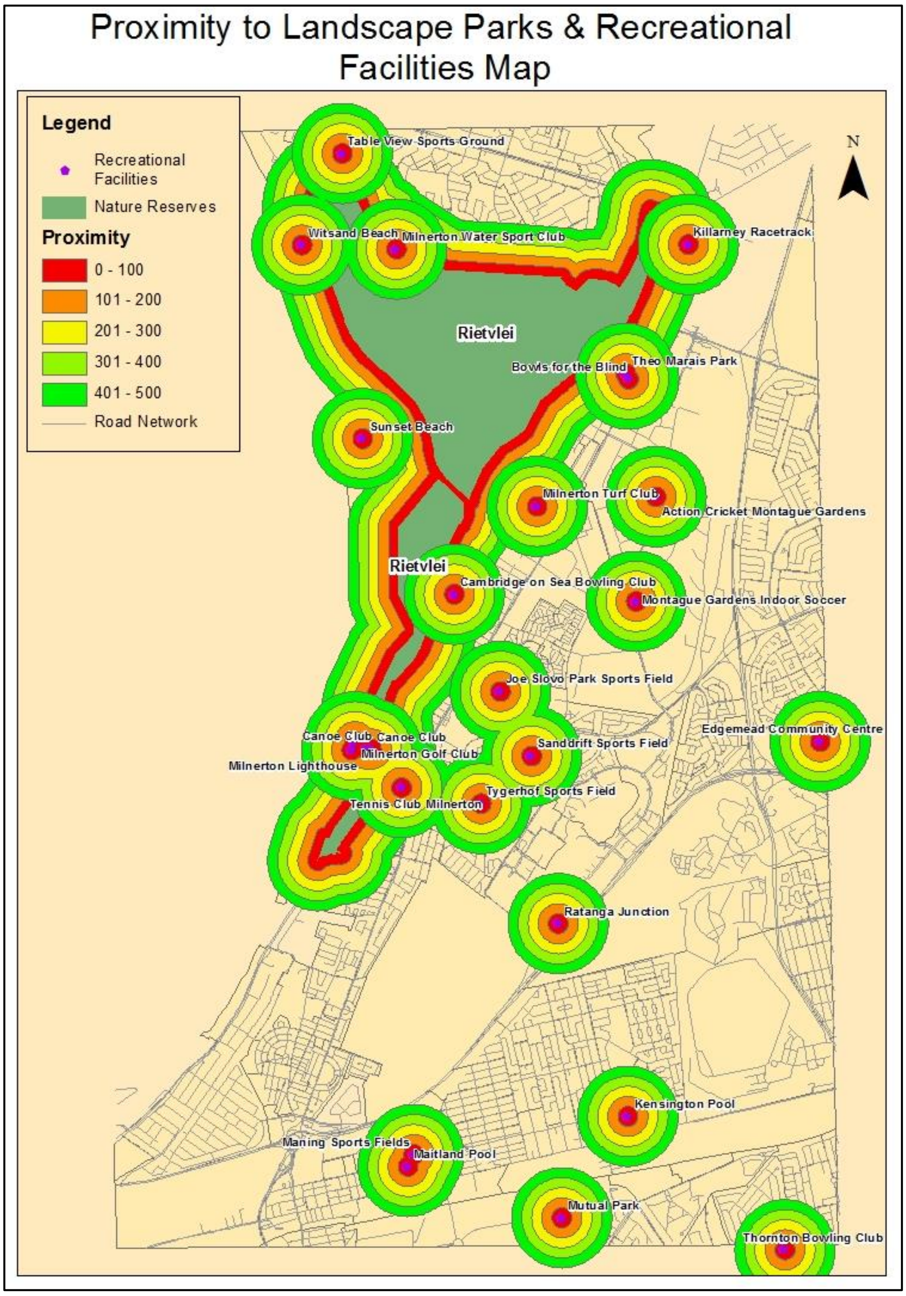

Figure 7-11: Proximity to Landscape Parks and Recreational Facilities Map
Source: Map created from City of Cape Town Municipality's GIS database

7.5.4. Water Courses and Lakes

The presence of water courses and lakes provides a barrier to the movement of people and vehicles. It is also a sensitive feature to be preserved against pollution by transportation emissions and spills. Figure 7-12 shows the location of all the water courses and lakes in the study area.

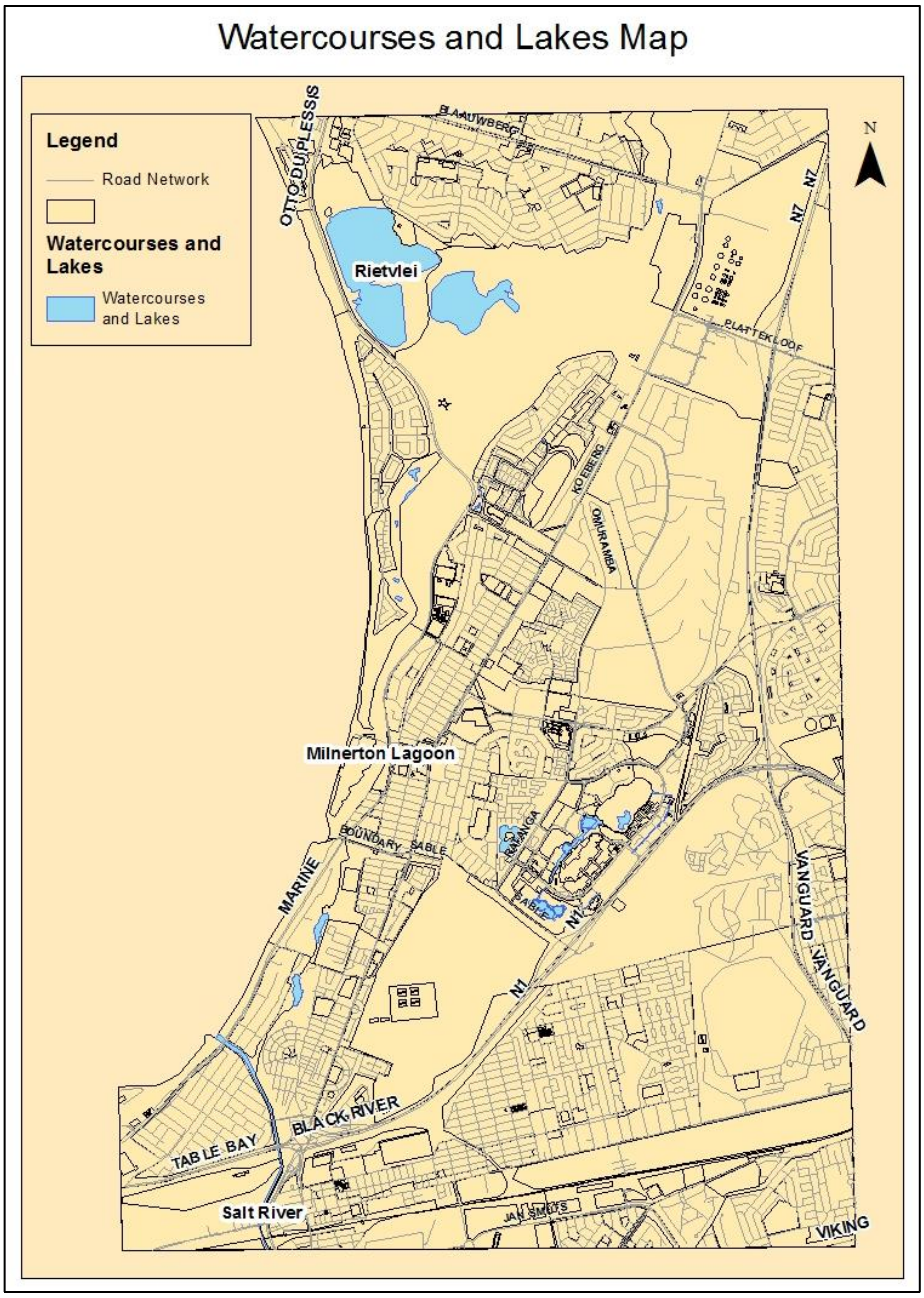

Figure 7-12: Water Courses and Lakes Map
Source: Map created from City of Cape Town Municipality's GIS database

7.6. Transportation Theme

7.6.1. Private Car Ownership

Figure 7-13 illustrates the percentage of households owning a private car per voting ward in the study area. It is evident from this map that the large majority of households found in this area own at least one private vehicle.

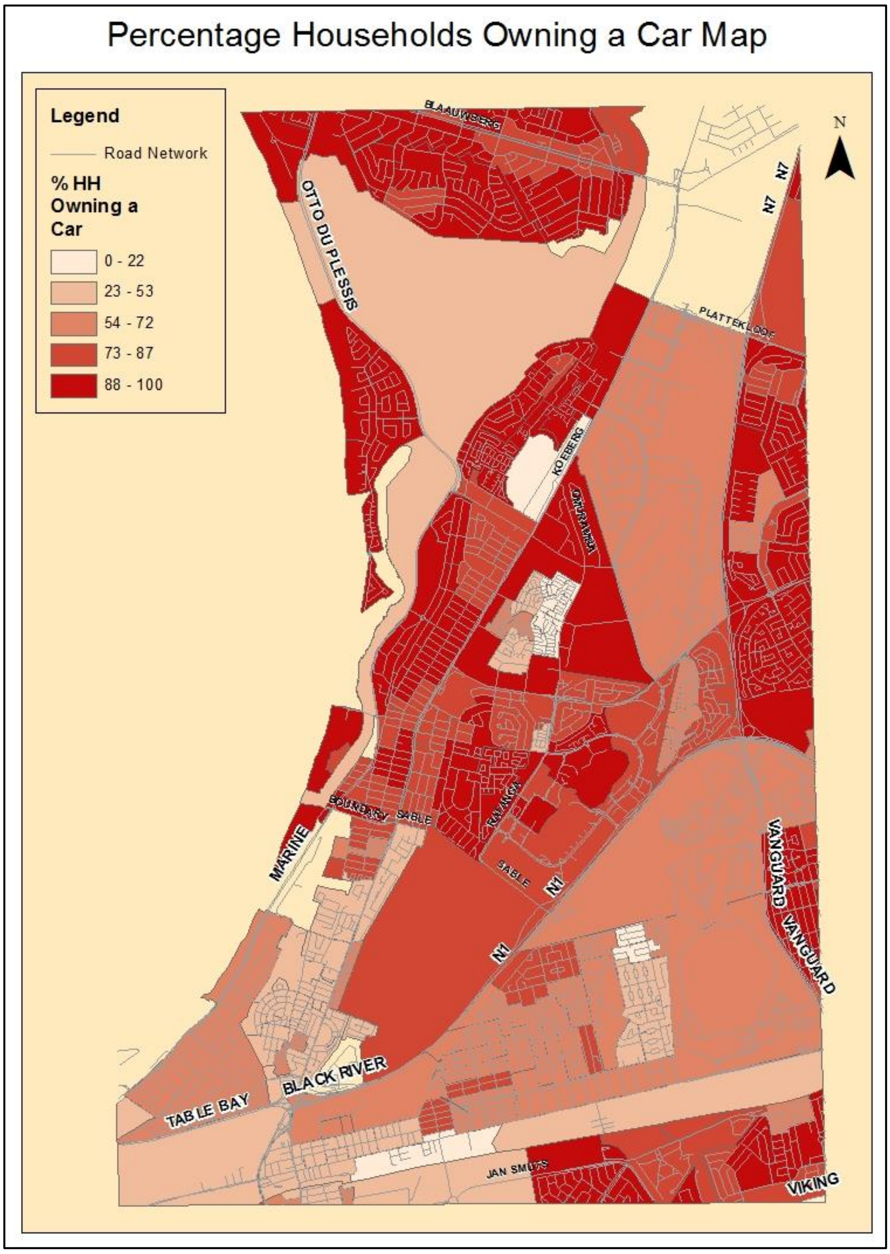

Figure 7-13: Percentage of Households Owning a Car Map
Source: Map created from National Census 2011 database

7.6.2. Proximity to Destinations

The location and proximity to various types of destinations are shown in Figure 7-14. The destinations include essential services that all communities require and frequent, such as places of entertainment, private hospitals, museums, post offices, police stations, libraries, town halls, clinics, shopping centers and places of worship. It is evident that there is a good representation of these destinations across the study area.

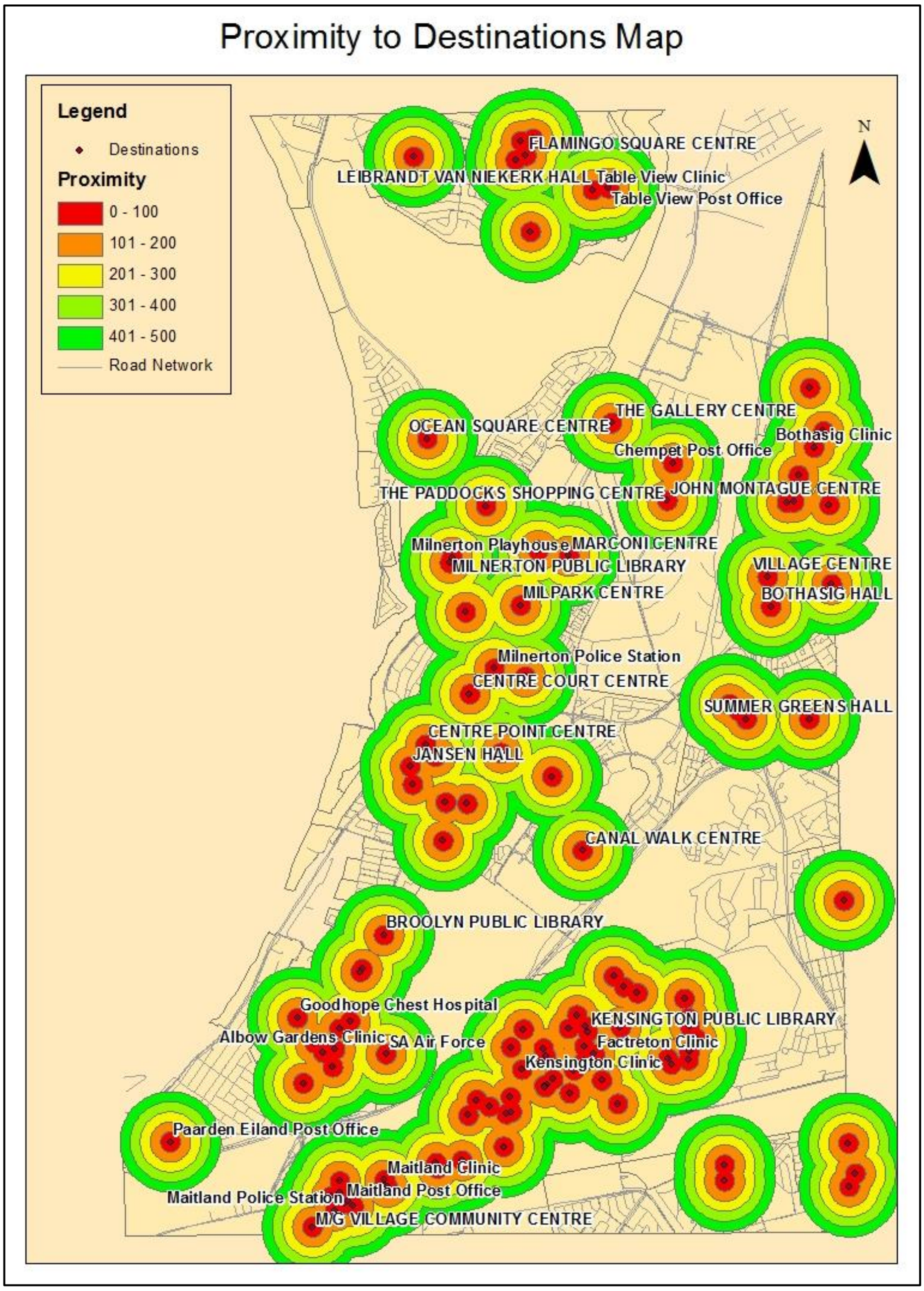

Figure 7-14: Proximity to Destinations Map
Source: Map created from City of Cape Town Municipality's GIS database

7.6.3. Proximity to Other Public Transport Facilities

As part of the roll-out of the MyCiTi IRT System areas served by minibus taxis were completely replaced and main routes operated by the Golden Arrow Bus Services (GABS) were replaced where it would be in competition with the new MyCiTi BRT services. Figure 7-15 illustrates the public transport network and facilities in the study area prior to the implementation of the MyCiTi IRT System.

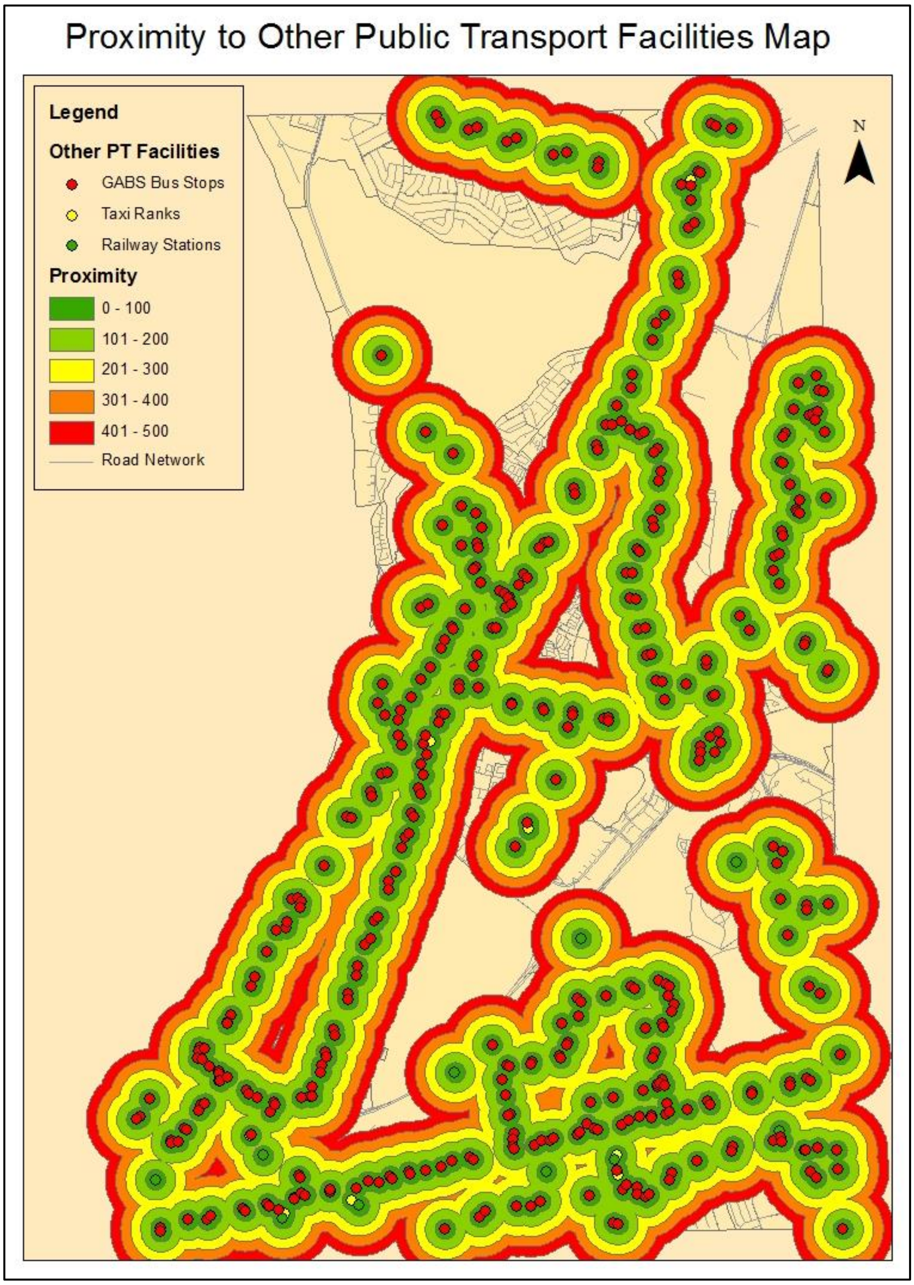

Figure 7-15: Proximity to Other Public Transport Facilities Map
Source: Map created from City of Cape Town Municipality's GIS database

7.6.4. Hazardous Routes

As the MyCiTi Bus Service is mostly used by passengers who have to either walk or cycle to and/or from the bus station/stop, routes on which casualties with Non-Motorised Transport users often occur are hazardous to these users. Figure 7-16 plots the hazardous routes for NMT users in the study area.

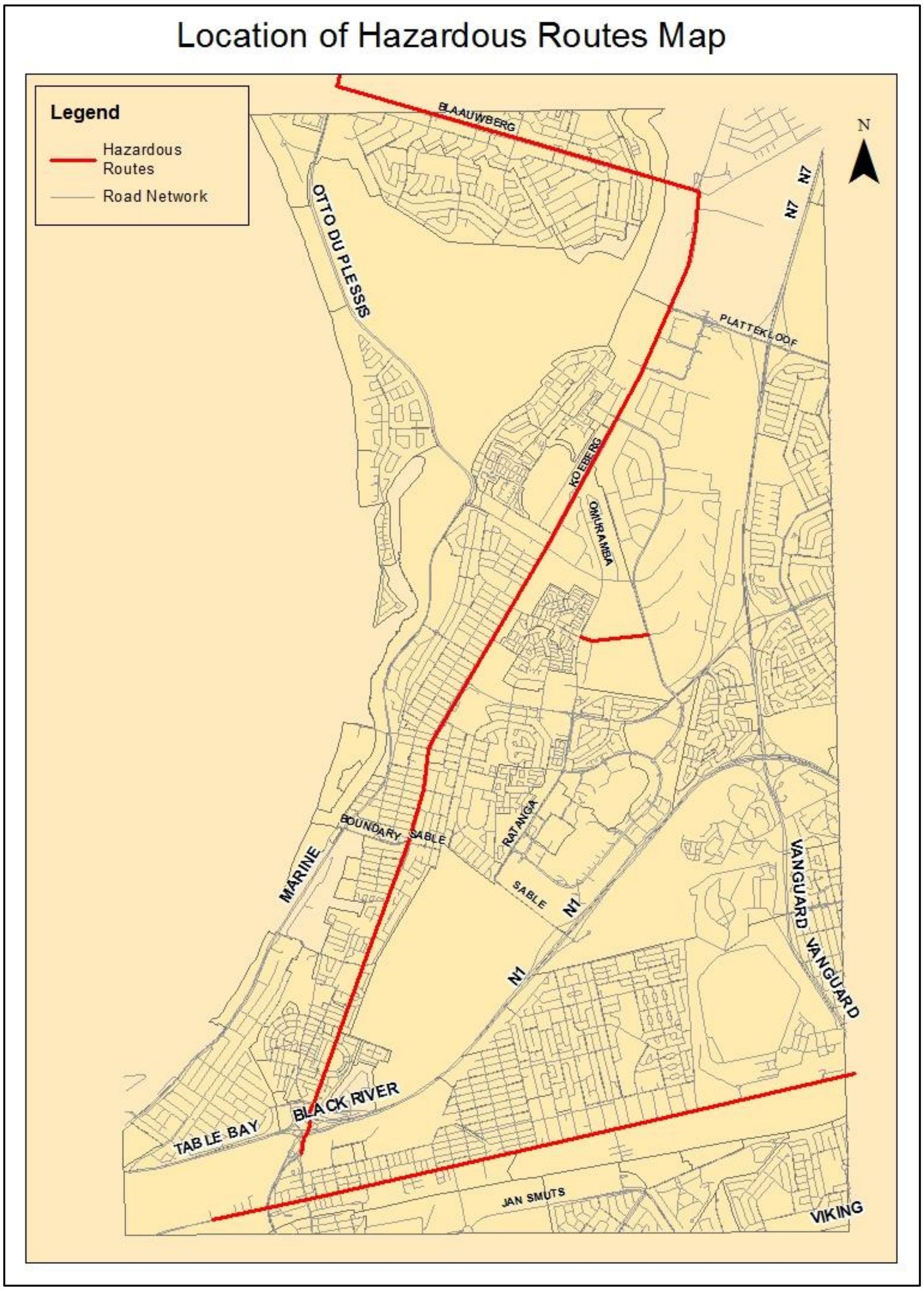

Figure 7-16: Location of Hazardous Routes Map
Source: Map created from Western Cape Government's GIS database

7.7. Non-Motorised Transport Infrastructure Theme

7.7.1. Pedestrian Infrastructure

Figure 7-17 shows the extent of the pedestrian infrastructure in the study area differentiating between where there is no sidewalk, a sidewalk on one side of the road and a sidewalk on both sides of the road. From this map it can be seen that the arterial roads or mobility spines have sidewalks on both sides of the road and the connecting distributor streets generally have a sidewalk on one side of the road. However; the vast majority of roads in the study area, particularly the residential streets, do not have any sidewalks at all.

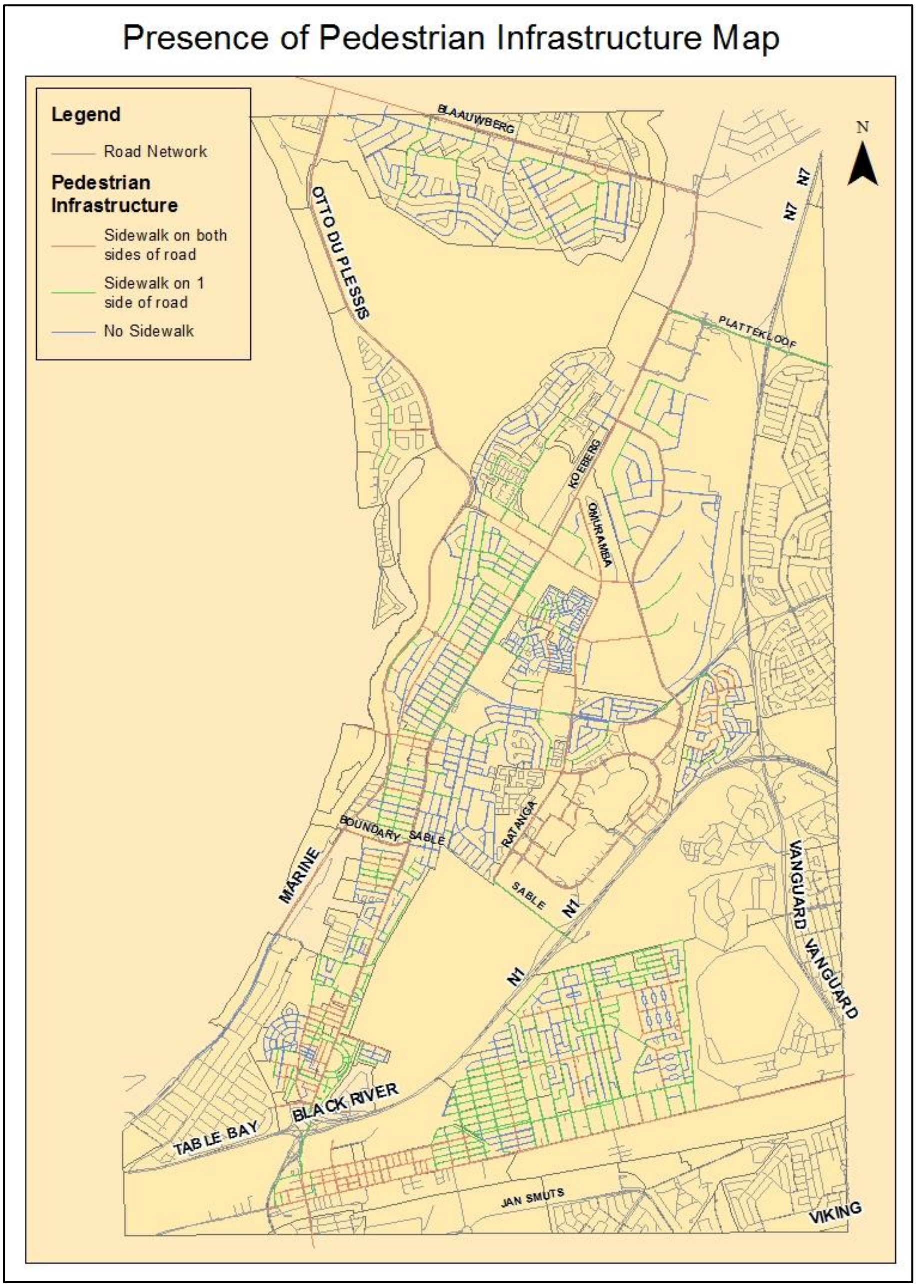

Figure 7-17: Pedestrian Infrastructure Map
Source: Map created based on Google Earth Imagery

7.7.2. Bicycle Infrastructure

Figure 7-18 shows the extent of the bicycle infrastructure in the study area, by indicating where a facility for cyclists has been provided. From the map it can be seen that the provision of cycle facilities is not extensive in the study area.

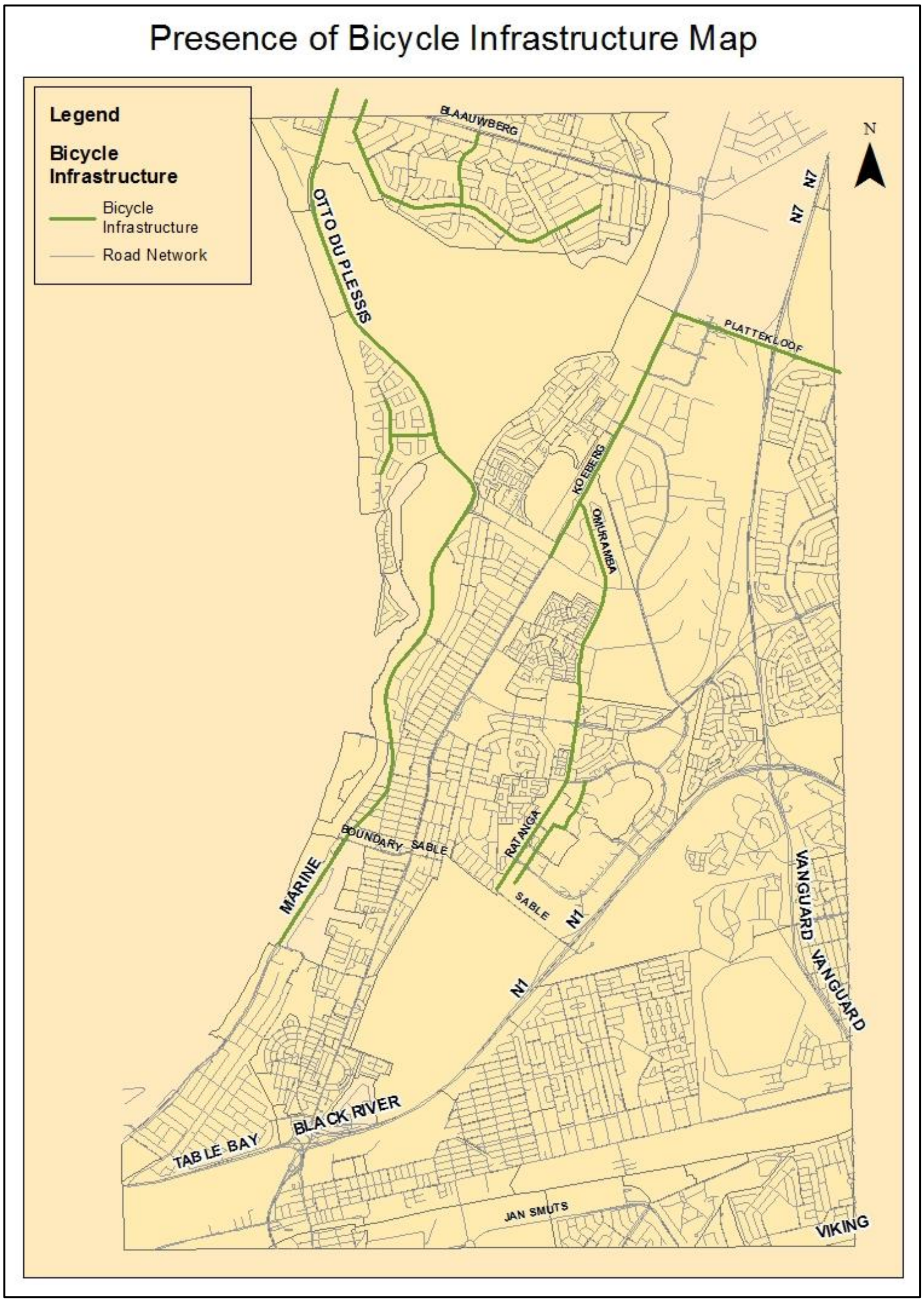

Figure 7-18: Bicycle Infrastructure Map
Source: Map created based on Google Earth Imagery

8. Results of Analysis

8.1. Introduction

The intent of this chapter is to present and provide insight into the results obtained during various stages of conducting this study. The chapter commences with the public transport demand analysis in which the Origin-Destination pairs used in this analysis are identified. The results of the Spatial Multi-Criteria Analysis and suitability results extraction follow, after which, the network analysis and route prioritisation results are shown. This chapter ends off by comparing the routes obtained for both approaches with the existing MyCiTi feeder routes in the study area, along with the results of the sensitivity assessment.

8.2. Public Transport Demand Analysis

The first step in the analysis procedure was to identify the O-D pairs to be used for developing the BRT feeder routes in the study area. The same O-D pairs were used in both approaches. When following Built Environment Approach, the road-based public transport demand analysis was used to simply inform which O-D pairs to use and in the prioritisation of routes (discussed in *Section 8.6*). The Transit-Oriented Approach included a second round of SMCA, wherein one of the criterions was an associated public transport demand map. The development of this map is documented in *Section 8.2.2*.

8.2.1. Identification of O-D Pairs

The Origin-Destination matrices used by the Transport for Cape Town planning department to develop the MyCiTi BRT routes were analysed to determine the road-based public transport demand in the study area. Table 8-1 and Figure 8-1 show the resultant O-D pairs identified for the BRT feeder route development. From this analysis, it was apparent that Century City followed by Montague Gardens were strong destinations or attractors of public transport trips, whilst Joe Slovo and Kensington were strong origins of similar trips.

Table 8-1: OD Matrix

O/D	5508	5523	5561	5612
5508	0.0	0.6	0.0	0.5
5523	0.0	0.0	0.0	0.0
5561	7.5	12.6	0.0	3.6
5612	35.6	4.1	0.0	0.0

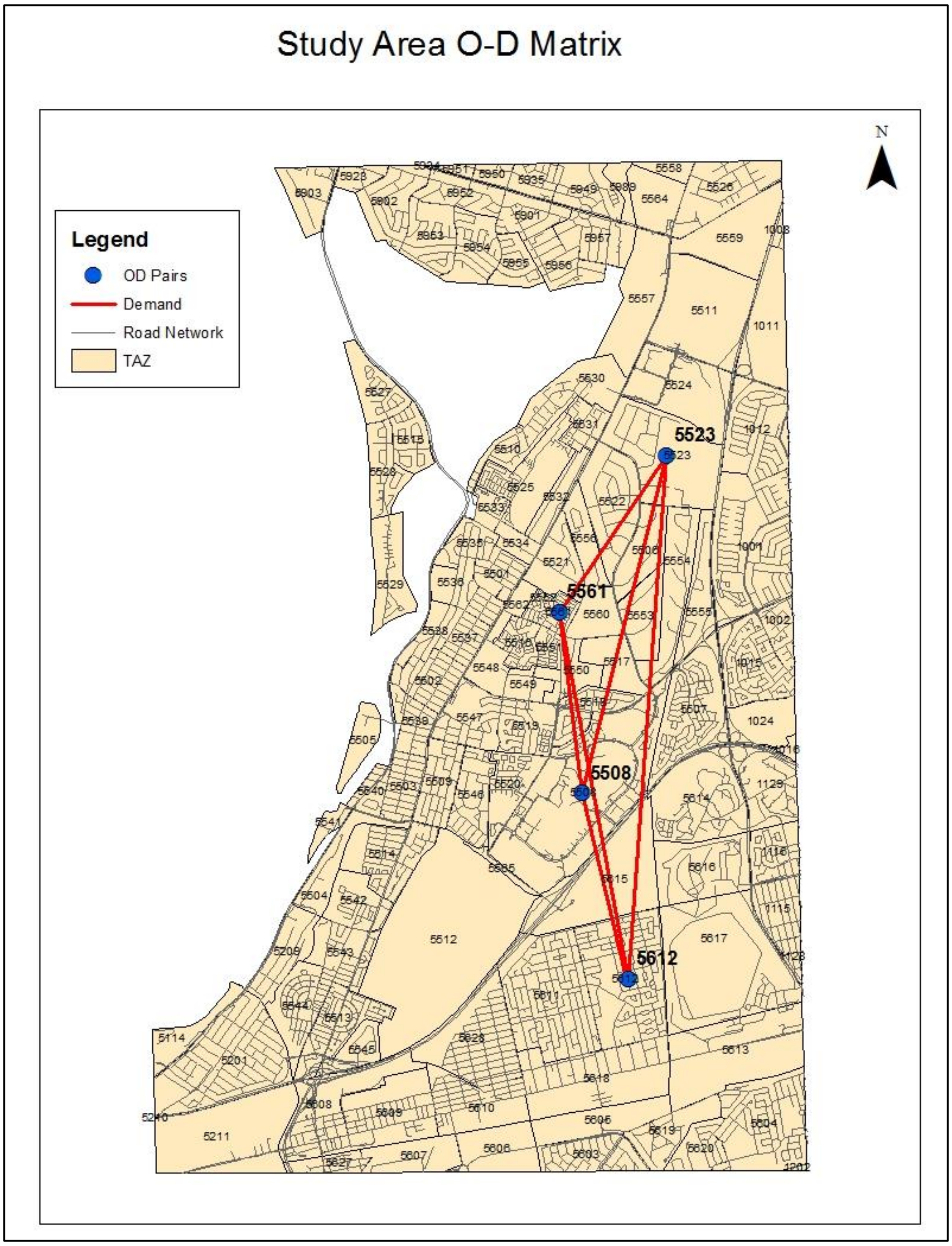

Figure 8-1: Public Transport OD Pairs

8.2.2. Associated Public Transport Demand

The second approach entailed the use of an associated public transport demand map as a criterion in a second round of SMCA. This means that in the second approach the public transport demand had a direct influence on the route development, which was based on mean suitability values along the existing road network. The associated public transport demand map created is shown in Figure 8-2.

In the production of this map, the centroid of each TAZ was treated as the centre of gravity for the public transport trip production and attraction for each zone. An influence radius of 500 metres around the public transport trip desire lines was utilised to create an associated trip demand area connecting each O-D pair. In light of the spatial nature of the SMCA applied in the next step, it was opted to use associated demand areas, rather than simple desire lines, so that the area-wide characteristic of transport demand could be represented and incorporated into the analysis. The radius of 500 metres was selected, in order to maintain consistency with the distance assumed by TCT that commuters are willing to walk to transit services. However; Hitge & Vanderschuren (2015) found that people are in actual fact walking average distances of 1.5 kilometres to access BRT services.

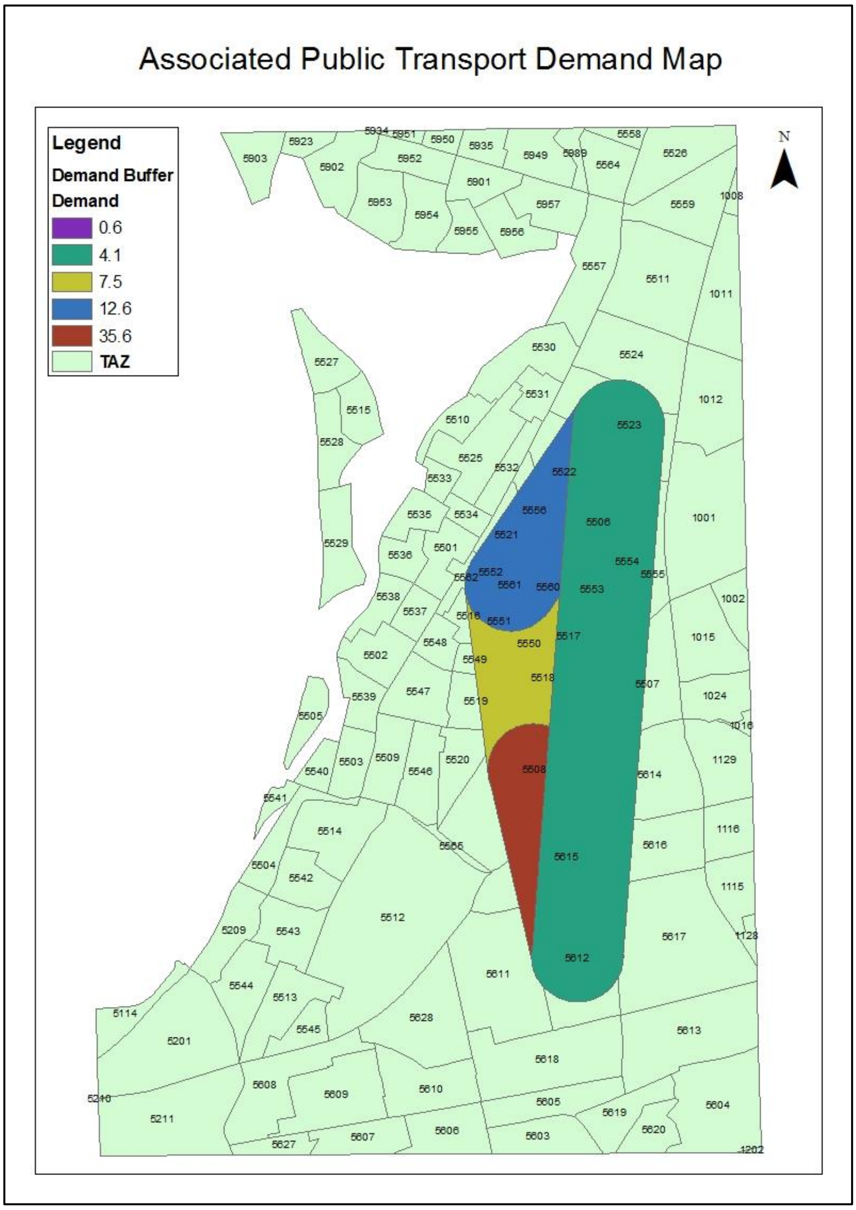

Figure 8-2: Associated Public Transport Demand Map
Source: Map created from City of Cape Town Municipality's GIS database

8.3. SMCA Analysis

As explained in *Chapter 6*, this study involved the application of two approaches. The first method included one round of SMCA to create a built environment composite suitability map, whereas the second approach comprised an additional round of SMCA to include the associated public transport demand as a criterion in the suitability analysis for BRT feeder bus routes.

The Spatial Multi-Criteria Analysis was performed using the SMCE module in ILWIS 3.3 Academic, where all criteria identified are included as inputs to form a composite suitability map. In the composite suitability map, also referred to as a “friction map,” each pixel depicts the accumulative suitability performance values as a function of the input criteria for BRT feeder bus routes. In other words, the composite suitability value in a particular pixel indicates the appropriateness of having a BRT feeder bus route in that pixel.

8.3.1. Built Environment Suitability Analysis (SMCA Part 1)

The first SMCA analysis completed was based on the built environment characteristics and criteria established in *Section 6.3,* where an equal weighting scheme was assigned to the set of input maps. The composite suitability map obtained from this analysis is illustrated in Figure 8-3. As can be seen from the composite suitability map, the highest suitability score obtained was 0.5 with no pixel depicting 100% suitability for BRT feeder routing. That said, the composite suitability values were relatively consistent with little variation across the study area.

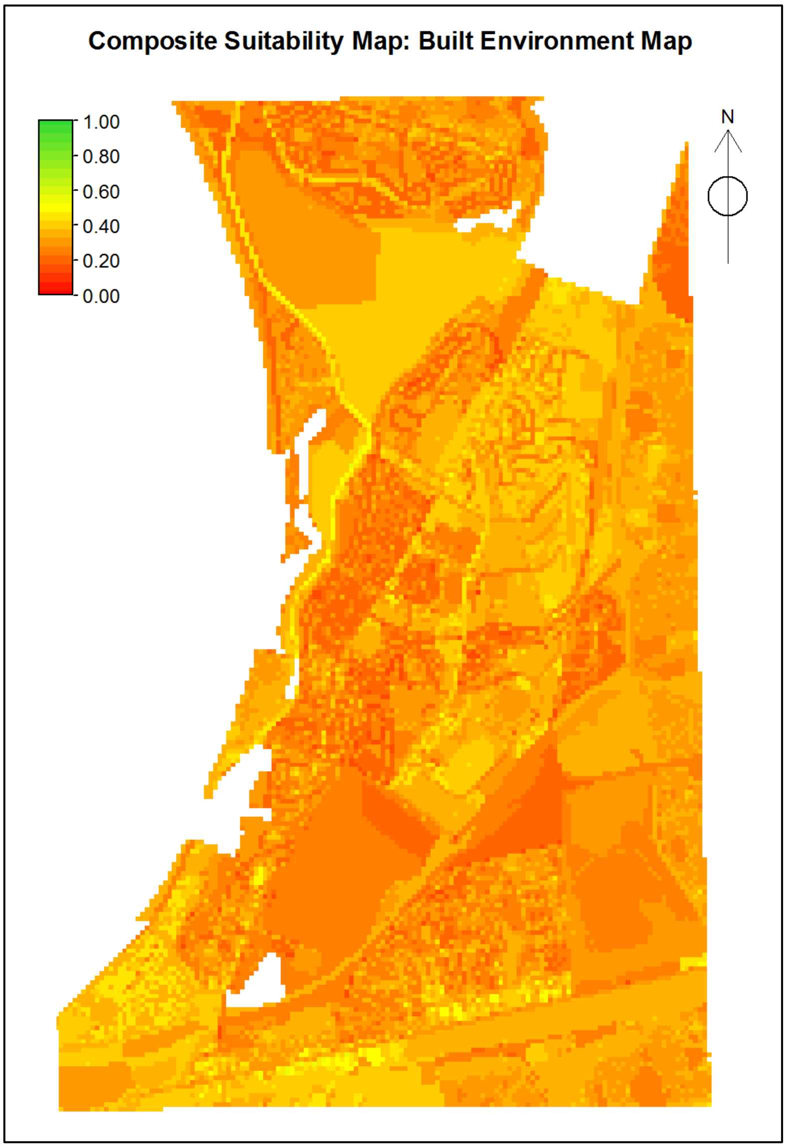

Figure 8-3: Built Environment Composite Suitability Map

8.3.2. Transit-Oriented Approach (SMCA Part 2)

The second method applied comprised completing an additional round of SMCA in ILWIS. In the second SMCA analysis conducted, only two input maps or criteria were used; namely the built environment composite suitability map (shown in Figure 8-3), and the associated public transport demand map (depicted in Figure 8-2). An equal weighting of 50% was assigned to each criterion, and both maps were standardised as benefits using the direct method.

The resultant composite suitability map for round two is illustrated in Figure 8-4. As expected, the pixels falling within the high associated public transport demand areas obtained higher suitability values, particularly in the areas connecting Factreton and Century City. The remainder of the pixels situated outside the associated demand areas remain unchanged from the original built environment composite suitability map.

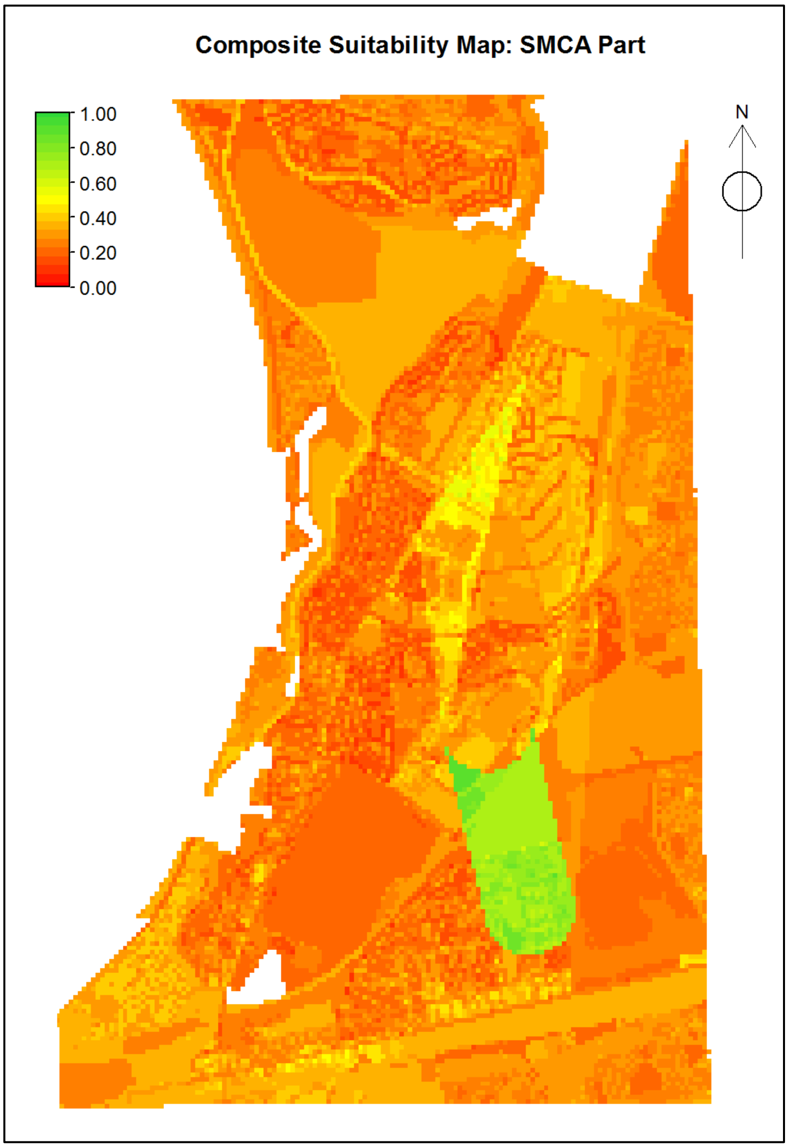

Figure 8-4: SMCA Part 2

8.4. Results of Suitability Extraction

The next step of the analysis procedure was to extract Line Weighted Mean suitability values along the existing road network. Using the composite suitability maps shown in Figure 8-3 and Figure 8-4, the Line Weighted Mean (LWM) suitability values were computed along road segments in the existing road network for the study area. These values were then inverted to represent the impedance values per road segment, resulting in the maps shown in Figure 8-5 a) and b) for the SMCA composite suitability maps part 1 and 2, respectively.

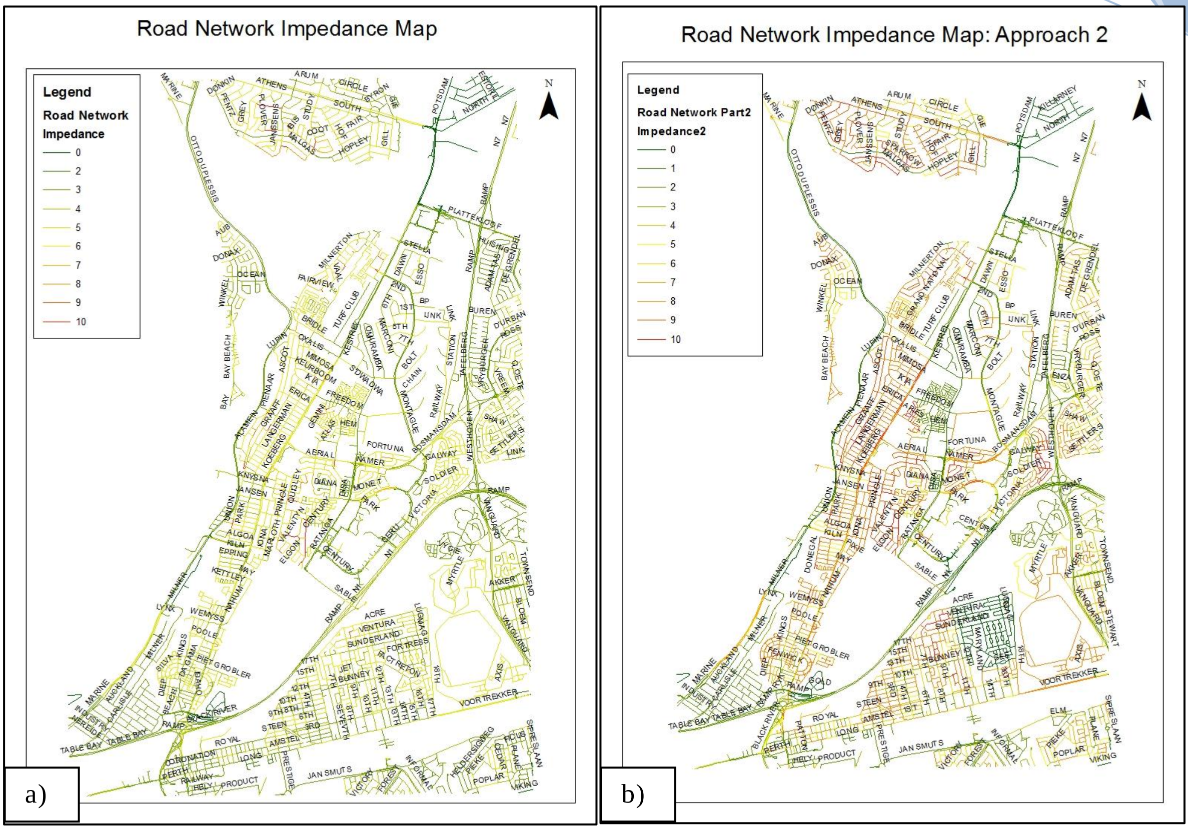

Figure 8-5 a) and b): Road Network Impedance Maps: Approach 1 and 2

As can be seen, very few road segments were assigned high impedance values, with the majority scoring below an impedance value of 5. These road segments are thus more favourable for BRT feeder routes as they have lower impedance values.

From Figure 8-5 b), it is evident that the second approach produces significantly more variation in the road network impedance values, thus clearly distinguishing the more suitable road segments from the less suitable ones for BRT feeder routing compared to the first approach.

8.5. Network Analysis

The network analysis was carried out using the ArcGIS Network Analyst extension pack to produce a set of BRT feeder routes. The O-D pairs identified in *Section 8.2.1* were utilised to develop the potential BRT feeder routes for the study area. The impedance values for each road segment formed the basis for the least cost calculation, which attempts to minimise the accumulated impedance in determining the resultant routes.

8.5.1. Built Environment Approach (1)

The BRT feeder routes obtained when the first approach was followed are shown in Figure 8-6. The route properties are listed in Table 8-2, from which it can be seen that Route 12 has the highest accumulated impedance value. When the average impedance per kilometre is considered, then Route 7 is the worst performing and Route 4 is the best performing.

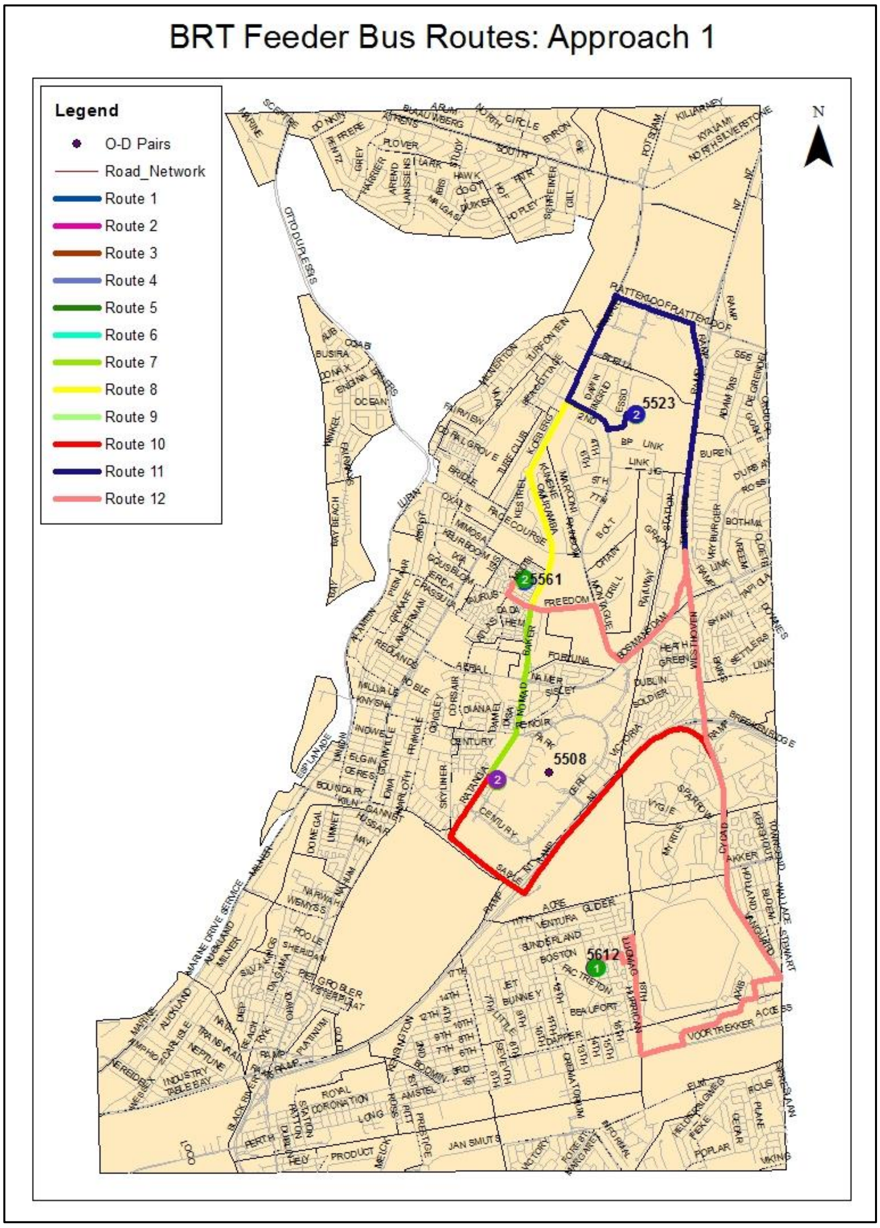

Figure 8-6: BRT Feeder Bus Routes: Approach 1

Table 8-2: Route Properties: Approach 1

Route	From	To	Accumulated Impedance Value (θ)	Length (km)	Avg. Impedance per km (θ/km)
1	5508	5523	70.31	5.17	13.6
2	5508	5561	74.3	2.57	28.9
3	5508	5612	167.5	11.35	14.8
4	5523	5508	69.17	5.17	13.4
5	5523	5561	69.32	3.75	18.5
6	5523	5612	189.45	14.08	13.5
7	5561	5508	69.68	2.55	27.3
8	5561	5523	64.91	3.8	17.1
9	5561	5612	205.36	12.15	16.9
10	5612	5508	170.86	11.37	15.0
11	5612	5523	189.59	14.08	13.5
12	5612	5561	209.38	12.11	17.3

8.5.2. Transit-Oriented Approach (2)

When the second approach was adopted, the routes shown in Figure 8-7 were obtained, and the route properties are listed in Table 8-3. From Figure 8-7, it can be seen that the only difference between the routes developed for each approach is Route 11, otherwise the rest of the routes traverse the same path. The difference in the network analysis results between Approach 1 and 2 are illustrated in Figure 8-8.

Analysis of the route properties showed that Route 9 now has the highest accumulated impedance value, and Route 4 the lowest. However; when the average impedance per kilometre was considered, Route 7 was the worst performing and Route 3 and 10 were equally the best performing.

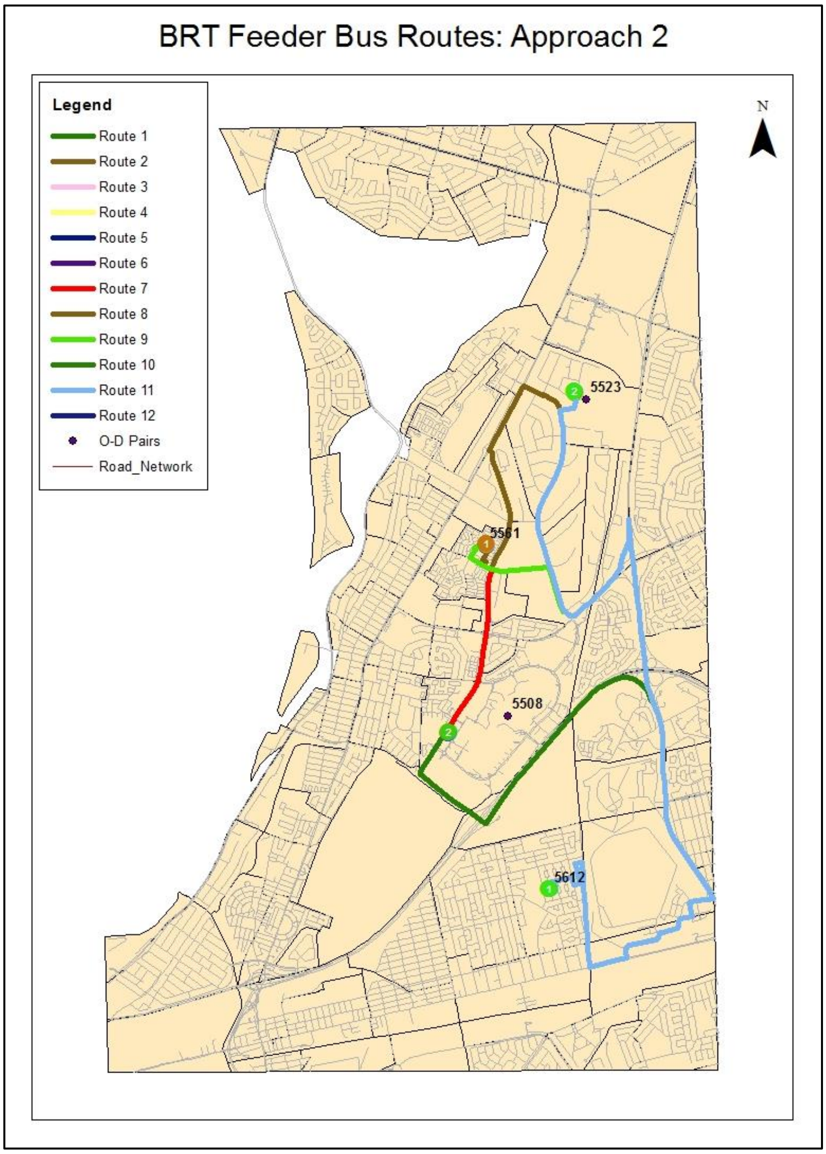

Figure 8-7: BRT Feeder Bus Routes: Approach 2

Table 8-3: Route Properties: Approach 2

Route	From	To	Accumulated Impedance Value (θ)	Length (km)	Avg. Impedance per km (θ/km)
1	5508	5523	75.49	5.36	14.1
2	5508	5561	69.23	2.56	27.0
3	5508	5612	139.2	11.05	12.6
4	5523	5508	75.48	5.36	14.1
5	5523	5561	55.48	3.67	15.1
6	5523	5612	172.41	13.09	13.2
7	5561	5508	69.29	2.55	27.2
8	5561	5523	55.97	3.7	15.1
9	5561	5612	177.24	12.08	14.7
10	5612	5508	139.42	11.07	12.6
11	5612	5523	173.06	13.12	13.2
12	5612	5561	176.18	12.04	14.6

As can be seen from Figure 8-8, the only difference between the network analysis results for Approach 1 and 2 is in the path traversed by Route 11 (connecting Factreton and Montague Gardens). In the first approach, this route exits the N7 at the Plattekloof road interchange and then follows along Koeberg Road before turning into Montague Drive. For Approach 2, on the other hand, Route 11 exits the N7 earlier at Bosmansdam Road, before turning up into Montague Drive.

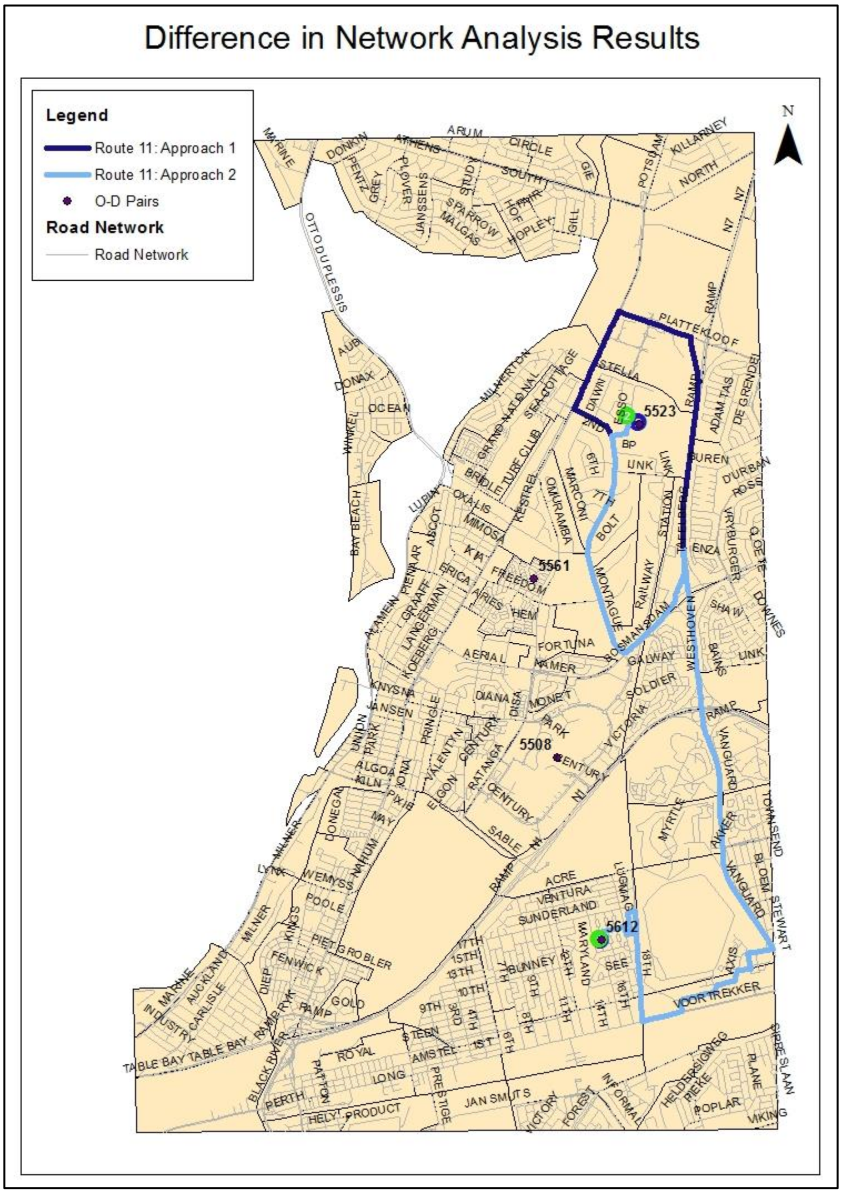

Figure 8-8: Difference in Network Analysis Results

8.6. Prioritisation of Routes

In prioritising which route or selection of feeder bus routes should be implemented for both approaches, the public transport travel demand for each route was compared and used to weigh each route.

8.6.1. Built Environment Approach (1)

The results obtained are listed in Table 8-4 (illustrated in Figure 8-9). From these results, it is evident that Route 10 is the best performing and Route 5 is the worst performing, with the lowest and highest weighted impedance values per kilometre, respectively.

Table 8-4: Weighted Route Demand Results: Approach 1

Route	From	To	Accumulated Impedance Value (θ)	Length (km)	Avg. Impedance per km (θ/km)	PT Demand (PH Trips)	Weighted Impedance
1	5508	5523	70.31	5.17	13.6	0.6	22.7
2	5508	5561	74.3	2.57	28.9	0.0	99760.7
3	5508	5612	167.5	11.35	14.8	0.5	31.9
4	5523	5508	69.17	5.17	13.4	0.0	699.0
5	5523	5561	69.32	3.75	18.5	0.0	1536631.1
6	5523	5612	189.45	14.08	13.5	0.0	2919.8
7	5561	5508	69.68	2.55	27.3	7.5	3.7
8	5561	5523	64.91	3.8	17.1	12.6	1.4
9	5561	5612	205.36	12.15	16.9	3.6	4.7
10	5612	5508	170.86	11.37	15.0	35.6	0.4
11	5612	5523	189.59	14.08	13.5	4.1	3.3
12	5612	5561	209.38	12.11	17.3	0.0	5894.7

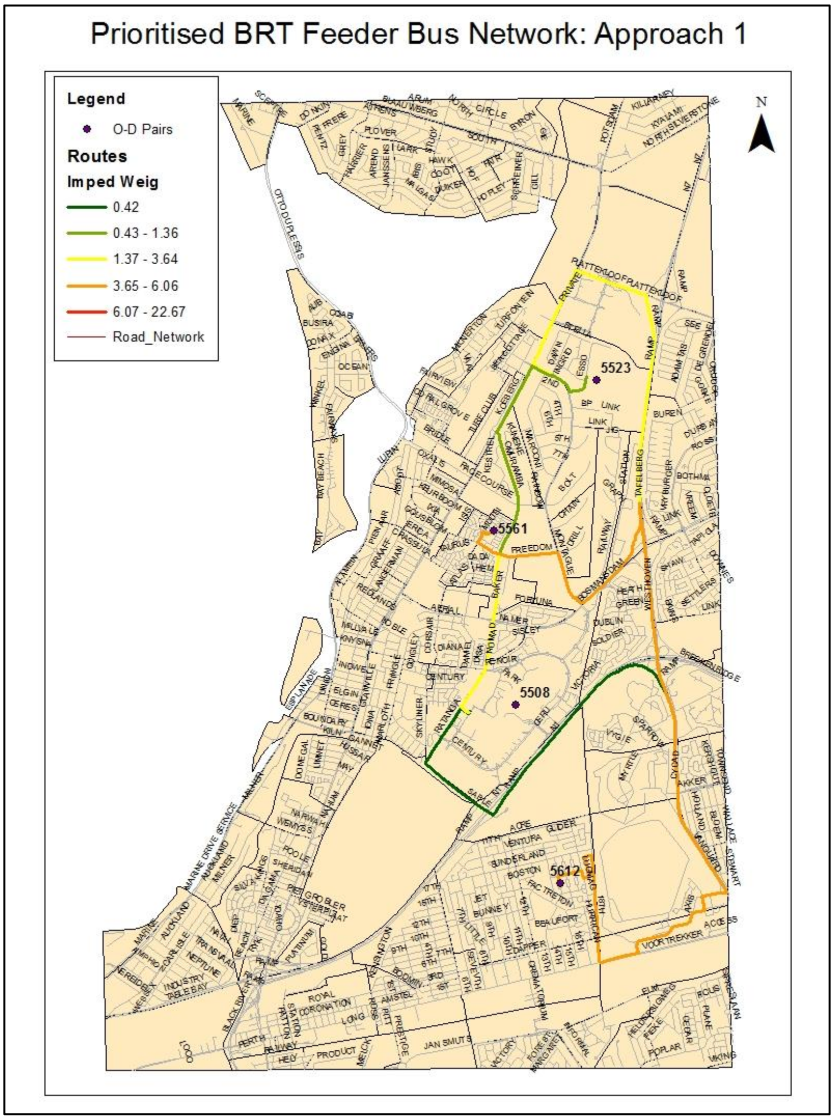

Figure 8-9: Prioritised BRT Feeder Bus Network: Approach 1

8.6.2. Transit-Oriented Approach (2)

Table 8-5 and Figure 8-10 show the weighted route demand analysis results attained for the second approach. From these results, it is evident that Route 10 is the best performing and Route 5 is the worst performing, with the lowest and highest weighted impedance values per kilometre, respectively.

Table 8-5: Weighted Route Demand Results: Approach 2

Route	From	To	Accumulated Impedance Value (θ)	Length (km)	Avg. Impedance per km (θ/km)	PT Demand (PH Trips)	Weighted Impedance
1	5508	5523	75.49	5.36	14.1	0.6	23.5
2	5508	5561	69.23	2.56	27.0	0.0	93316.4
3	5508	5612	139.2	11.05	12.6	0.5	27.2
4	5523	5508	75.48	5.36	14.1	0.0	735.8
5	5523	5561	55.48	3.67	15.1	0.0	1256645.3
6	5523	5612	172.41	13.09	13.2	0.0	2858.2
7	5561	5508	69.29	2.55	27.2	7.5	3.6
8	5561	5523	55.97	3.7	15.1	12.6	1.2
9	5561	5612	177.24	12.08	14.7	3.6	4.1
10	5612	5508	139.42	11.07	12.6	35.6	0.4
11	5612	5523	173.06	13.12	13.2	4.1	3.2
12	5612	5561	176.18	12.04	14.6	0.0	4988.8

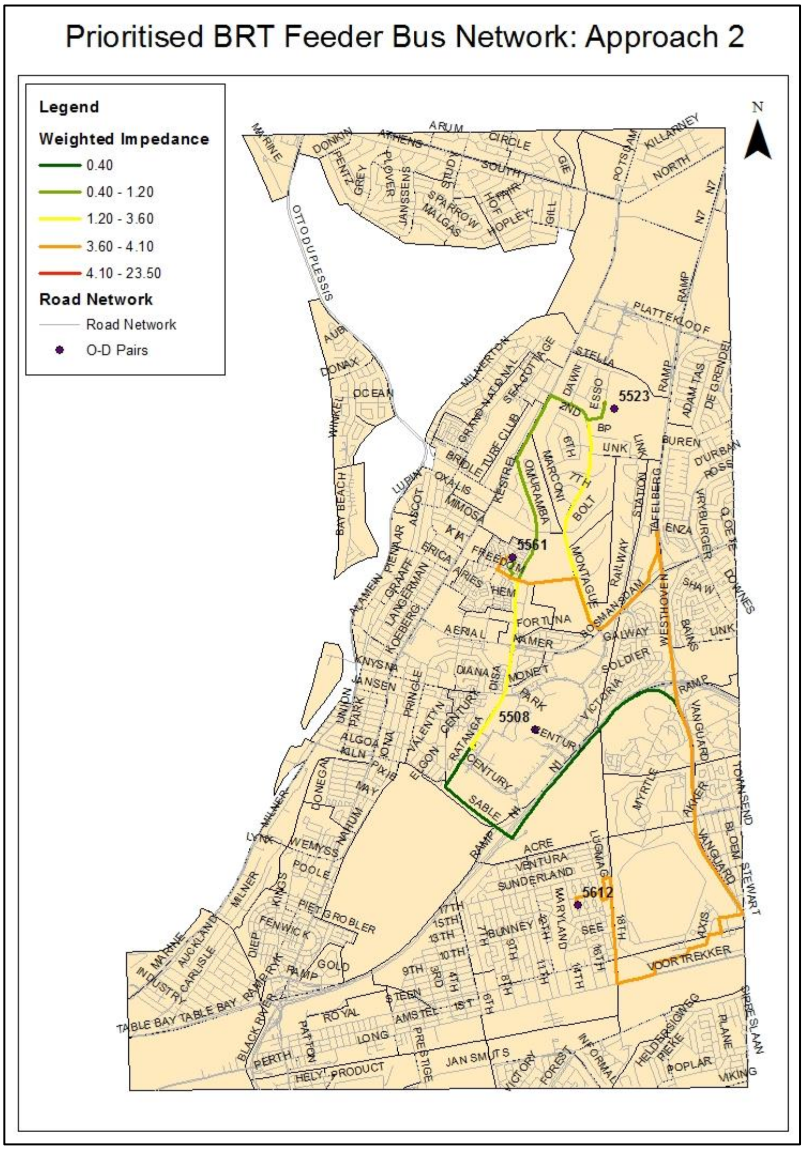

Figure 8-10: Prioritised BRT Feeder Bus Network: Approach 2

8.7. Comparison with Actual MyCiTi Phase 1 Network

At present, the Phase 1A network is fully constructed whilst the Phase 1B network, which comprises of only feeder routes, is still under construction. Phase 1A consists of a combination of trunk (shown in red) and feeder services (shown in green). The existing MyCiTi BRT Network in the study area is illustrated in Figure 8-11. This section will compare the routes developed as part of this study to those in the actual MyCiTi feeder bus network. This task will be completed through the use of the key performance indicators (KPIs) identified in *Section 3.3.1*.

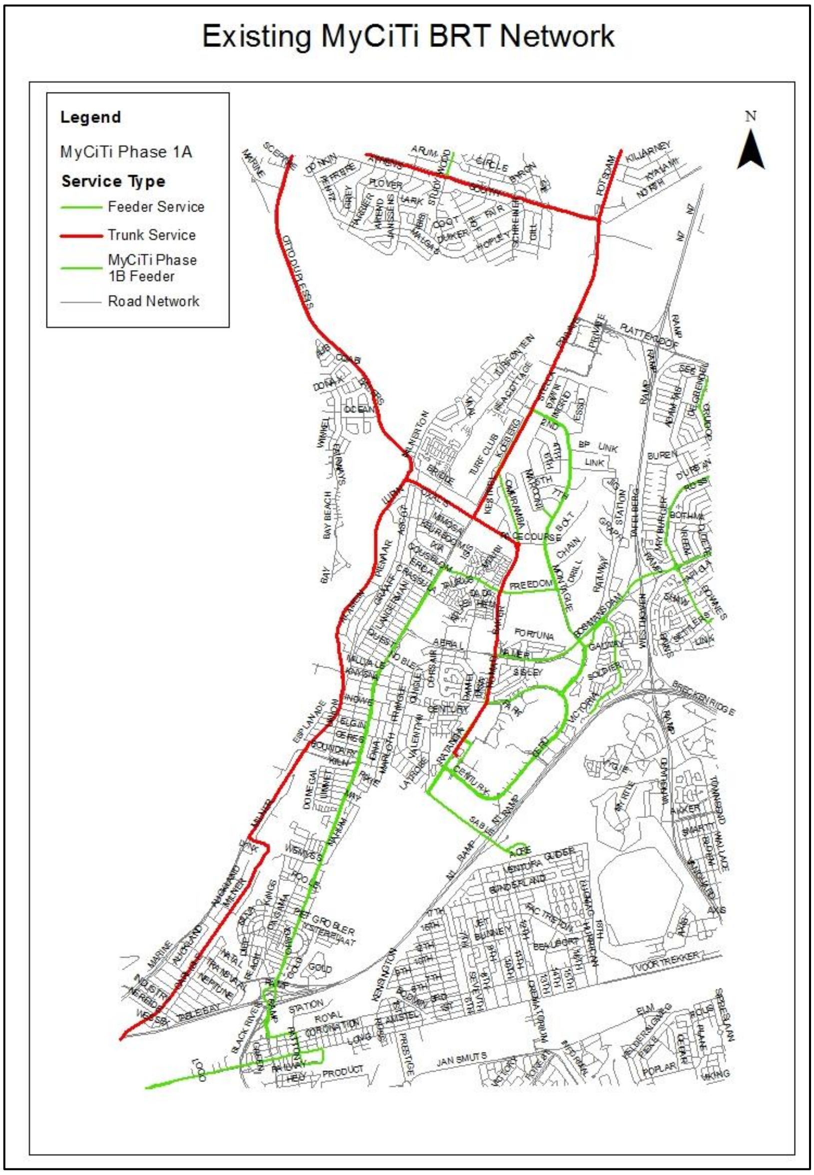

Figure 8-11: Existing MyCiTi BRT Network

8.7.1. Average Travel Time

One of the goals of a BRT system is to achieve a reasonable average travel time so that this becomes an attractive mode of travel to commuters. This is particularly the case for the feeder system, as these buses operate in mixed traffic conditions, therefore, risk of speed impediment is imminent, due to traffic congestion. An average travel speed of 40km/h has been used, as this is the expected operational speed for feeder bus services in Cape Town.

Table 8-6 shows the average travel time for the MyCiTi feeder routes falling in the study area, and Table 8-7 shows the average travel time for the feeder routes developed in this research. From both these tables, it can be seen that the MyCiTi feeder routes achieved the lowest average travel time at 11.51 minutes, followed by the Approach 2 routes at 11.97 minutes. This indicated that the MyCiTi feeder routes perform better with respect to average travel time, even though the difference in results is minimal.

Table 8-6: Average Travel Time for MyCiTi Feeder Routes

MyCiTi Feeder Routes	Length (km)	Avg. Travel Speed (km/h)	Avg. Travel time (min)
251	11.27	40	16.9
260	5.5	40	8.3
261	9.01	40	13.5
262	4.9	40	7.4
Average			**11.51**

Table 8-7: Average Travel Time for Research Feeder Routes

Route	Approach 1			Approach 2		
	Length (km)	Avg. Travel Speed (km/h)	Avg. Travel time (min)	Length (km)	Avg. Travel Speed (km/h)	Avg. Travel time (min)
1	5.17	40	7.8	5.36	40	8.0
7	2.55	40	3.8	2.55	40	3.8
8	3.8	40	5.7	3.7	40	5.6
9	12.15	40	18.2	12.08	40	18.1
10	11.37	40	17.1	11.07	40	16.6
11	14.08	40	21.1	13.12	40	19.7
Average			**12.28**	Average		**11.97**

8.7.2. Coverage

In order to ensure that a BRT system serves the needs of its potential commuters, the routes developed should offer the highest coverage of destinations and services people need and would like to have access to. The coverage KPI assessed how many of these destinations were within a 500 metre radius of each feeder route.

Table 8-8 shows the coverage of the MyCiTi feeder bus routes, whilst Table 8-9 shows the coverage of the feeder routes developed as part of this research. It is evident that the MyCiTi feeder routes out-perform the routes produced in this study based on the KPI of coverage. However; from a coverage perspective, the Built Environment Approach achieved a higher coverage score than the Transit-Oriented Approach, with 14 destinations served compared to 12.

Table 8-8: Coverage of the MyCiTi Feeder Routes

MyCiTi Feeder Routes	Coverage
251	17
260	18
261	39
262	8
Average	**21**

Table 8-9: Coverage of the Research Feeder Routes

Route	Approach 1	Approach 2
	Coverage	
1	9	8
7	4	2
8	7	6
9	20	20
10	16	15
11	26	22
Average	**14**	**12**

8.7.3. Directness

One of the benefits offered by using the private vehicle is that trips are often more direct compared to that completed by bus, as in the latter case, a number of people's needs are being served in one trip. Routes that are more convoluted are also frequently associated with longer travel times.

Table 8-10 shows the directness of the MyCiTi feeder routes, and Table 8-11 shows the directness of the feeder routes developed in this study. Directness was computed as the ratio of the actual length versus the Direct "as the crow flies" distance. The directness scores attained were marginally different for each set of routes. Nonetheless, the MyCiTi feeder bus routes achieved a better score for directness of its routes in comparison to the routes produced in this research.

Table 8-10: Directness of the MyCiTi Feeder Routes

MyCiTi Feeder Routes	Actual Length (km)	Direct Distance (km)	Directness
251	11.27	2.71	4.16
260	5.5	3.3	1.67
261	9.01	6.74	1.34
262	4.9	2.64	1.86
Average			**2.25**

Table 8-11: Directness of the Research Feeder Routes

Route	Approach 1			Approach 2		
	Actual Length (km)	Direct Distance (km)	Directness	Actual Length (km)	Direct Distance (km)	Directness
1	5.17	3.85	1.34	5.36	3.85	1.39
7	2.55	2.02	1.26	2.55	2.02	1.26
8	3.8	2.1	1.81	3.7	2.1	1.76
9	12.15	4.13	2.94	12.08	4.13	2.92
10	11.37	2.11	5.39	11.07	2.11	5.25
11	14.08	5.8	2.43	13.12	5.8	2.26
Average			**2.53**	Average		**2.47**

8.7.4. Consideration of Environmental Factors

The two approaches followed in this research featured environmental factors as a theme in the SMCA conducted; thereby allowing the necessary consideration of important environmental factors in the BRT feeder route development. This was done in a clear and orderly fashion, ensuring that the feeder routes produced are as sustainable as can be.

The interviews conducted with the TCT planning officials, along with the planning documentation for the MyCiTi IRT system, fail to mention the inclusion of environmental factors in the route planning procedure. Hence, it was concluded that this crucial step was not considered in practice, leaving question as to whether the network developed could have been more sustainable.

8.7.5. Level of NMT Planning Inclusion

Both methodologies applied in this study allowed for direct consideration of NMT facilities in the development of the BRT feeder routes. This facilitated a high level of integration, and thus, appreciation of the role that NMT modes have to play in the successful operation of BRT feeder services. Through the use of SMCA, the consideration of NMT facilities in the BRT feeder route planning was systematic and transparent.

From the interviews conducted with the Transport for Cape Town planning officials, and the review of various studies conducted in preparation for the implementation of a BRT system in Cape Town, it became apparent that NMT facilities were considered in executing the planning of the MyCiTi IRT system. Studies specific to NMT infrastructure to be implemented as part of the BRT roll-out were carried out, and general improvements to the surrounding NMT infrastructure were made within a 500 metre radius of the BRT trunk service. In terms of the BRT feeder route development for MyCiTi; however, consideration of pedestrian and cyclist trends were definitely made, but this was not done in a transparent or systematic manner, therefore, this is critiqued. This was evident from the Atlantis feeder routes, which had to be revised to be more cognisant of local NMT behaviour. It is thus viewed that the level of NMT planning inclusion is lower than in the approaches followed in this study.

8.8. Sensitivity Analysis

A sensitivity analysis was conducted through the application of an additional set of criteria weighting, and the entire methodology used in this study was followed through thereafter. The final network results obtained could then be compared to assess the susceptibility of the final results to the choice of weighting scheme.

8.8.1. Built Environment Approach (1)

Figure 8-12 a) and b) depict the BRT feeder routes obtained when following the Built Environment Approach, where Figure 8-12 b) represents the results of the sensitivity analysis. From this comparison, it is evident that all resultant routes, except Route 11, are exactly the same. The only difference being, that in the sensitivity analysis Route 11 exits the N7 at Bosmansdam Road, whilst the original version only exits later at Plattekloof Road.

Table 8-12 provides a comparison between the weighted impedance values obtained in the original analysis and the sensitivity analysis. It was found that an average weighted impedance value of 137 164.5 was reached in the original analysis, whilst a slightly lower value of 136 120.5 was arrived at in the sensitivity analysis. This represents a percentage difference of only 1%, thus it can be concluded that the effect of applying a different weighting scheme had a minimal influence on the final results for the Built Environment Approach.

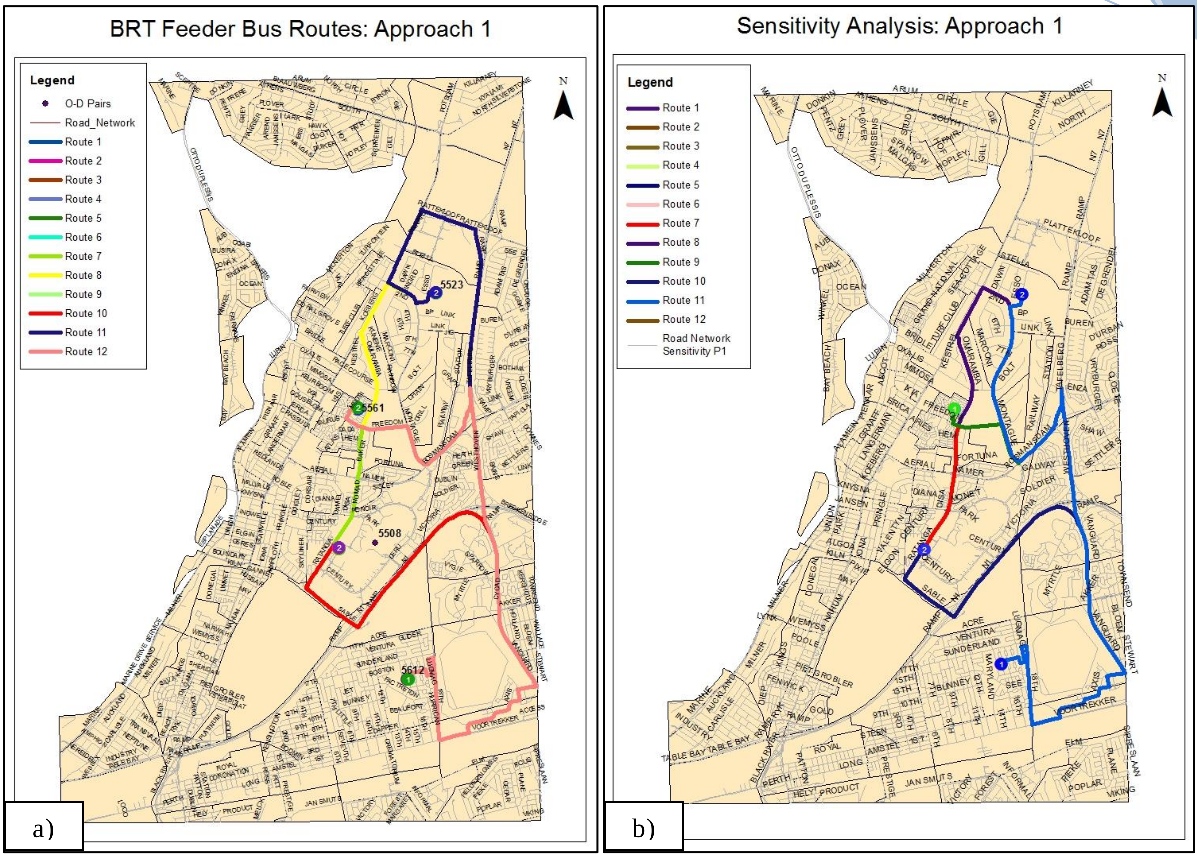

Figure 8-12: Sensitivity Analysis: Approach 1 a) Original Analysis and b) Sensitivity Analysis

Table 8-12: Sensitivity Analysis Results Approach 1

Route	From	To	Original	Sensitivity Analysis
			Weighted Impedance	
1	5508	5523	22.7	22.2
2	5508	5561	99760.7	104341.8
3	5508	5612	31.9	31.0
4	5523	5508	699.0	696.9
5	5523	5561	1536631.1	1519352.2
6	5523	5612	2919.8	3154.5
7	5561	5508	3.7	4.1
8	5561	5523	1.4	1.5
9	5561	5612	4.7	4.8
10	5612	5508	0.4	0.4
11	5612	5523	3.3	3.6
12	5612	5561	5894.7	5833.3
Average			**137 164.5**	**136 120.5**

8.8.2. Transit-Oriented Approach (2)

The original analysis results and sensitivity analysis results for the Transit-Oriented Approach are represented by Figure 8-13 a) and b), respectively. By comparing the resultant routes obtained, it can be seen that there is in fact no difference, unlike the case for Approach 1.

Table 8-13 provides a comparison between the weighted impedance values for the original and sensitivity analysis for Approach 2. In this case, there was a percentage difference of 4% between the average weighted impedance values for each analysis, however, this is still considered minimal.

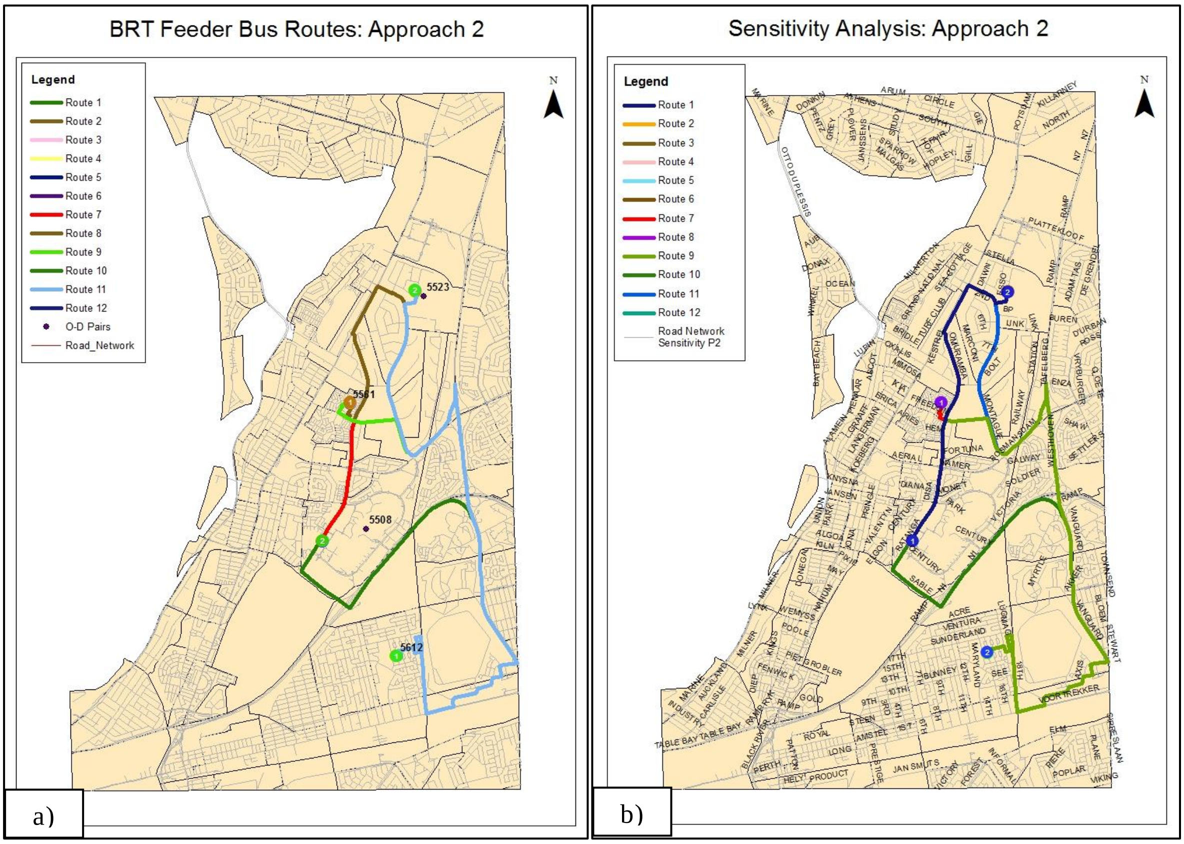

Figure 8-13: Sensitivity Analysis: Approach 2 a) Original Analysis and b) Sensitivity Analysis

Table 8-13: Sensitivity Analysis Results: Approach 2

Route	From	To	Original	Sensitivity Analysis
			Weighted Impedance	
1	5508	5523	23.5	24.3
2	5508	5561	93316.4	95064.0
3	5508	5612	27.2	27.3
4	5523	5508	735.8	758.4
5	5523	5561	1256645.3	1315834.7
6	5523	5612	2858.2	2921.1
7	5561	5508	3.6	3.7
8	5561	5523	1.2	1.3
9	5561	5612	4.1	4.1
10	5612	5508	0.4	0.4
11	5612	5523	3.2	3.3
12	5612	5561	4988.8	5029.3
Average			**113 217.3**	**118 306.0**

9. Discussion of Results

9.1. Introduction

This chapter delves into the rationale behind the results produced in this study, as presented in *Chapter 8*. The resulting BRT feeder networks are then compared to the existing MyCiTi BRT feeder networks, based on the Key Performance Indicators established. Lastly, the practical relevance of this research study is presented.

9.2. Public Transport Demand Analysis

9.2.1. Identification of O-D Pairs

The public transport demand analysis comprised carrying out an O-D Analysis aimed at identifying the four main O-D pairs within the study area, and included only road-based public transport modes, i.e. bus and minibus taxi morning peak hour trips. It, therefore, came as no surprise that O-D pairs having the most morning peak hour trips in the study area, comprised suburbs that are not served by the current rail network in Cape Town.

The two main origins of road-based public transport trips are Factreton and Joe Slovo respectively, which are both lower income residential areas, where private vehicle ownership is low. The two main attractors of road-based public transport trips are Century City and Montague Gardens, respectively. Century City comprises of a very large shopping centre and a number of commercial businesses, and Montague Gardens contains a mixture of industrial and commercial businesses, thus these two areas provide numerous employment opportunities. Therefore, the strong public transport demand between these O-D pairs in the morning is expected, as people need to travel to work.

It is interesting to note that Factreton is currently not served by the MyCiTi BRT network, even though it is the strongest producer of road-based morning peak hour trips in the study area. It is possible, however, that this could be attributed to external dynamics involving the various public transport associations operating in the area.

9.2.2. Associated Public Transport Demand

The second approach involved the creation of an associated public transport demand map for input into an additional round of SMCA. It was opted to use associated public transport demand, which took the form of polygons, as opposed to public transport desire lines, represented by linear lines between an origin and destination pair. This method of depicting the public transport demand is regarded as more representative of reality, as it recognises that transportation trips originate from an area rather than a point.

The geometric centroid of each TAZ was used as the centre of gravity for public transport trips produced and attracted, and therefore, formed the start and end point of each route produce. However, it is recognised that this may not be fully illustrative of the actual case. In real life, the layout of an area highly influences where a public transport transit point is located, and this may not coincide with the geometric centroid of that particular area. Knowledge of the local conditions may allow better representation of the centre of gravity for public transport trips in the respective TAZ’s.

An influence radius of 500 metres was used along the desire lines to illustrate the associated public transport demand for the respective O-D pairs identified. This was based on the assumed distance that people are willing to walk to transport services, however, it is known that in developing countries people are willing to walk distances of up to 1000 metres, or more, to access public transport services. Again, the use of 500 metres may not be fully representative of the case in reality. But, in using a distance of 500 metres this study is in line with the principles used for the MyCiTi BRT system allowing better comparison of results.

9.3. Spatial Multi-Criteria Analysis

9.3.1. Built Environment Suitability Analysis (SMCA Part 1)

At the outset of this research, a list of criteria was established to be used as inputs for the SMCA. The goal of the SMCA was to produce suitability results in which each pixel represents the appropriateness of that pixel for BRT feeder routes. It was thus surprising to see that there were no areas which were highly suitable in the study area, where the highest suitability score obtained was only 0.54. This indicates that the urban fabric found in the study area is not very well suited to mass transit systems, and consequently, that principles of Transit Oriented Development have not been adopted in this area.

The range of the resulting suitability values present in the composite map is quite small, as all values are between 0.1 and 0.54. Despite the fact that these values are on the lower end of the suitability scale, it also shows that attributes of the built environment in this area are relatively consistent.

In performing the SMCA, five criteria themes and sixteen criterion maps[2] were included. The list of criteria established comprises a set of conflicting BRT feeder route suitability measures, which are often vastly different from one another. It was, therefore, successfully proven that SMCA does have the ability to handle many different criteria that are often contradictory, in a way that is transparent and automated, providing a much cleaner and streamlined approach to evaluating the built environment for compatibility with BRT feeder networks.

9.3.2. Transit-Oriented Approach (SMCA Part 2)

The second approach applied in this study involved the execution of an additional round of SMCA, in which there were only two input maps receiving an equal weighting of 50% each. The two criterion maps included the built environment composite suitability map and the associated public transport demand map. The suitability analysis could in fact have been completed in one round, in which the associated public transport demand map would feature as an input map along with the list of built environment criteria. The weighting scheme applied would address the importance of each factor in determining the overall suitability values for BRT feeder routes. For this reason, it is suggested that if this method were to be adopted in future, that only one round of SMCA is conducted in which the associated public transport demand features as a criterion, because it would be quicker and easier.

[2] Land Use, Building Density, Average Annual Household Income, Average Residential Density, Employment Opportunities, Presence of Vulnerable Road Users, Proximity to Environmentally Sensitive Areas, Proximity to Heritage Sites, Proximity to Landscape Parks and Recreational Facilities, Water Courses & Lakes, Private Car Ownership, Destinations, Proximity to Other Public Transport Facilities, Hazardous Routes, Presence of Pedestrian Infrastructure and Presence of Bicycle Infrastructure

The Transit-Oriented approach is very unique in the clear manner in which built environment characteristics are married with public transport demand to produce feeder bus routing, and this research is the first attempt to do so. This approach ultimately supports Transit Oriented Development through the direct inclusion of the elements defining the urban fabric as criteria in the route development, thereby insuring that the transport system is aligned to its spatial surroundings.

Unlike the built environment composite suitability map, the resultant suitability map obtained in round 2 provided a bigger range of suitability scores, with a minimum of 0.08 (least suitable) and a maximum of 0.91 (most suitable). As expected, the pixels containing high suitability scores were found within the polygon connecting Factreton and Century City, the O-D pair with the highest associated public transport demand. This outcome is very effective in illustrating the simplicity and transparency of the SMCA method, as the results obtained are logical.

9.4. Suitability Extraction

The next step in the analysis was to extract the average composite suitability scores along the existing road network using a Line Weighted Mean calculation. The existing road network is represented by line features in ArcGIS, so the actual width of each road segment is lost. The suitability scores are extracted strictly along the lines representing the road network, therefore, the choice of pixel size is critical in ensuring that the suitability scores of the area surrounding the road is accounted for, as a larger pixel size will encompass more land area.

One disadvantage of performing this exercise is that pixels in which there are no road segments are disregarded in the analysis from here on; meaning that inclusion of data for these areas is seemingly futile. Furthermore, modifications to the existing road network in support of more efficient BRT routes are not incorporated, as the analysis is strongly dependent on the existing road network used.

9.5. Network Analysis

The network analysis was performed by means of a least cost calculation based on the accumulative road segment impedance. The method followed was quantitative and transparent, thereby providing a method backed by facts as opposed to value judgement, and thus, it cannot easily be faulted. As public transport systems are often also a political issue, this approach is highly appropriate and useful.

9.5.1. Resultant Routes

Both approaches produced routes that traversed exactly the same paths, apart from Route 11 (Factreton to Montague Gardens). Even though the routes developed were very similar, the associated impedance values were significantly different. This was of course expected, as the composite suitability maps produced for each approach comprised a dissimilar range of suitability scores.

For both approaches, Route 7 (Joe Slovo to Century City) had the highest average impedance per kilometre. The route with the lowest average impedance per kilometre was, however, different in each approach. Route 4 (Montague Gardens to Century City) obtained the lowest average impedance per kilometre for the Built Environment Approach, and Routes 3 and 10 obtained the lowest average impedance per kilometre for the Transit-Oriented Approach. It should be noted that Routes 3 and 10 represent the same O-D pair, being Century City to Factreton and vice versa. These results allude to the conclusion that Route 4 falls within pixels that were not significantly affected by the addition of the associated public transport demand in the second methodology i.e. low demand route.

9.6. Prioritisation of Routes

When applying the first approach, the morning pubic transport demand was simply used to identify the O-D pairs for developing the potential feeder bus routes, and later in prioritising the routes developed. In the second approach, the public transport demand was used as a criterion in performing a second round of SMCA and was, therefore, already incorporated in the impedance values and consequently, the route assignment per O-D pair. As with the first approach, the public transport demand was also used for prioritising the routes developed. This resulted in a form of double-counting of the public transport demand in the second approach.

For the first approach, Route 10 (Factreton to Century City) was deemed the best performing followed by Route 8 (Joe Slovo to Montague Gardens), and Route 5 was the worst performing, even though this route is actually the reverse of Route 8. As the morning public transport demand was used, Route 5 may have performed better than

Route 8 should the evening public transport demand been utilised instead. The same results were obtained for the Transit-Oriented Approach, however, this could be expected as the corresponding routes in each approach belong to the same O-D pair and happen to traverse along the same path. On the other hand, should the paths traversed have been different for the same O-D pair, then the average impedance per kilometre would suffice as a means to select which path to adopt. That said, in future applications the network analysis operation can simply be performed for O-D pairs having the highest associated public transport demand to streamline and fast-track the process.

9.7. Comparison of Networks based on KPIs

The BRT feeder routes developed in this study were compared to the MyCiTi feeder bus routes falling within the study area to determine whether the research methods used provided an improved network. The MyCiTi feeder bus routes, however, have different start- and end-points to those used in this study, and thus, the areas served are slightly different. In hindsight, the use of either the same start- and end-points as the MyCiTi feeder routes, or a slightly larger study area so that all the same TAZ's covered by the MyCiTi feeder routes are included, could have provided a stronger base for comparison.

9.7.1. Average Travel Time

The average travel time was assessed using the goal average travel speed of 40km/hr. It is noted that this may differ in reality, due to local traffic congestion that causes a reduced average travel speed on a particular route. The application of this KPI could have been improved by including actual average travel speeds along a given route based on live traffic conditions.

After assessing the average travel time for the routes developed in this study and the MyCiTi routes in the study area, it was found that MyCiTi had a marginally lower average travel time, but all three sets of routes were around 12 minutes, which is acceptable. However, both Approach 1 and 2 comprised of 6 feeder routes, whilst MyCiTi only had 4 feeder routes and this does have an impact on the final results.

9.7.2. Coverage

When it came to coverage, MyCiTi out-performed the study routes. This outcome can be attributed to the SMCA process which included a large list of criteria resulting in some factors getting "lost" in the analysis, whereas the MyCiTi routes were based on a much smaller set of criteria, due to the manual nature of the route development. This effect could be mitigated through allocating factors, such as coverage, as a theme rather than a factor within a theme, and/or by assigning higher weightings. In this way, the important factors can be prioritised in the analysis procedure.

9.7.3. Directness

Again, when it came to directness of the routes developed, MyCiTi performed marginally better than the study routes. This could be attributed to the manual development of the MyCiTi feeder routes, which ensured that the most direct path was followed. The network analyst tool simply tried to minimise the accumulated impedance per route, which sometimes resulted in convoluted sections of a few routes. The size of the study area also influenced the number of possible paths available. This was the case with Route 10 and 11, as part of the road network was cut off resulting in a route that was more convoluted than it should have been.

9.7.4. Consideration of Environmental Factors

The development process of the MyCiTi feeder routes did not include any visible consideration of environmental factors. The SMCA approach used in this study did include a few environmental factors in a very transparent and systematic way. This demonstrated the ability of SMCA to ensure that the consideration of environmental factors is done in a clearly logical manner, thereby facilitating integration in the planning procedure.

9.7.5. Level of NMT Planning Inclusion

It was established that the MyCiTi approach to the development of its feeder bus routes did not appreciate the influence and importance of local NMT behaviour and infrastructure in a systematic and transparent way. This became evident in the implementation of the Atlantis feeder routes, which were highly contested by the residents.

Even though NMT infrastructure was included in the SMCA approach as highly weighted criteria; the level of inclusion could have been improved through the use of more comprehensive data on local NMT behaviour and trends. One such example, which is particularly relevant in crime ridden areas like Atlantis, would be to map hazardous locations in terms of crime and gang-related activities, and not only with respect to vehicle-pedestrian collisions.

As mentioned in *Section 8.7.5*, Hitge & Vanderschuren (2015) found that people were walking an average distance of 1.5 kilometres to access the MyCiTi BRT service. This distance is three times that assumed by the City of Cape Town in implementing the system, indicating that this assumption was too conservative. This also implies that NMT planning should have extended as far as 1.5 kilometres around each transit point as opposed to the 500 metres applied in practice.

All in all, the SMCA approach utilised in this study still provides a stronger method for ensuring that NMT receives the necessary importance in the route development process.

9.8. Sensitivity Analysis

The only part of the methodology that involved qualitative analysis was the weighting assignment of criteria in the SMCA hence, the susceptibility of the results to the weighting scheme used was tested by applying a different set of weightings. The results of this sensitivity analysis showed that the weighting scheme used had a minimal impact on the final results, as the difference in the networks developed was insignificant.

What is interesting to note, however, is that despite there being a 4% difference in the average weighted impedance of the sensitivity analysis network and the original network for the Transit-Oriented Approach, the routes developed were exactly the same. On the other hand, the Built Environment Approach resulted in a lower difference of just 1%, yet there was a difference in the paths traversed for Route 11. Overall, it can be concluded that the results obtained when following the original weighting scheme were reliable.

9.9. Relevance of Results to Industry

Raised environmental and social awareness seen around the world has driven campaigns to reduce dependency on the private vehicle, promoting greener modes of transport instead, such as public and non-motorised transportation. It was against this backdrop that the MyCiTi IRT system was first introduced to Cape Town, South Africa. Successful promotion of public and non-motorised transportation modes is highly dependant on the full appreciation of the unique characteristics associated with each mode. This presents a complex problem that calls for a planning tool capable of processing the multifaceted operational requirements of a multi-modal system, and traditional, over-simplified methods are not necessarily suitable for this cause. Furthermore, transportation planners in South Africa are faced with the unique challenge of having to overcome the Apartheid-entrenched urban fabric in its cities. The SMCA approach has proven more effective in appreciating the built environment characteristics and does so in a logical manner, unlike traditional transportation planning methods originating from developed countries, such as the United States and the United Kingdom.

The application of SMCA dates back to 1988 (Diamond & Wright) followed by Jansen and Rietveld (1990) and Carver (1990), all of which were conducted in Europe. Previous studies in this field included site suitability, urban and regional planning and transportation planning problems, however, this was the first successful case applied to BRT feeder bus routing. This study was also an extension of the research completed by Keshkamat (2007), in which the most suitable route was developed for the Via Baltica Corridor in Poland. His study used a given O-D pair and set out to find the preferred path for the highway. This research successfully expanded on his study through solving the routing problem for a number of O-D pairs and then prioritising the routes to be implemented. Furthermore, this was the second application of SMCA completed in South Africa, after Beukes (2011) applied this tool to the planning of three major arterials in Cape Town.

The use of SMCA supported by the Network Analyst tool in ArcGIS, as completed in this research, demonstrated that BRT feeder bus routes could be developed in a transparent and systematic manner that incorporates all built environment characteristics and public transport demand. When compared to the MyCiTi feeder bus routes, the routes developed in this study measure quite closely in terms of average travel time, coverage and directness. Based on the KPIs of level of NMT planning integration and consideration of environmental factors, the research routes are considered to out-perform the MyCiTi feeder routes.

When the two approaches used in this study are compared, the second approach performs better based on the KPIs of average travel time and directness. It is also considered the more appropriate method, as the associated public transport demand had a direct influence on the suitability and consequently, the impedance values used in determining the least cost path. It must be noted that should this method be applied in future, only one round of SMCA is necessary in which the demand features as a criterion. Furthermore, the sensitivity analysis revealed that, when a different set of weighting was applied, exactly the same routing results were obtained, thereby reinforcing the reliability of this method.

This research has shown that even though the use of SMCA in the planning of BRT feeder bus routes provides an immensely powerful advantage to transportation planners, the reliability of the results is greatly dependent on the quality of the data and choice of criteria utilised. The methodology presented in this thesis can be considered complex by some, thus it is imperative that the user understands the basic principles of BRT systems planning, and is capable of using ArcGIS or a similar GIS software programme.

Overall, it can be concluded that this tool provides transportation planners with an effective method for planning BRT feeder bus routes based on the numerous and conflicting criteria characteristic of such systems, in a systematic and transparent way. Furthermore, the benefits provided by this tool can be extended to the planning of:

- Pedestrian infrastructure,
- Bicycle infrastructure networks,
- Railway line routing,
- Tramway line routing, and
- Road network routing.

10. Conclusions and Recommendations

10.1. Introduction

This chapter presents an overview of the study undertaken. All results obtained and observations made are deduced in light of the research objectives of this work. In review of these conclusions, recommendations are then made in the effort of increasing the use of this method in industry, as well as improving any further research on this topic going forward.

10.2. Summary of Findings

The following conclusions were drawn from the analysis of the results obtained in this study.

10.2.1. Establish Key Performance Indicators for assessing the quality of the feeder bus routes developed in this study

A list of KPIs was established to assess whether the research results performed better than the actual MyCiTi feeder bus routes in meeting the objective of enhancing the level of integration in the planning procedure. The outcomes of this analysis demonstrated that similar results were achieved in terms of average travel time, coverage and directness. The research routes, however, excelled in the areas of NMT planning integration and consideration of environmental factors. Thus, it was concluded that the SMCA approaches provide enhanced benefits as similar operational efficiencies are attained compared to the MyCiTi feeder bus routes, over and above the added advantage of improved NMT planning inclusion and consideration of environmental factors. Moreover, it achieves these exceptional results in a transparent and systematic manner.

10.2.2. Define criteria to be considered in multi-modal transport systems

A set of criteria was defined that describes the impacts of the built environment on the routing of BRT Feeder services. This list of criteria, despite the presence of vast differentiation and conflict between criterions, was successfully incorporated into a

Spatial Multi-Criteria Analysis to produce a composite suitability map in which each pixel contains a value describing the appropriateness of including a BRT Feeder route through that specific pixel.

10.2.3. Test whether SMCA can enhance integration in transportation planning of BRT feeder routes

At present, limited research has been conducted on the application of SMCA in BRT network planning. This study managed to successfully demonstrated the ability of SMCA to enhance the level of integration in the planning of the MyCiTi feeder bus system, and consequently, in the MyCiTi Integrated Rapid Transit System. In so doing, it has broadened the level of research completed on the application of SMCA to transportation routing problems.

Two different approaches to solving the BRT feeder bus network in the study area, based on the composite suitability map, were successfully applied in the aim of finding a technique that is transparent, accurate and relevant, yet simple to apply in industry.

The urban fabric in South African cities is still deeply entrenched with Apartheid planning traits that attempted to use infrastructure to physically segregate previously disadvantaged communities from commercial and social opportunities. The SMCA approach has proven more effective in appreciating the built environment characteristics and does so in a logical manner, unlike traditional transportation planning methods - such as the Four-step Model - originating from developed countries, such as the United States and the United Kingdom. Furthermore, it has managed to clearly and logically integrate the built environment characteristics i.e. urban form, passenger demand and NMT modes of transport in the development of improved feeder bus routes.

10.2.4. Establish a BRT feeder network which marries built environment characteristics with passenger demand

This study managed to successfully establish two sets of BRT feeder networks, which was developed using SMCA-based approaches. The criteria on which the SMCA was based included a vast set of built environment characteristics along with that of NMT modes. In this way, the BRT feeder routes were produced based directly on the crucial traits and requirements of walking and cycling modes.

The resulting feeder bus networks were very similar, with only Route 11 traversing a slightly different path between the two methods applied. The Transit-Oriented Approach did, however, produce lower average impedance values per kilometre. In light of these findings, the Transit-Oriented Approach is deemed the stronger methodology, as it includes the public transport demand as a criterion in the SMCA, thus it has a direct influence on the final routing results.

The public transport demand was used as a means for prioritising the set of routes produced. However, it was concluded that the analysis could be streamlined by only solving the routes with the highest demand at the outset of the assessment. The demand is pivotal in the success of a route, thus O-D pairs with insufficient demand can be excluded early on in the process.

The sensitivity analysis illustrated that, when a different weighting scheme was applied, the results obtained were not significantly different. Therefore, the original results can be considered reliable.

10.3. Recommendations

After successful completion under scope of this study, the following are the recommendations pertaining to further research on the subject of this thesis.

- Due to compatibility of the software programmes required, it is highly recommended that all geographic modelling and mapping be executed in ArcGIS as opposed to QGIS. Additionally, the network analyst tool in ArcGIS allows the easy computation of the least cost path based on a user-defined impedance attribute, whereas QGIS requires a basic level of coding to be able to perform the same function.
- NMT user behaviour is complex and influenced by a number of conditions and factors that were not explored in this study, due to lack of data availability. It is, therefore, suggested that additional NMT characteristics, such as the mapping of local hazardous locations in terms of crime and gang-related activities, is incorporated as a criterion in the SMCA to improve the level of

NMT integration even further. Given the GIS based approach followed, this could be done through geo-coded data from police recorded crime and violence cases.

- This study set out to use SMCA for a BRT feeder bus route problem solving and did not consider the positioning of bus stops along the route. Thus, it is suggested to attempt utilising this tool for locating bus stops once the route has been established.

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Appendices

A1. Interviews

- Andre Frieslaar
- Gershwin Fortune
- Ronald Haiden
- Edward Beukes

Interviews

Name:	Andre Frieslaar	**Position:**	CEO: HHO Africa
Date:	25 April 2016	**Time:**	10:00 – 11:00

Planning of MyCiTi Phase 1A and 1B

The purpose of conducting this interview is to gain an understanding of the approach followed in planning the network and infrastructure provision for Phase 1A Trunk and Phase 1B Feeder Services. The information gathered in this interview will be used to inform my Master's dissertation which is based on the MyCiTi IRT System.

Q: When you think of an Integrated Transport System, what does it look like and what are its defining features?

A: Integration happens on a number of levels. Firstly, there should be modal integration where conflict between various modes are reduced or limited, such as providing safe crossing opportunities for passengers when getting to the station. Secondly the fare system should be integrated. Thirdly, there should be integration between cycling and pedestrian infrastructure with the MyCiTi stations to facilitate access to the system by using these modes; this would be in the form of extending cycle lanes and sidewalks within a 500m radius of the station. The other aspect of integration is for people with disabilities and making sure that they can access the station through installing dropped kerbs and ramps at the correct grade. There was also the aspect of integration with other public transport modes such as railway stations. For example, central station is located outside the Prasa Cape Town railway station.

Q: When implementing Phase 1A, which modes were included in the IRT System?

A: MyCiTi trunk and feeder services to Atlantis, cycling and pedestrian modes were included.

Q: What planning criteria were used to determine the routes for the following elements and in what sequence?

a) MyCiTi Trunk Service
b) MyCiTi Feeder Service
c) Bicycles
d) Pedestrians

A: For a trunk service, you want the most direct route between the origin and destination. Class 2 and 3 arterial routes were favoured as people are generally not found on a freeway or highway therefore access to the service would be limited compared to that on an arterial road. You also need enough road reserve to be able to install dedicated busways for the trunk. The decision of what route to be implemented first lay with the City of Cape Town and was not determined by HHO.

For the feeder service, the team looked at the coverage, where there was sufficient road reserve to allow priority infrastructure for the feeder buses should the road be too congested to maximise efficiencies. The feeder routes were tested using temporary poles for the bus stops before the permanent infrastructure was built and routes finalised. The routes were provided by the Client but the team was involved in the iterations to finalise the routes.

For NMT, the brief was to look at a 500m radius around each station other than the NMT facility which runs parallel to the trunk route along the R27 corridor which was provided to give people the freedom to choose their mode of travel. Key destinations within that 500m radius were identified to provide connection to the stations via the shortest path possible with pedestrian infrastructure and cycle lanes where possible. The class of NMT facility to provide was determined through looking at the available road reserve so a mixture of class 3 and 4 cycling lanes were mainly provided. No road widenings were made to add cycle facilities. The R27 NMT facility was a mixture of class 1 and 2 due to the high speeds. The NMT Department for the City of Cape Town was consulted in determining the NMT routes implemented

Given the routes/network, how was the level of infrastructure provision determined and how was the infrastructure prioritised between the elements below?

a) MyCiTi Trunk Service
b) MyCiTi Feeder Service
c) Bicycles
d) Pedestrians

A: The philosophy for Phase 1A was to provide as much priority to the MyCiTi services as possible so that high efficiencies are achieved through dedicated lanes in each direction. Where spec was limited, reverse lanes had to be implemented to give the buses priority at certain points along the route such as on Koeberg Road.

Traffic calming was implemented in the form of reducing speed limits, such as on the R27 from 70 to 60km/hr. Other measures such as speed humps and roundabouts were not implemented. Priority for pedestrians at intersections where stations were located was provided through block crossings.

An attempt was made to improve the environment in the station precincts by involving urban designers so that people were made aware that they are in a mixed use zone. This was done through changing the paving at these intersections and implementing tactile paving to warn the cyclists that they need to give priority to the pedestrians. Outside of the precinct, limited attention was given to improving the environment for NMT users and passengers.

Given the Phase 1A and 1B MyCiTi BRT routes, how was the treatment area defined for:

a) Bicycles
b) Pedestrians

A: A treatment area of 500m radius was applied equally to cyclists and pedestrians. The 500m radius was an instruction that came from the Client and was not determined by HHO. If a cycle lane existed outside of the treatment area this was connected to.

In your opinion, was the planning of each mode under the MyCiTi IRT System integrated?

a) If yes, then why?
b) If no, then how do you think it could have been improved?

A: For a first time approach, the planning approach was an improved effort compared to how transportation planning and implementation had been done in the past. Various specialists were consulted such as the UA specialist and the result was a very innovative and detailed approach. The project was a new and first step for the City of Cape Town Municipality and its residents and the progress that has been made in that respect is an achievement.

There is room for a more coordinated approach by the various departments responsible for the different elements of the MyCiTi system. Part of the challenge is that the IRT implementation department has more money to spend compared to others who are left doing more maintenance activities and this results in envy between departments who could worked together better otherwise.

Going forward there is also room for integration of the MyCiTi system with the surrounding environment and land uses where it becomes part of the character of the corridor in such a way that there becomes a hive of activity around public transport, whereas on the R27 corridor, a number of the stations are isolated from the surrounding activities. The outcome would be integrated land use transport precincts through better integration with urban and town planners.

Interviews

Name:	Gershwin Fortune	**Position:**	Director: IRT Planning
Date:	29 April 2016	**Time:**	10:00 – 11:00

Planning of MyCiTi Phase 1A and 1B

The purpose of conducting this interview is to gain an understanding of the approach followed in planning the network and infrastructure provision for Phase 1A Trunk and Phase 1B Feeder Services. The information gathered in this interview will be used to inform my Master's dissertation which is based on the MyCiTi IRT System.

Interlude

Trunk System:

- Aim to optimise average travel speeds between origins and destinations along the route to minimise the number of fleet required to serve a route
- Average speed is determined by the station spacing and rights of way (allowing the bus to operate in its own dedicated lane). In Meeting these two criteria there are only a limited number of classes of roads which will allow the desired average travel speeds leaving the options obvious. Between Tableview and Cape Town there are the following options:
    - R27 Marine Drive
    - Koeberg Road (Class 3) This would have entailed changing the entire character of Koeberg rd as intersections would have to be closed
    - N7, N1 This is a very high order of road but there are no people living there so boarding and alighting opportunities are limited
- Locating of stops/stations depends on land use, spacing, sufficient boarding and alighting opportunity, coverage (500m walking distance)

Feeder System:

- Criteria for identifying routes: Coverage, directness of routing, land use, NMT access, congestion along the route
- Received a high number of complaints for Atlantis due to safety and security concerns. Presence of gang war areas. The other problem is congestion. Impact of the taxi industry – assumed that taxi would be removed completely, in the end they continued to operate along the route.

Was the effect of the NMT environment that passengers would experience appreciated in the implementation of phase 1A?

Yes and no. NMT access around a stop was looked at within 500m walking distance. In terms of universal access, the stop is but beyond that is not. 500m was not viewed as enough.

The city is now investigating a hybrid model where the taxis are included to make up for the massive change between the peak and off peak demand. The taxis also perform a certain service in that they are able to infiltrate informal settlements where the MyCiTi bus cannot. But the level of service provided by the taxis needs to be improved first so there is no overcrowding is clean and safe to use.

The number of transfers should also be a criterion as people do not like to transfer and this deters them from using the system. The city is therefore moving away from a hub and spoke network through adding trunk route extensions which allows for the reduction of the number of transfers.

Q: When you think of an Integrated Transport System, what does it look like and what are its defining features?

A: It looked exactly like Adderley and Gardens Stations. A multimodal system is one where passengers can quickly and seamlessly move from one mode to another. There shouldn't be a clear division or boundary between the modes. No difference in ticketing systems, level of services must be the same, universal access (need to be able to transfer between modes easily), availability of other opportunities within the system so while waiting for the next mode you can shop or have a coffee. Integration happens within the station.

Q: When implementing Phase 1A, which modes were included in the IRT System?

A: NMT, Bus.

Q: What planning criteria were used to determine the routes for the following elements and in what sequence?

a) MyCiTi Trunk Service
b) MyCiTi Feeder Service
c) Bicycles
d) Pedestrians

A: The city had an NMT masterplan. Guiding strategies were developed to support integration between this plan and the MyCiTi routing. The existing master plan was used to inform where the feeder bus routes would go.

Given the routes/network, how was the level of infrastructure provision determined and how was the infrastructure prioritised between the elements below?

a) MyCiTi Trunk Service
b) MyCiTi Feeder Service
c) Bicycles
d) Pedestrians

A: This was also guided by the NMT master plan

Given the Phase 1A and 1B MyCiTi BRT routes, how was the treatment area defined for:

a) Bicycles
b) Pedestrians

A: The 500m walking distance came out of the ITP and on work done with the Infrastructure team. The aim was a 5min walking trip which equated to about 500m of walking distance. More recently the PTSIG also mentions a 500m walking distance.

Interviews

Name:	Ronald Haiden	**Position:**	Director: MyCiTi Infrastructure
Date:	26 April 2016	**Time:**	12:30 – 14:00

Planning of MyCiTi Phase 1A and 1B

The purpose of conducting this interview is to gain an understanding of the approach followed in planning the network and infrastructure provision for Phase 1A Trunk and Phase 1B Feeder Services. The information gathered in this interview will be used to inform my Master's dissertation which is based on the MyCiTi IRT System.

Q: When you think of an Integrated Transport System, what does it look like and what are its defining features?

A: It would be multi-modal, it would operate on certain corridors and have rights of way, and it should be able to penetrate into destinations and origins. Where the service has to operate in mixed traffic conditions it should not have to be stuck on congested roads because then it becomes inefficient and does not provide a privilege to its passengers over travelling by car or taxi. If various road based public transport vehicles are used in the system it should be integrated to allow easy transfer between vehicles at a station. There should be appropriate support services to bring people from the starting point of their journey to the trunk stations such as taxis or feeder buses, or otherwise sufficient NMT infrastructure should they wish to make the trip on foot or bicycle. At the moment there is not a great enough incentive for GABS buses and minibus taxis to take their passengers to a MyCiTi station for a transfer due to the difficulty in getting to the station as it is located at intersections and in the median which is not ideal for passengers who now have to be dropped of further away from the station and have to cross through an intersection to get to the station.

The system should also allow for integrated ticketing, something that is still a challenge for MyCiTi as these cards cannot be used on any other public transport mode, they can only be recharged at certain locations and the card expires after 3 years. The fare system should also reward you for making transfers to different modes such as from rail to bus compared to completing a trip using one mode only.

In South Africa, the various modes operate quite independently of one another with little transfer. Often passengers have their preferred mode of transport and will complete their journey using one mode or service so there is little transfer between rail and bus or minibus taxi.

Q: When implementing Phase 1A and 1B, which modes were included in the IRT System?

A: When starting with the initial planning of the MyCiTi system there were a number of goals the team wanted to achieve. The first was to raise the image of public transport in Cape Town as the rail service is often overcrowded, unsafe and dirty and the GABS is noisy, uncomfortable and inaccessible for people with special needs, likewise for rail. The transport system at that time discriminated against people with special needs and divided the city as was intended in the Apartheid era. TCT therefore wanted to transform the system to provide equal opportunities for all Capetonians.

The MyCiTi system was planned to replace the GABS and minibus taxis on the Phase 1A routes. MyCiTi feeder services and NMT modes were planned in support of the MyCiTi trunk service.

Q: What planning criteria were used to determine the routes for the following elements and in what sequence?

a) MyCiTi Trunk Service
b) MyCiTi Feeder Service
c) Bicycles
d) Pedestrians

A: Everything was planned together and not in isolation of one another so that a system was created in which modes complemented and supported one another. The focus of the planning was however the BRT and then the support network was developed around the BRT.

Planning parameters included mainly maximizing the coverage and the geometry of the road so that enough space was available to provide dedicated rights of way for the trunk buses and sufficient space for the feeder buses to manoeuvre through the area. Exposure to the people also had to be maximised so that ridership could be high enough by providing transport opportunities from where the people live to where they need to be i.e. work, shopping complexes, education facilities, etc.

Given the routes/network, how was the level of infrastructure provision determined and how was the infrastructure prioritised between the elements below?

a) MyCiTi Trunk Service
b) MyCiTi Feeder Service
c) Bicycles
d) Pedestrians

A: First MyCiTi Trunk, then feeder, pedestrians and cyclists.

Q: Given the Phase 1A and 1B MyCiTi BRT routes, how was the treatment area defined for:

a) Bicycles
b) Pedestrians

A: The treatment area was supposed to be a 500m walking distance and not a 500m radius as applied by HHO for Phase 1A. The 500m walking distance was a suggestion made by Ron Haiden based on his experience of this being a comfortable distance to walk from a transit station to a destination.

This was applied equally to the pedestrians and cyclists even though people would probably be willing to cycle longer distances than a pedestrian is willing to walk to transit.

Q: In your opinion, was the planning of each mode under the MyCiTi IRT System integrated?

a) If yes, then why?
b) If no, then how do you think it could have been improved?

A: When comparing MyCiTi to other international systems of similar kind, it is not as integrated as it can be with respect to NMT modes and the BRT system. Overseas, the pedestrian and bicycle routes and facilities are pleasant to use and the environment is much nicer and safer than here. The coverage of the system is much better than MyCiTi and there are a number of modes to choose from. Safe bicycle parking would be available within line of sight of public transport stations and there would always be sufficient lighting. Stations would also be located in a square with buildings facing onto it so visibility was always very good. The network coverage is so good that it wasn't necessary to use a car to make your trips.

However; based on the fact that this project was high pressure and the first of its kind in South Africa, the approach was as integrated as it could have been at the time.

Interviews

Name:	Edward Beukes	**Position:**	TCT: Principal Professional Officer
Date:	25 April 2016	**Time:**	10:00 – 11:00

Planning of MyCiTi Phase 1A and 1B

The purpose of conducting this interview is to gain an understanding of the approach followed in planning the network and infrastructure provision for Phase 1A Trunk and Phase 1B Feeder Services. The information gathered in this interview will be used to inform my Master's dissertation which is based on the MyCiTi IRT System.

When you think of an Integrated Transport System, what does it look like and what are its defining features?

When implementing Phase 1A and 1B, which modes were included in the IRT System?

Which planning criteria were used to determine the routes for the following elements and in what sequence?

a) MyCiTi Trunk Service
b) MyCiTi Feeder Service
c) Bicycles
d) Pedestrians

A: Firstly, land use developments plans were developed to project how the city would develop going forward: Business as Usual, Pragmatic Densification Scenario, Pragmatic Transit Development Scenario. The latter was used for the long term planning of the IPTN.

The land use model was very static and was not dynamic so changes in development trends could not easily be tested in the model.

A Household travel survey was conducted for the city of Cape Town which aimed at capturing what people's existing travel habits are. From this survey, the status quo could be understood and the results were used to build a transport travel demand model with a base year of 2013.

Based on the model outputs, corridors were identified where the travel demand was great enough to warrant the provision of a trunk bus service. The feeder routes were then determined to support the trunk route and feed passengers to the trunk stations where they would board onto a higher speed, direct service.

A number of the routes implemented were chosen based on personal experience and knowledge of travel patterns in certain areas. Certain routes were therefore obvious choices based on this knowledge. In practice, the feeder services have posed the greatest challenge as some routes did not perform as well as expected and the permanent infrastructure built have gone to a waste as a result of these services having been cancelled. This was particularly the case in Atlantis where the residents complained about the routes implemented as all commuters were forced to use MyCiTi because GABS and minibus taxi services were bought out for Atlantis. The approach that ensued thus involved a great deal of workshops with the community to revise the routes. The lesson learnt from this is that a community centred approach is necessary to ensure that the commuters are satisfied and to maximise ridership.

Overall the planning process adopted was a very manual data driven approach.

A2. Difficulties Faced

A number of difficulties were incurred during the analysis process and these were largely due to the choice of GIS software. Most of the previous literature on SMCA involved the use of ArcGIS for the preparation of the base criteria maps thus it was opted to try using QGIS instead.

This, however, resulted in the following challenges:

- QGIS could easily be used for the rasterization of polygon and line maps. However, point maps would often not represent the vector data it was converted from.
- Due to the challenge of rasterizing point maps, it was decided to import the vector maps into ILWIS and perform the raster conversion using this program instead. Polygon, line and point maps could easily be rasterised in ILWIS, however, pixels in which there were no data values were assigned question marks and left empty. When the SMCE operation was performed using these raster maps, the composite suitability map produced was a blank map containing no values in each pixel. This is when it was decided to redo the rasterization task using ArcGIS in which no data pixels are assigned a value of zero and these could be read in ILWIS to produce the composite suitability map.
- In order to extract the suitability values along the existing road network Hawth’s tool had to be used to perform a line weighted mean operation. However; this tool was replaced by Geospatial Modelling Environment (GME), which is only compatible with ArcGIS. QGIS does offer a network analysis tool, which can determine shortest paths based on distance or travel time. However, this tool does not allow for another attribute, such as the Impedance value, to be used as the basis for the calculation.

A3. Ethics Form

EBE Faculty: Assessment of Ethics in Research Projects

Any person planning to undertake research in the Faculty of Engineering and the Built Environment at the University of Cape Town is required to complete this form before collecting or analysing data. When completed it should be submitted to the supervisor (where applicable) and from there to the Head of Department. If any of the questions below have been answered YES, and the applicant is NOT a fourth year student, the Head should forward this form for approval by the Faculty EIR committee: submit to Ms Zakiya Chikte (Zakiya.chikte@uct.ac.za); New EBE Building, Ph 021 650 5739).

Please note – it is important to keep a signed copy of this form as students must include a copy of the completed form with the dissertation/thesis when it is submitted for examination.

Name of Principal Researcher/Student: CARO-JOY BARENDSE **Department:** CIVIL ENGINEERING

If a Student: **Degree:** MSc Civil Engineering **Supervisor:** A Prof Marianne Vanderschuren

If a Research Contract indicate source of funding/sponsorship:

Research Project Title: Enhancing Integrated Transport Planning A spatial Multi-criteria Analysis Approach to the MyCiTi Integrated Rapid Transit System, South Africa

Overview of ethics issues in your research project:

Question 1: Is there a possibility that your research could cause harm to a third party (i.e. a person not involved in your project)?	YES	NO X
Question 2: Is your research making use of human subjects as sources of data? If your answer is YES, please complete Addendum 2.	YES	NO X
Question 3: Does your research involve the participation of or provision of services to communities? If your answer is YES, please complete Addendum 3.	YES	NO X
Question 4: If your research is sponsored, is there any potential for conflicts of interest? If your answer is YES, please complete Addendum 4.	YES	NO X

If you have answered YES to any of the above questions, please append a copy of your research proposal, as well as any interview schedules or questionnaires (Addendum 1) and please complete further addenda as appropriate.

I hereby undertake to carry out my research in such a way that

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

Signed by:

	Full name and signature	Date
Principal Researcher/Student:	Caro-Joy Barendse	05/02/2016

This application is approved by:

Supervisor (if applicable): M Vanderschuren		16/2/16
HOD (or delegated nominee): Final authority for all assessments with NO to all questions and for all undergraduate research.		16/2/16
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.		16/2/16

NEW STUDENTS
UNIVERSITY OF CAPE TOWN

Faculty of Engineering & the Built Environment

MEMORANDUM OF UNDERSTANDING

between the

POSTGRADUATE STUDENT AND SUPERVISOR

The intention behind the MOU is to clarify 'up-front' the agreed roles and responsibilities of both candidate and supervisor, to ensure that the supervision experience is as mutually productive as possible.

The MOU must be completed by masters and doctoral candidates within six months of initial registration, or at the start of the dissertation/project in course-work masters degrees. The Annual Progress Review, where relevant, must be completed each subsequent year, to be submitted not later than the 15th October.

Both supervisor and candidate are strongly urged to read the *Faculty Handbook for Research Based Education*, prior to completing this agreement.

For students registered for the 60 credit minor dissertation , items marked with *** are optional.

Final sign-off for masters candidates is the HoD, and for PhD candidates, the Dean/Dean's nominee.

Three copies of the MOU should be signed: one for the candidate, one for the supervisor; one for the HOD / the Faculty Office.

Please note that you may access OpenUCT at the following link - http://open.uct.ac.za/

Memorandum of Understanding between

Cara-Joy Barendse (name of postgraduate student)

(signature)

0-/0-/2016 (date)

and

A. Prof Marianne Vanderschuren (name of supervisor)

(signature)

16/2/16 (date)

Tick one of the following:

Doctorate	Masters (full thesis) 180 credit	Course-work/research Masters 120 credit ✓	Coursework Masters with minor dissertation 60 credit

A. CANDIDATE AND SUPERVISOR DETAILS:

*(*** Indicates optional for 60-credit Minor dissertations.)*

A.1	**Full name of candidate**	Cara Joy Burendse

A.2	**Academic and professional qualifications:***
	BSc. Civil Engineering (UCT)

A.3	**Full-time or part-time. Please specify.**
	~~Full-time~~ Part-time

A.4	**Thesis/dissertation title:**
	Enhancing Integrated Transport Planning: A Spatial Multi-criteria Analysis Approach to the MyCiTi Integrated Rapid Transit System, South Africa

A.5	**Personal particulars:**	
	(a) Student number:	BRNCAR017
	(b) Address:	3 St Stephens Rd, Pinelands, 7405
	(c) Email:	cara-joy.burendse@rhdhv.com
	(d) Telephone no(s):	0761 61 6492
	(e) Fax no:	

A.6	**Supervisor:**	
	(a) Title, Initials and Surname:	A Prof Marianne Vanderschuren
	(b) Staff no:	
	(c) Department:	Civil Engineering

A.7	**Co-supervisor (s) if any:**	
	(a) Title, Initials and Surname:	
	(b) Department:	
	(c) Institution:	
	(d) Responsibilities:	

B. SUPERVISOR'S EXPECTATIONS AND ARRANGEMENTS:

B.1	**Supervisor's expectations:**
	The supervisor must set out what he/she expects of the candidate in terms of reaching certain milestones or goals during the course of the research.
	Monthly progress reports

	Other expected milestones or goals: • •

B.2	**Supervisor's plans and commitments:**
	The supervisor must set out his/her plans for providing supervision, including the pattern and intended frequency of meetings:
	Availability via mail, phone Skype, and Face to -face

B.3	**Supervision arrangements:**
	(a) Expected absence of supervisor(s) on leave/sabbaticals (giving arrangements for supervision if away for more than 2 months in any one year), or conference attendance during the next 3 years***
	N/A
	(b) Field work: Outline arrangements for field work:
	No field work required
	(c) Laboratory work: Outline expectations of the lab work component of the project as well as lab arrangements (if any) and supervision arrangements for lab work:
	No lab work required
	(e) Estimated timing of formal seminars:***
	N/A
	(f) Access to computers and software:
	None required

	(g) Responsibility for payment of costs (printing, stationary, photocopying, etc):
	Student's responsibility
	(h) Teaching commitments by the student and details of remuneration:***
	None required
	(i) Courses and classes:*** List any class, workshop or course that the student must attend as a pre-requisite and costs associated with this. Clarify the responsibility for costs associated with these (if any)

B.4	**Co-Supervisory roles (if applicable):** The role of co-supervisors should be clarified. It should be noted that all co-supervisory suggestions and proposals should be reported back on, and discussed with, the primary supervisor.
	N/A

B.5	**Funding plans:** Specify any approved financial assistance to be provided, or organized, by the supervisor(s) to support this study (e.g. bursaries, teaching allowance etc.).
	Student responsibility.
	If, on withdrawing or being refused re-registration, the student becomes contractually obliged to repay any of the above, **this should be noted below**. Funding from external agencies may stipulate such a provision.
	Please note that most bursaries require re-payment if the degree is not completed. The student is responsible for discerning this from the bursary conditions, so please take note of this before accepting the bursary.

C. EXPECTATIONS AND PLANS OF THE CANDIDATE:

C.1	The candidate must set out in as much detail as he/she can, what he/she expects of the supervisor and the department
	I expect to receive support in the form of feedback on submitted work.
C.2	Comment by supervisor on this:
	Agree
C.3	The candidate and supervisor must set out their agreed plan and broad timetable for the dissertation. The candidate should be informed on the Faculty's maximum time limits for completion.***
	Monthly
C.4	Agreed date of completion is: 01 August 2016

D. INTELLECTUAL PROPERTY ISSUES:

D.1	As the student, by signing this document, I confirm that I have read the UCT IP Policy http://www.uct.ac.za/about/policies/.
D.2	Who funds the research (exclude bursaries)?
	Department of Transport & Public Works
D.3	In terms of the funding arrangement, has the IP been assigned to the funder (i.e. either because the full cost model has been applied to the project, or in terms of a research contract)?
	YES / ~~NO~~ (delete the non applicable)
D.4	In terms of the IP Rights from Publicly Financed Research and Development Act, the Student and Supervisor acknowledge that in all cases where the answer to D.3 is "No" there is an **obligation to disclose** an invention to Research Contracts and IP Services with 90 days of the discovery, using an Invention Disclosure Form (download from www.rcips.uct.ac.za/ip/overview/). There is an obligation to maintain the invention confidential within UCT until the IP has been evaluated by RCIPS to determine its ability to be protected. RCIPS should be contacted well in advance of any planned public disclosure, such as presentation at an external meeting or conference, publication in a journal, submission of an abstract, publication on a website or blog and the submission of a thesis for examination.

D.5	In terms of the UCT IP Policy, the university owns the IP arising from postgraduate research (unless ownership has been assigned to a third party), this includes inventions, discoveries and other developments of a technical nature whether or not these may be the subject of legal protection, as well as tangible research property arising from research activities such as prototypes, drawings, designs and diagrams, biological organisms and material, reagents, integrated circuit chips, software and data.
D.6	Copyright in a dissertation of thesis vests in the student who has written the dissertation or thesis, subject to the rights of the University provided in rules for degrees, diplomas and certificates. In terms of Rule GP8, when presenting a thesis for examination, a candidate shall be deemed by so doing to grant free license to the University to publish it in whole or in part in any format that the University deems fit. The student takes note of this requirement should they enter into an agreement with a publisher to publish their thesis.
D.7	The University assigns the copyright of all scholarly and literary publications to the authors of such works refer to policies in handbooks for authorship issues.
D.8	Graduate students often use data that belongs to the University, or a research group, or an external party. Any issues relating to data ownership should be noted here:

E. ETHICS IN RESEARCH:

E.1	**Assessment of ethics in research:** All research projects in the EBE Faculty are required to complete the **Assessment of Ethics in Research Projects** form. This form, together with the required procedure, is available online at http://www.ebe.uct.ac.za/research/ethics/
	(a) Have you completed and submitted the 'Assessment of Ethics in Research Projects' form?
	YES / NO
	(b) If you answered NO to (a), please indicate when you expect to submit this form:
	(c) If you answered YES to (a), did your form require a sign-off by the Ethics in Research Committee?
	YES / NO
	(d) If you answered YES to (c), what was the date on which you received approval from this committee?
	Please note that a dissertation submitted without ethics clearance, obtained beforehand, will not be marked.

F. PRESENTATION OF RESEARCH FINDINGS AND AUTHORSHIP:

F.1	Publication must give appropriate credit to all authors for their roles in the research. Authorship allocates credit to those involved in the research and also allocates responsibility for the integrity of the research and its publication. Authorship practices should reflect the integrity of the research process by honestly indicating the actual contributions to the publication. The reputation of both the institution and individual researchers is negatively affected by poor authorship practices. When more than one person is involved in research, an ethical judgment must be made as to who should be included as an author and as to the sequence of names of the authors on the publication.

- All external presentations and publications centred on the student's research must be agreed with the supervisor, and Project Leader where project is externally funded, before commitment and their content agreed before delivery. This includes submission of papers for conferences and for publication in refereed journals, submission of popular science articles related to the research and presentation of research to third party with commercial or other interest in the work.
- The student agrees to co-operate and work with their supervisor in the preparation of journal and conference papers concerning their work, as part of the academic process.
- The authorship guidelines of UCT detailed in the Authorship Practices Policy will inform authorship of all publications prepared on the work covered in the thesis. The essence of these guidelines, extracted from UCT's authorship guidelines, is summarised below:

"An author is someone who makes a **significant or substantial contribution** to the production of the publication. The precise meaning of 'significant or substantial contribution' may be discipline-specific but is commonly understood as requiring that **1) each author should have participated in formulating the research problem, or analysing and interpreting the data or have made other substantial scholarly effort or a combination of these; and/or 2) have participated in writing the paper; and 3) should have approved the final version for publication and be prepared to defend the publication against criticisms."**

- Specific agreements with respect to authorship should be noted below:

G.	**Any requirements specific to a department should be noted here:**
	None required

H.	**SOCIAL MEDIA**
	While EBE welcomes and encourages open discussion on social media sites, including but not limited to Facebook, Twitter, LinkedIn, YouTube pages, online story-sharing forums and blogs- as a student, by signing this document, I accept that information posted on any of the social media platforms should not include: • abusive, harassing, defamatory or hurtful comments about any student or member of staff • foul or threatening language or "hate speech" • material that may infringe on any patent, copyright or intellectual property

Please confirm that the student is still registered for the appropriate qualification (MPhil or MSc) and that the nature of the research is in keeping with the guidelines for the Master of Philosophy or the Master of Science

I. OBSERVATIONS BY THE HOD/ DEAN/DEAN'S NOMINEE:

I.1	**OBSERVATIONS BY THE HOD**	
	I have reviewed this completed MoU am satisfied that it reflects the shared understanding of supervisor and candidate and that the department is able to meet the obligations to candidates set out in this MoU:	
	Signed:	
	Name:	
	Date:	

I.2	**OBSERVATIONS BY THE DEAN/DEAN'S NOMINEE (PhD candidates only)**	
	I have seen this completed MoU and I have the following comments:	
	Signed:	
	Name:	
	Date:	