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# Getting people out of their cars:

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**A case study on Cape Town's Phase 1A - Bus Rapid Transit starter route  
and the potential impact of a modal shift on the carbon footprint**

## **Master's Dissertation**

Submission in partial fulfillment for the degree of:  
Master of Philosophy in Environmental Management

August 2011

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## Acknowledgements

I would like to extend my sincere gratitude to the following people, without whom this Master's dissertation would not have been possible:

First, and foremost, I would like to thank my supervisor, Dr. Yvonne Lewis, for always making herself available and for providing a much-needed sounding board during this research. I appreciate her patience in reading and reviewing my various drafts, as well as her guidance and wisdom in compiling this research. This dissertation most certainly would not have been possible without her assistance. I would like to also extend my sincere gratitude to my co-supervisor, Dr. Richard Hill, whose continued support throughout my postgraduate studies has been invaluable. In addition, I would like to acknowledge his detailed and constructive comments for this research, which provided a very positive contribution to this work.

I am also eternally grateful for the staff at the Environmental and Geographical Sciences Department at the University of Cape Town, who've expanded my horizons and inspired me to work hard. In particular, I would like to acknowledge Dr. Pippin Anderson and Associate Professor Merle Sowman for enriching my learning experience and for always having an open door to assist in brainstorming and troubleshooting. You are both extraordinary assets to the EGS Department.

In addition, I would like to thank several people at the Centre for Transport Studies at the University of Cape Town, who provided essential input for conducting my stated preference survey. I extend my gratitude to Dr. Marianne Vanderschuren, who offered her generous assistance in the initial design process and explained the fundamentals of the stated preference methodology. Further, I would like to thank Associate Professor Romano Del Mistro and Doctoral student Ms. Dorothy Kobel, who extended their warm welcome to discuss the findings of my research. In particular, I would like to acknowledge Ms. Kobel, whose assistance analyzing data was a crucial component for completing this study. I would also like to thank Associate Professor Roger Behrens for meeting with me and for providing a deeper context for my research.

Thank you to Mr. Greg Distiller from the Statistics Department at University of Cape Town for his consultation during the data analysis phase of this research.

I would also like to thank various government staff members at the City of Cape Town, who provided the majority of secondary data used in this research. In particular, I would like to thank Ms. Niki Covary at the Department of Transport who played an essential role in obtaining the data required for completing this project. I would also like to thank Mr. E. John Spotten at the Department of Transport for providing necessary traffic count and bus rapid transit data. Further, I extend my gratitude to Ms. Karen Small at the Statistics and Population Census Department, for providing the detailed population and income data used in this research.

Additionally, I would like to express gratitude to my classmates for their support and friendship during my studies. In particular, I would like to thank Samantha Jenner and Gina Avlonitis, whose comradery and contagious work ethic inspired me every day.

Lastly, and most importantly, I'd like to thank Coilin Parsons, whose unwavering moral support and encouragement pushed me to cross this finish line.

## List of Acronyms and Abbreviations

ASIF	(A) transport activity; (S) mode share; (I) fuel intensity; (F) fuel type
AWG-LGA	Ad-hoc Working Group on Long-term Cooperative Action under the Convention (UNFCCC)
AWG-KP	Ad-hoc Working Group for Further Commitments for Annex-I Parties under the Kyoto Protocol
BRT	bus rapid transit
CBD	Central Business District
CDM	Clean Development Mechanism (under the Kyoto Protocol)
CDM-PDD	Clean Development Mechanism - Project Design Document
CH <sub>4</sub>	methane
CNG	compressed natural gas
CO <sub>2</sub>	carbon dioxide
CO <sub>2</sub> e	carbon dioxide emissions
DEFRA	Department for the Environment, Food and Rural Affairs (UK)
ECAP	Cape Town Energy and Climate Change Action Plan
EF	emissions factor
HOV	high-occupancy vehicle
IEA	International Energy Agency
IDP	integrated development plan
IMEP	Integrated Metropolitan Environmental Policy
IPCC	Intergovernmental Panel on Climate Change
IRT	Integrated Rapid Transit
ITP	Integrated Transport Plan
ITS	intelligent transport systems
kg	kilogram
km	kilometer
km/hr	kilometers/hour
L	liter
LL	log likelihood
LRT	light rail transit
MNL	multinomial logit
MVRLO	Motor Vehicle Registration & Licensing Office
N <sub>2</sub> O	nitrous oxide

NGO	nongovernmental organization
NHTS	National Household Travel Survey
NMT	non-motorized transport
O <sub>3</sub>	ozone
OD	origin/destination
ROW	right-of-way
RP	revealed preference
DEAT (DEA)	formerly the Department of Environmental Affairs and Tourism - now Department of Environmental Affairs (South Africa)
SADoT	South African Department of Transport
SDF	spatial development framework
SEA	Sustainable Energy Africa
SP	stated preference
tCO <sub>2</sub> eq	tons of carbon dioxide equivalent
UCT	University of Cape Town
UNFCCC	United Nations Framework Convention on Climate Change
USDOT	United States Department of Transport
US EPA	United States Environmental Protection Agency
VKT	vehicle kilometers traveled
WCED	World Commission on Environment and Development, also known as the Brundtland Commission
WWF	World Wildlife Fund

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## **Abstract**

Anthropogenic (human-produced) greenhouse gas emissions are largely believed by climate scientists around the world to be the main contributor to climate change. Further, experts predict that if sufficient action is not taken to reduce the carbon footprint, climate change will have significant, negative impact on the environment in the future. Transportation, in particular, is responsible for one fourth of the world's greenhouse gas emissions. Characterized by an urban form of low-density, urban sprawl, the City of Cape Town has a high demand for transport, with 27% of its total carbon footprint attributed to transportation. This figure is projected to nearly triple by the year 2050. With car ownership increasing at a rate of 3.4% per annum, the City faces significant challenges in achieving sustainability targets in the future. As a measure to reduce the number of trips made by private vehicles, the City has recently begun implementing a multi-modal public transportation system, known as the Integrated Rapid Transit network. The initial stage of the transportation network, Phase 1A, features a bus rapid transit starter service, which became operational in May 2011. Using a stated preference survey, this study sought to determine what percentage of car trips would be avoided as a result of the Phase 1A - bus rapid transit starter service. Secondly, a scenario-based approach was used to compare the findings of the stated preference survey, which projected a 35% modal shift, with the 10% modal shift projected by the City of Cape Town. In terms its impact on the carbon footprint, this research suggests that neither modal shift is environmentally sustainable in the absence of other mitigation measures.

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# 1 Introduction

## 1.1 Background: climate change, transportation and Cape Town's carbon footprint

Anthropogenic (human-produced) greenhouse gas emissions are largely believed by climate scientists around the world to be the main contributor to climate change (IPCC 2007). Further, experts predict that if sufficient action is not taken to reduce the carbon footprint, or amount of greenhouse gases emitted into the atmosphere, climate change will have significant, negative impact on the environment in the future (UNFCCC 2010b). The transportation sector alone is responsible for roughly one-fourth of the world's carbon dioxide (CO<sub>2</sub>) emissions, and its contribution is projected to increase at a rate of 2-3% per year for the next three decades (Zegras 2007, p. 5136). To prevent this alarming trend from continuing, the international community has proposed a variety of mitigation measures to reduce emissions from the transportation sector, among others. While establishing legally-binding commitments for reducing emissions have proven to be difficult in the international arena, many national and local governments around the world are increasingly recognizing their critical role in reducing emissions.

The City of Cape Town, in particular, has demonstrated its commitment to sustainable development, defined in the Brundtland Report (WCED 1987) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Due to a lasting legacy from Apartheid city-planning policies in which different racial groups were placed at great distances from one another, Cape Town has an urban form characterized by "low-density sprawl, fragmentation and separation", as well as inefficient use of space (Donaldson 2006, p. 344). As a result, the demand for transportation is significant, and contributes 27% of the City's carbon footprint (UCT, SEA 2011).

The City has established a range of plans and policies underscoring a holistic, integrated approach to mitigating climate change (City of Cape Town 2009a, 2009b, 2010b). Among other development policies, its Integrated Transport Plan (ITP) (2009) establishes the Integrated Rapid Transit (IRT) network, which aims to join together the City's existing modes of transport, including rail-based and road-based services. Its principal component for transforming road-based public transportation is to establish dedicated lanes for a bus rapid transit (BRT) system (City of Cape Town 2009b, p. 301), a mode of transport that has shown significant results reducing emissions from private transport. The IRT will roll out in four main phases (1 through 4), beginning with Phase 1A. The initial segment of IRT Phase 1A, which became operational during the course of this study, features a dedicated BRT 'trunk' route extending from the Central Business District (CBD) to the Northern Suburbs (see Figure 1-1 on page 2). These routes will eventually be accompanied by several additional bus feeder services (City of Cape Town 2010a, pp. 20-25).

In line with sustainable development goals and greenhouse gas mitigation efforts, the aim of this research is to determine the impact of the IRT, and specifically that of the Phase 1A - BRT starter service, on the carbon footprint of Cape Town. The most significant parameter for the BRT to reduce the carbon footprint is the number of private cars trips the BRT is able to prevent. With this in mind, this research examines the impact of a modal shift from private transport to the BRT on the carbon footprint. This process is undertaken in two steps, as described in Section 1.2 below.

## 1.2 Scope and rationale of research

### 1.2.1 Scope

This focus of this research is geographically confined to the urban areas near the Phase 1A - BRT starter route, which extends from Cape Town CBD (indicated by a star in Figure 1-1) to the Northern Suburbs (Bayside stop). The carbon footprint examined in this study pertains to greenhouse gas emissions from car trips contained exclusively within the study area, which is shown in light blue in Figure 1-1. This research does not explore other sources of mobile emissions, such as additional, road-based public transport services offered by the minibus taxi and private bus industries. Further, this study does not include lifecycle emissions from the construction phase of the BRT infrastructure in its calculations.



Figure 1-1: Map of location and research study area - IRT Phase 1A

## 1.2.2 Rationale

Car ownership in the City of Cape Town is increasing at a rate of 3.4% per annum, a rate that is projected to continue through the year 2050 if significant action is not taken (UCT, SEA 2011, p. 11). This would more than triple the carbon footprint from passenger transport from current levels. The implementation of the IRT system has direct implications for Cape Town's climate change mitigation efforts. As the IRT system expands beyond Phase 1A, it is important to understand what modal shift targets will be necessary to reduce passenger transport emissions to sustainable levels. Further, it is essential to address the travel preferences of the car-driving population to implement a public transportation system that will suit their needs and induce a sufficient modal shift in the future.

## 1.2.3 Research Objectives

### 1) *Predict the size of the modal shift from private transport to the Phase 1A - BRT starter service*

The first objective of this research is to determine the probability that car drivers residing and working within the study area will shift to the BRT starter service. To achieve this objective, a stated preference (SP) survey is conducted among car users to assess their willingness to change their travel behavior. Data analysis from the survey provides the probability that existing car users will prefer to use the BRT once in service.

### 2) *Determine the change in greenhouse gas emissions as a result of the modal shift*

The second objective of this research is to calculate the impact of the projected modal shift on the carbon footprint of Cape Town. This is achieved through analysis of two scenarios. The first scenario applies the modal-shift projection from the City of Cape Town; the second scenario utilizes the projected modal shift from Research Objective 1.

To achieve Research Objective 2, baseline emissions from car trips must be established. Using a distance-based approach, this is achieved first through analysis of traffic count data to determine vehicle kilometers traveled (VKT) by cars within the study area. This is followed by identifying relevant fuel efficiency and emissions factors.

To calculate the avoided emissions from car trips, the number of car VKT are reduced according to modal-shift projections in their respective scenarios. Further, the scenarios include the added emissions from the BRT starter service, calculated based on specifications in the *Business Plan: Phase 1A of Cape Town's MyCiTi Integrated Rapid Transit System* (City of Cape Town 2010a), hereafter referred to as the 'Phase 1A Business Plan'. As well, specific BRT-related emissions data is use from the City of Cape Town's Clean Development Mechanism - Project Design Document (CDM-PDD) (Lopez 2008). Net emissions reductions are calculated by subtracting the added BRT emissions from the reduced car emissions.

## 2 Literature Review

### 2.1 Climate change and transportation

#### 2.1.1 The impacts of climate change and the need for an international commitment to sustainable development

As mentioned above, anthropogenic greenhouse gas emissions are considered to be the main contributor to climate change (IPCC 2007). The United Nations Framework Convention on Climate Change (UNFCCC), is the international body which seeks to stabilize emissions from anthropogenic causes to a level that “avoids dangerous human interference with the climate system” (Winkler 2007, p. 692). According to the UNFCCC (2010b) if left unchecked, the severity of impacts from climate change are expected to increase over time, “including sea level rise, shifts in growing seasons, and an increasing frequency and intensity of extreme weather events such as storms, floods and droughts”. Further, if the rise in average global temperatures exceeds 1.5-2.5°C, as is currently projected, scientists expect extensive melting of glaciers and 20-30% of species to risk extinction (UNFCCC 2010b). Climate change will also have substantial negative impacts on socioeconomic conditions across the world, and will pose potentially insurmountable obstacles to eradicating poverty in developing countries.

In an effort to mitigate the impacts of climate change, the UNFCCC calls for immediate and medium-term shifts in the global economy to energy-efficient, low-emissions alternatives across all sectors. Adopting the principles of sustainable socioeconomic and environmental development will require “stringent emission reductions” of anthropogenic greenhouse gases through various mitigation measures (UNFCCC 2010b). Reducing the carbon footprint requires targeting a number of greenhouse gases for reductions, including carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O) and ozone (O<sub>3</sub>) (IPCC 2007). These greenhouse gases are commonly referred to collectively in terms of their carbon dioxide equivalents (CO<sub>2</sub>eq)<sup>1</sup>.

In 1995, the Parties to the UNFCCC established the Kyoto Protocol as the key (and only) legally-binding international mechanism for reducing greenhouse gas emissions (Zegras 2007, p. 5139; Streimikiene, Girdzijauskas 2009, p. 130). Under the Protocol, Annex-I (developed) countries committed to thresholds for yearly emissions. These can be supplemented, among other measures, through funding of Clean Development Mechanism (CDM) projects in non-Annex-I (less-developed) countries, which promote sustainable development (Streimikiene, Girdzijauskas 2009). While the legal obligations under the Protocol are set to expire by the end of 2012, multilateral negotiations are underway to establish successive commitments from Parties<sup>2</sup>. While a legally-binding agreement has not been established post-2012, should the Parties reach a consensus, non-Annex-I countries will likely have increasing responsibilities for sustainable development in the years to come

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<sup>1</sup> “A metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential” (US EPA 2011)

<sup>2</sup> These talks are hosted by the Ad-hoc Working Groups on ‘Long-term Cooperative Action under the Convention’ (AWG-LCA) and ‘Further Commitments for Annex-I Parties under the Kyoto Protocol (AWG-KP) (UNFCCC 2011d).

(Raubenheimer 2007). The Copenhagen Accord, established at the Conference of the Parties (COP) 15 in December 2009, aims for Annex-I countries to become carbon neutral by the year 2050, and would allocate an approximate yearly limit of 1 tCO<sub>2</sub>eq per capita for non-Annex-I countries. This amounts for an 80% reduction in the global carbon footprint by the year 2050 (WWF SA 2010, p. 14; UNFCCC 2010a).

South Africa is a Party to the UNFCCC and a non-Annex-I signatory of the Kyoto Protocol (Raubenheimer 2007). Fulfilling its obligation as a signatory, South Africa previously submitted a National Climate Change Response Strategy (subsequently approved by the UNFCCC Cabinet in 2004) outlining national climate change mitigation strategies that emphasize the integration of cross-sectoral policies and inform relevant national and provincial legislation for greenhouse gas emissions reductions. Among other deliverables, the National Strategy underlines the obligation of South Africa to undertake greenhouse gas inventory of its various sectors, as well as ongoing monitoring of air quality (SA DEAT 2004). Under the Copenhagen Accord, South Africa has expressed a commitment to reduce emissions by 42% below a business as usual growth trajectory by the year 2025 (UNFCCC 2010a).

### **2.1.2 Understanding the role of transport in contributing to climate change and mitigation measures for reducing transport-related greenhouse gas emissions**

The transportation sector is currently responsible for roughly one-fourth of the world's greenhouse gas emissions, which are projected to increase at a rate of 2-3% per year for the next three decades (Zegras 2007, p. 5136). Passenger transportation alone is responsible for roughly two-thirds of this figure (p. 5135). While developed countries have contributed the majority of accumulated, anthropogenic greenhouse gases over the past century, estimates from the International Energy Agency (IEA) suggest that less-developed countries will contribute up to 63% of the world's transport-related greenhouse gas emissions by the year 2030 (Zegras 2007, p. 5136). Further, in a business as usual scenario, global road-based transport is projected to increase by 40% by the year 2030, and 90% by 2050 (Uherek et al. 2010, p.4799). This is fuelled, in part, due to projections of increased car ownership. As socioeconomic conditions in less-developed countries improve, experts predict a significant increase in personal vehicle ownership, further increasing greenhouse gas emissions from these countries (Kingham, Dickinson & Copsey 2001). This trend appears to hold true for South Africa as well. The South African National Household Travel Survey (NHTS) conducted in 2003 showed a strong positive correlation between income level and car ownership. As incomes increase in South Africa, car ownership is also expected to increase.

Various mitigation measures have proven to be effective in reducing trips made via private vehicles. A frequently used policy is to provide government subsidies for operating public transport, reducing the cost to the consumer per trip if they switch from private vehicle use (Basso et al. 2011, p. 679; Barrett et al. 2008). As well, establishing high-occupancy vehicle (HOV) lanes has proven to increase car sharing, further decreasing the mode share of private vehicles (Konishi, Mun 2010). Toll roads are also an effective measure for reducing car trips (Konishi 2010; Barrett 2008); another effective practice is to improve infrastructure for non-motorized transport (NMT), providing passengers an alternative to motor vehicles (City of Cape Town 2009c, p. 10). 'Congestion pricing' is another method for reducing car trips. This practice involves applying a tariff for driving private vehicles into designated areas, usually a city center or business district (Basso et al. 2011, p. 676; Konishi, Mun 2010; Liu, Triantis & Sarangi 2010, p. 597; Barrett et al. 2008). This specific method for

restricting car access is useful for effecting a “change in the modal split, moving commuters from cars to the transit system” (Basso et al. 2011, p. 679). While Basso et al. (2011) have shown that congestion pricing is far more successful at reducing car trips than standard transit subsidies, they admit, along with Konishi and Mun (2010) and Liu, Triantis & Sarangi (2010) that this concept is nearly impossible to implement from a political perspective. Only a handful of cities around the world, such as London and Stockholm, have successfully put this policy into practice (Konishi, Mun 2010; Liu, Triantis & Sarangi 2010, p. 597).

According to a large body of literature, the above measures are most beneficial when the public transport system has been ‘optimally designed’, which is the most effective means for reducing mode share of private vehicles (Sun, Zhou & Wang 2008; Laporte, Mesa & Ortega 2000; Leiva et al. 2010; Savage 2010; Basso et al. 2011, p. 677; Kingham et al. 2001, p. 154). The term ‘optimal design’ covers all aspects of public transit operations, such as the frequency of trips, capacity of vehicles, as well as the number and spacing between stops (Basso et al. 2011, p. 677). Discussions in the relevant literature indicate that the most effective component of optimal design is to provide a dedicated corridor exclusively for public transport vehicles, allowing for them to travel at higher speeds in less time (Sun, Zhou & Wang 2008; Laporte, Mesa & Ortega 2000; Leiva et al. 2010; Savage 2010; Basso et al., 2011). Referring to Mohring (1979), Basso et al. (2011) highlight the widely-held opinion that the speed of a transport mode is “one of the most important attributes of the system, and as such, it should be one of the central objectives of city planners, if they want to increase patronage” (Basso et al. 2011, p. 683).

Examining transport emissions from a more holistic perspective, much of the relevant literature highlights integration of planning policies to address transport issues. Specifically, to reduce emissions for passenger transport, it is paramount to understand the relationship between transportation needs and urban form (Barrett et al. 2008; Roy 2009; Owens, Cowell 2002; Uherek et al. 2010; Lee, Washington & Frank 2009). Among others, Barrett et al. (2008) and Roy (2009) discuss the need for transit-oriented development, which encourages urban densification along key transportation routes. This, they argue, increases the ridership base, and has been shown in Europe to reduce the need for private transport by 16% over a 20-year period (Uherek et al. 2010). Uherek et al. (2010) and Owens and Cowell (2002) further argue that effective (and integrated) policies for mixed land-use planning (versus single land-use plans, which are common in urban sprawl developments) can reduce the need to travel all together. Referring to the “inefficient land use pattern[s]” of low-density sprawl, Uherek et al. explain that by densifying urban areas to be more compact, people are more likely to live within walking distance to their desired destinations. They discuss further that if these policies were followed, the remaining number of car trips would be shorter than with low-density development. While they argue that “emissions decrease progressively with the increase of urban densities,” they suggest that the correlation is more evident in the case of energy consumption (Uherek et al. 2010). They suggest, rather, that such factors as “climate, fuel mix and industry activity are probably more important” to consider for greenhouse gas mitigation.

Lastly, Zegras (2007) discusses the various considerations to take into account when attempting to understand and curb transport-related energy consumption. Referring to Schipper, et al. (2000), he summarizes the key elements of transport-related energy use as being “a function of total activity (A), mode share (S), fuel intensity (I) and fuel type (F)” (Zegras 2007, p. 5137). Daily activities (A), he explains, are the core force behind transportation emissions and are influenced by a variety of factors such as, among others, population

demographics, including income and age, and existing urban form. Mode share (S), or percentage of daily trips attributed to available modes of transport, has a strong correlation with greenhouse gas emissions, given the varied fuel efficiency of vehicle types. Fuel intensity (I) refers to efficiency of vehicles. Lastly, market share of fuel type (F), such as diesel or gasoline, affects total greenhouse gas emissions. Addressing each of the ASIF components, he argues, is critical for reducing transport-related emissions.

## **2.2 Bus rapid transit**

A wide array of literature has highlighted the benefits of BRT as a cost-effective, efficient form of public transportation. This section discusses the unique characteristics of BRT and benefits of this mode of transport. The latter portion of this section highlights its potential for mitigation of greenhouse gas emissions.

### **2.2.1 Concept and definition**

The term 'bus rapid transit' refers to a collection of service attributes that apply to particular form of bus transport. While not all components are essential to consider a bus service as 'BRT', it is generally agreed to consist of a few essential components, as cited in a vast body of literature (Levinson et al. 2003; Hensher, Golob 2008; Levinson et al. 2002; Jarzab, Lightbody & Maeda 2002; Carey 2002; Wright, Fulton 2005; Hossain 2006). Its most distinguishing feature is the main, segregated 'trunk' route used exclusively for bus traffic, allowing for bus services to imitate fixed-route electric light rail transit (LRT). BRT vehicles operating on trunk routes are typically high-capacity vehicles, such as 12 m or 18 m articulated buses, which are often custom-built for quick loading and unloading of passengers. Lower capacity vehicles are often used as feeder services on mixed-traffic roads to connect lower-density residential areas with the main trunk route. Off-vehicle fare collection along the trunk routes is also a key feature of BRT, which involves passengers purchasing a ticket prior to boarding the vehicle. This ensures that passengers can board and de-board the bus quickly, minimizing waiting time at bus stops. To enable this process, enclosed boarding platforms are also a mainstay of the BRT, allowing customers to enter the boarding area only after payment. Rather than scheduled stop times, BRT systems often use intelligent transport systems (ITS) to monitor the distance between buses, maintaining a relatively high frequency of bus trips and thereby minimizing waiting time for passengers (Levinson et al. 2003). This also allows for flexible service provision; rather than having extreme lag times in off-peak hours, BRT services can be operated by smaller vehicles with lower load capacity and fuel requirements (Sun, Zhou & Wang 2008).

### **2.2.2 The debate between light rail transit and bus rapid transit systems**

Light rail transit (LRT) is a prominent and well-respected fixed-rail passenger transport system. At first glance, LRT often appears to be the most appealing alternative to the general public, a phenomenon not unknown to city planners. According to Hensher and Waters (1994) and Tirachini et al. (2010), an ongoing debate has ensued for decades among transport scholars regarding the costs and benefits of light rail transit (LRT) versus bus rapid transit (BRT). A few key issues form the crux of this debate, according to these studies. The first issue relates to consumer preference for one mode of transport over the other. The second issue relates to the relative speeds achievable by these transport systems. Cost is also an important factor, these studies argue, in particular those related to construction and operation. In reference to consumer preference, Hensher

and Waters (1994) argue that a misperception exists among city planners that consumers view LRT systems as being more stylish, and subsequently, a more appealing form of transit. The authors imply that while this may in fact be the general public opinion, when other factors such as speed and cost are included in the decision-making process, LRT systems fall short of their ridership projections in favor of BRT alternatives (p. 149). Further, the authors point out that when transfers and feeder routes are involved, riders prefer bus-to-bus connections, similar to most BRT systems, rather than bus-to-rail transfers which are implicit to many LRT systems (p. 155).

With regard to speed, as discussed in Section 2.2.3, many studies have shown that BRT systems can achieve similar and often faster speeds than their LRT counterparts (Levinson et al. 2003; Hidalgo 2009). Tirachini et al. (2010) admit that while some LRT systems can have an advantage in operational speed, waiting times and access to services are often superior in BRT systems (p. 240). However, they contend, when systems have shown to be overcrowded, the importance of vehicle speed increases (p. 240). However, when relating these issues to cost and benefits of BRT systems, Tirachini et al. (2010) argue that LRT falls short. In particular, they claim that the "high rail capital cost makes it a very unattractive investment for low level of demand" as is typical with low-density urban forms (p. 240). Hensher and Waters (1994) agree with this contention, pointing out that most LRT systems require extensive subsidies to implement and operate, whereas BRT systems are more economically viable. While the debate between LRT and BRT may never be put to rest, these authors have shown the clear benefits of a BRT system, in particular in urban areas with low population density.

### 2.2.3 History and current prevalence

The BRT concept has gained significant popularity since its inception nearly 40 years ago, with a growing presence across six continents<sup>3</sup>. The world's first BRT line began operation in 1974 in the Brazilian city of Curitiba. Its BRT network has been widely praised by heads of state and academics alike as a model for implementing BRT systems around the world (McManus 2006, p. 48; Satterthwaite 2007; Currie, Wallis 2008; Santos, Behrendt & Teytelboym 2010; Hensher, Golob 2008; Levinson et al. 2002; Jarzab, Lightbody & Maeda 2002). Faced with escalating automobile traffic and unchecked city growth radiating from its CBD, in 1965 Curitiba adopted a new master plan focusing on linear growth on key transport corridors, and used exclusive rights-of-way (ROWs) on the wide city boulevards to build dedicated bus lanes for the BRT (Goodman, Laube & Schwenk 2006, p. 75). Today, over 70% of the population in Curitiba uses the BRT to commute to work, 28% of whom previously drove their personal vehicle (p. 75).

Held in equally high esteem, the *Transmilenio* BRT network in Bogota, Colombia, serves as a prime example of a high-quality, efficient public transportation network (Levinson et al. 2003; Wright, Fulton 2005; Gilbert 2008, p. 453). It has been shown to carry more passengers per hour than many rail-based systems, with a maximum capacity of 35,000 passengers per hour (Hensher, Golob 2008). From a socioeconomic perspective, it has proven to be an effective tool through its contribution towards bridging social inequities (Gilbert 2008, p. 453). Santos, Behrendt & Teytelboym (2010) point out that achieving these remarkable results is due to

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<sup>3</sup> Estimates for number of BRT systems vary widely depending on the source and date of publication. The total number is likely well over 100 worldwide (Hidalgo 2009; Currie, Wallis 2008; Wikipedia contributors 2011; Lindau et al. 2008; Leiva et al. 2010; Munoz-Raskin 2010; Estupinan, Rodriguez 2008; Ponnaluri 2010; Khanna et al. 2010; Deb, Filippini 2010; Cervero, Kang 2010)

supportive planning and transport policies, and may be difficult to replicate without them. However, the majority of BRT systems across the world maintain high ridership levels, motivating more cities to establish BRT systems at an estimated growth rate of 4-6 cities per year (Kantor, Moscoe & Henke 2006, p. 90).

## **2.2.4 Benefits of BRT: reducing costs, travel times and emissions**

### *Financial viability*

Various benefits observed from BRT networks around the world speak to its viability as a socioeconomic and environmentally sustainable solution to Cape Town's transport problems. There is a broad consensus in available literature that BRT is a cost-effective solution for providing mass transit infrastructure (Levinson et al. 2003; Hensher, Golob 2008; Jarzab, Lightbody & Maeda 2002; Carey 2002; Hossain 2006; McManus 2006; Goodman, Laube & Schwenk 2006; Currie 2006; Falbel et al. 2006). Bus rapid transit has proven to be financially viable in areas of low density, where other forms of transport, such as rail-based options, are too expensive to operate (Levinson et al. 2003; Carey 2002; Falbel et al. 2006). Construction costs for a BRT line can be significantly less expensive than other forms of transport, making it a particularly attractive option for cities in developing countries (Gilbert 2008). In Bangkok, for example, construction of BRT infrastructure cost 1/16<sup>th</sup> of the cost to build the city's elevated SkyTrain (Hossain 2006, p. 76). Further, BRT infrastructure can cost up to 20 times less than an LRT equivalent, and between 10 to 100 times less than a metro rail-based system with the same coverage (Hensher, Golob 2008, p. 502). In addition to lower costs of construction, BRT systems can be rolled out more quickly than rail-based alternatives (Levinson et al. 2003, p.24; Levinson et al. 2002; Carey 2002).

### *Reduced travel times*

In addition to reduced costs, BRT networks have also proven to reduce travel speeds for designated trips. On average, BRT buses operate at higher speeds than city buses traveling in mixed traffic. They "generally save 2-3 minutes per mile"<sup>4</sup> on trunk routes, or 32-47% of total travel time (Levinson et al. 2003, p. 28). A study conducted by Currie and Graham (2006) highlights time savings for trips taken with BRT in Australian three cities: Adelaide, Sydney and Brisbane. Regarded as one of the "fastest urban transit systems in the world," BRT vehicles in Adelaide reach a maximum speed of 100 km/h, with an average speed of 80 km/h. Further, BRT services reduced the travel time along its route from 40 minutes to 25 minutes (38% reduction). Brisbane has experienced even more significant decreases in travel time, reducing a 60-minute trip to just 18 minutes (70% reduction). Sydney travelers have benefitted even further, with travel times reduced by at least one hour as a result of the BRT. It is important to note that while speeds can be drastically reduced along BRT trunk routes, time savings are far less significant for feeder services and systems that operate in mixed-traffic lanes (Levinson et al. 2003, p. 28). For example, several Asian BRT networks operating in mixed-traffic have an average speed of only 20 km/h (Hidalgo 2009, p. 39).

### *As a method for greenhouse gas mitigation*

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<sup>4</sup> 1 mile = 1.6 kilometers

BRT has been identified by transport experts as an attractive, 'near-term' strategy for reducing carbon emissions, especially those generated from work-related trips (Hensher, Golob 2008; Wright, Fulton 2005; Vincent, Jerram 2006; Nugroho, Fujiwara & Zhang 2010; Dung, Ross 2008). The city of Curitiba, for example, has found that it consumes 30% less fuel per capita than other similar-sized Brazilian cities without BRT, and has one of the lowest levels of ambient air pollution in the country (Goodman, Laube & Schwenk 2006, p. 76). It has been credited with reducing fuel consumption in the city of 2.2 million inhabitants by 27 million liters per annum (Goodman, Laube & Schwenk 2006). The potential of BRT to reduce the carbon footprint has been attributed to improved fuel efficiency of vehicles, a modal shift away from private vehicles, and centrally-managed dispatching technologies to maximize vehicle occupancies (Goodman, Laube & Schwenk 2006; Dung, Ross 2008; Gruetter Consulting 2006; Chongqing Municipality 2010; State of Mexico 2011). Vincent and Jerram (2006) point out that reduced boarding times from optimally-designed systems enable BRT vehicles to waste less fuel than standard city buses. In addition to this, traveling at optimal speeds improves fuel efficiency when compared to mixed-traffic city buses, reducing greenhouse gas emissions per km (Vincent, Jerram 2006, p. 222). Moreover, existing technology offers a variety of fuel-efficient BRT vehicle options. Among other available features, these can include compressed natural gas (CNG) engines, diesel engines equipped with catalytic converters to reduce air pollutants, as well as hybrid-electric diesel and "dual-power" trolley/diesel (Levinson et al. 2003, p. 24; Wright, Fulton 2005; Vincent, Jerram 2006, p. 225). As more efficient technologies come online, vehicles can be easily upgraded (Levinson et al. 2003; Wright, Fulton 2005; Vincent, Jerram 2006). In comparison with electric rail options, Vincent and Jerram (2006) highlight the potential for BRT to offer even greater greenhouse gas reductions. The reason, they imply, is that some electric rail systems (such as the Metrorail in Cape Town) are powered by inefficient forms of electricity-generation, such as the burning of coal. This is particularly relevant in South Africa, where 92% of electricity is generated from coal-burning (Letete, Guma & Marquard 2007). The implication here is that emissions factors from diesel and petroleum, the most commonly-used fuel to power most BRT vehicles, is lower than that of coal-burning electricity. Subsequently, powering a vehicle by petroleum or diesel shows greater potential for emissions reductions, versus electric rail vehicles that are powered by coal-based electricity generation.

The UNFCCC (2006) has an approved "Baseline Methodology for Bus Rapid Transit Projects", which provides a benchmark, step-by-step process for calculating greenhouse gas emissions attributed to implementing and operating BRT projects. Using this methodology, the fully-implemented BRT plans of Bogota, Chongqing (China) and Mexico City suggest a respective savings of 246,563 tCO<sub>2</sub>eq (UNFCCC 2011a), 218,067 tCO<sub>2</sub>eq (UNFCCC 2011b) and 145,863 tCO<sub>2</sub>eq per annum (UNFCCC 2011c). Using this same method of calculation, the City of Cape Town has projected an annual savings of 414,312 tCO<sub>2</sub>eq<sup>5</sup> after full implementation of their Integrated Rapid Transit (IRT) plan (Lopez 2008).

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<sup>5</sup> The City of Cape Town calculations were conducted in 2008 assuming a 20% modal shift from private vehicles and 50% shift from minibus taxis (Lopez 2008). The City has since indicated in the Phase 1A Business Plan that they project a modal shift of only 10% from private cars. Further, the long-term indications for the expanded IRT network are that it will "largely displace" services offered by minibus taxi and scheduled bus operators, effectively incorporating existing operators into the new IRT system (p. 5). No specific figures are given regarding a projected modal shift from minibus taxis to IRT system.

## **2.3 A closer look at Cape Town: its response to climate change, the carbon footprint and reducing emissions from passenger transport**

### **2.3.1 Response to climate change**

The City of Cape Town has compiled a series of plans and policies signifying its ongoing commitment to sustainable development. The City's Integrated Metropolitan Environmental Policy (IMEP) (City of Cape Town 2009a) defines its overarching commitment to conserving environmental resources and reducing the carbon footprint. This commitment defines "resource use targets and strategies" to "dramatically reduc[e] current over-consumption patterns in middle and upper classes while increasing appropriate resource use in impoverished and disadvantaged communities so as to extend quality living environments and basic services" (p. 3). For practical realization of this commitment, Within the IMEP defines clear actions and responsible departments according to five-year environmental targets, ranging from biodiversity conservation and waste management, to reducing the carbon footprint, improving energy efficiency and spatial planning goals to limit urban sprawl.

The IMEP policy is used, among other purposes, to inform development and implementation of various plans and policies within the City. In addition, Cape Town's Integrated Development Plan (IDP)<sup>6</sup> underscores the need for an integrated approach to adaptation and mitigation of climate change. Guiding the city administration in "setting its budget priorities and allocating resources", the IDP incorporates sustainable development goals across eight strategic focus areas<sup>7</sup>, including the need to develop sustainable infrastructure/services, reduce energy consumption and expand public transport systems (City of Cape Town 2010c, p. 2).

Under the strategic focus area for improving energy efficiency for a sustainable future, it identifies several key actions plans. Among others, the action plans aim to improve energy security by diversifying energy supply, reducing transport energy consumption "through the development of public and non-motorised transport, and the promotion of energy-efficient and cleaner-fuel vehicles", as well as to supporting a "more efficient city form and enforcing the urban edge" (City of Cape Town 2010c, p. 69). Under this modality, the City of Cape Town has developed the Energy and Climate Change Action Plan (ECAP), which identifies key criteria to meet its low carbon goals; namely, energy efficiency, renewable energy, public transport and compact city development (UCT, SEA 2011; City of Cape Town 2010b; Ward 2010). Forming the foundation for implementing and monitoring its energy and climate change program, ECAP establishes the overarching goal of achieving energy security across all sectors (UCT, SEA 2011).

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<sup>6</sup> Also referred to as Cape Town's Five-Year Plan, covering the period of 2007 – 2012 (City of Cape Town 2010c).

<sup>7</sup> The complete list consists of the following strategic focus areas: shared economic growth and development; sustainable urban infrastructure and services; energy efficiency for a sustainable future; public transport systems; integrated human settlements; safety and security; health, social and community development; good governance and regulatory reform (City of Cape Town 2010c).

### 2.3.2 City of Cape Town's carbon footprint

Building on the objectives of ECAP, the University of Cape Town (UCT) and non-governmental organization (NGO) Sustainable Energy Africa (SEA) collaborated to produce an energy scenarios report, taking inventory of energy consumption and greenhouse gas emissions in Cape Town across five sectors: residential, commercial, industrial, local government and transportation (UCT, SEA 2011). Their findings of cross-sectoral energy consumption and carbon emissions are shown in Figures 2-1 and 2-2, respectively. Figure 2-1 shows that the transportation sector is responsible for 50% of energy consumed in Cape Town. As transport activities consume half of the total energy used in the City, improving the efficiency in this sector has significant potential for reducing the carbon footprint. However, it is important to note, as shown in Figure 2-2, that transport contributes a disproportionate 27% of the total emissions. Electricity is responsible for the remaining two thirds of the city's carbon footprint, including residential, commercial and industrial energy consumption<sup>8</sup> (UCT, SEA 2011, City of Cape Town 2010c).

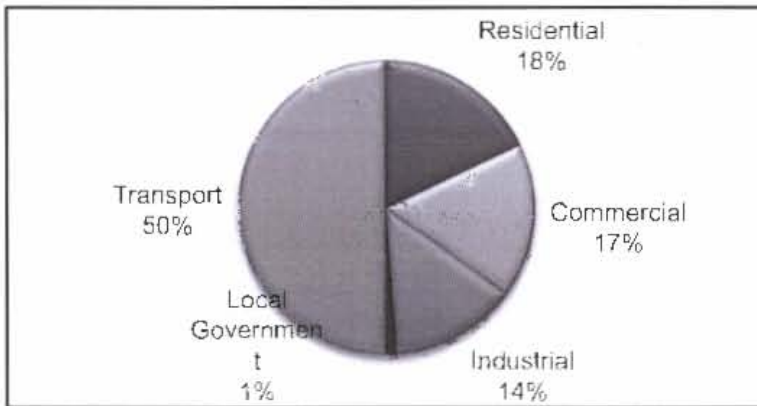


Figure 2-1: Energy Consumption per sector in Cape Town (2007)  
Adapted from: (UCT, SEA 2011, p. 13)

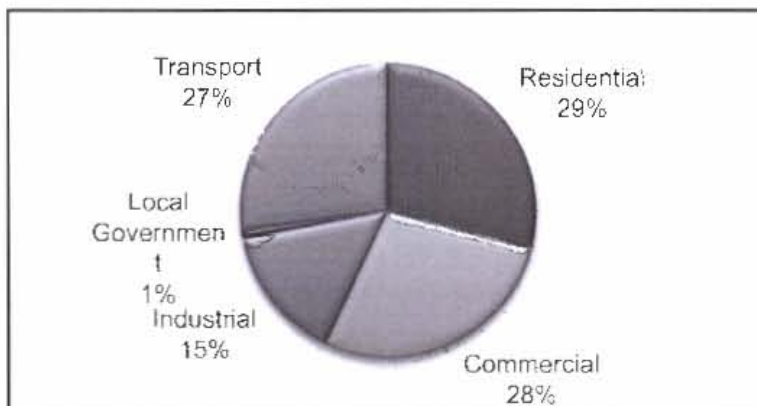


Figure 2-2: Carbon Emissions per sector in Cape Town (2007)

<sup>8</sup> This figure is remarkably high due to the inefficient emissions factor from coal-based power generation. It does not include embedded emissions from trade/commerce/materials produced outside the City, nor does it account for emissions from land-use change and loss of carbon sinks.

Adapted from: (UCT, SEA 2011, p. 13)

Using the baseline data from 2007, the Energy Scenarios Report prepared a business as usual scenario for future greenhouse gas emissions from Cape Town. As depicted in Figure 2-3, the total carbon footprint was approximately 17 million tCO<sub>2</sub>eq in 2010, with roughly 4.2 million tCO<sub>2</sub>eq from the passenger transport sector. The study estimates that by the year 2050, the combined emissions across all sectors would virtually quadruple in the City if no climate change mitigation measures were put into place (UCT, SEA 2011, p. 14).

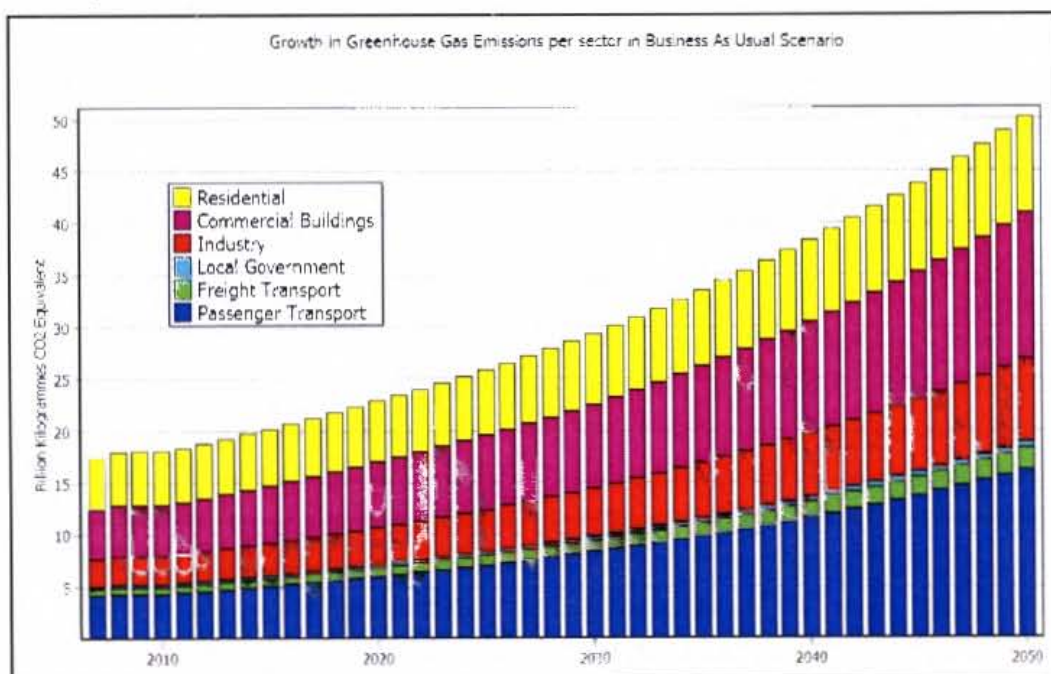


Figure 2-3: 'Growth in Greenhouse Gas Emissions per sector in Business as Usual Scenario' (UCT, SEA 2011, p. 14)

By the year 2050, assuming the South African population stabilizes at 55 million and that industrialized countries achieve carbon neutrality<sup>9</sup>, the acceptable per capita emissions in South Africa would be approximately 1 tCO<sub>2</sub>eq per person under the Copenhagen Accord, or a national footprint of 55 million tCO<sub>2</sub>eq (WWF South Africa 2010, p. 14; UNFCCC 2010a). Per capita emissions in Cape Town in 2009 were estimated to be 6.21 tCO<sub>2</sub>eq, with a target to reduce to 5 tCO<sub>2</sub>eq per capita by 2014 (City of Cape Town 2009a). According to City of Cape Town population estimates, its population may exceed 4 million by 2021 (City of Cape Town 2008c). Even if the population increased to 5 million by the year 2050<sup>10</sup>, the City would effectively have to reduce its total carbon footprint to just 5 million tCO<sub>2</sub>eq to meet international targets. A carbon footprint of 5 million tCO<sub>2</sub>eq in 2050 represents a 90% reduction from the business as usual projection in Figure 2-3. Moreover, it is worth noting that according to sustainability targets in the Copenhagen Accord, the projected carbon footprint in 2050 would take up more than 90% of the allowable emissions for the whole country. It is clear that this trajectory is highly unsustainable. For the City to meet necessary reduction targets, it will likely require drastic improvements in efficiency across all sectors, as well as extreme measures to reduce

<sup>9</sup> zero net emissions (WWF South Africa 2010)

<sup>10</sup> The figure of 1 million is presented here simply for the sake of argument, as the City's projections to which this section refers do not extend beyond the year 2021. Estimates for 2007 indicated approximately 3.5 million people were living in Cape Town, with an annual increase of 1.61% due to a combination of births, increased life expectancy and high migration rates. Future population growth will depend on migration rates, which have followed the high range trajectory projected in 2001. However, these are projected to decrease (City of Cape Town 2008c).

emissions. As shown in Figure 2-3, the carbon footprint for passenger transport is projected to increase the most of all sectors. Taking into consideration the international targets for emissions reductions, it is paramount that the City take significant measures to reduce emissions from this sector in particular.

### **2.3.3 Transport and passenger transport contribution**

The average modal split between private and public transport is currently 59:31, which changes to 50:50 during peak hours (City of Cape Town 2009b, p.17). Additionally, according to a study conducted in 2004/5, 67% of the daily trips into Cape Town's Central Business District (CBD) are from cars, while the remaining 33% are made with public transport (City of Cape Town 2008a). In 2003, over 45% of households in the Western Cape owned at least one car, which is the highest rate in the country (SADoT 2005, p. 6). In Cape Town specifically, private vehicle ownership is increasing at a rate of 3.4% per annum, and is projected to continue through the year 2050 (UCT, SEA 2011, p. 11). Socio-demographic indicators play a significant role in car ownership, as well as general travel preferences. According to the South African National Household Travel Survey (NHTS) (2003), approximately 15% of white South Africans indicated security from crime as their most important factor when choosing transport mode, versus 13% of colored people and only 6% of black people (SADoT 2005, p.14). Further, approximately 20% of black South Africans interviewed for the NHTS indicated travel cost as their most important decision-making factor when choosing mode of transport, versus 15% of colored people and only 10% of white people. Flexibility in transport was most important to 10% of white people, followed by less than 5% of colored and black people. These trends suggest that in general, crime is a more significant concern among white and colored populations when it comes to transportation behavior. Further, black and colored populations tend to be more concerned with the cost of making a trip than white people.

Given the trajectory of increased car ownership over the next few decades, in the absence of proper mitigation measures, the mode share and volume of private cars is likely to increase. Further, with continued population growth, the number of daily trips into the CBD will most certainly continue to increase from 2004/5 levels due to existing land-use patterns and an increased number of residents needing to travel to the city center for work. This will put further strain on all modes of transport in the future. In a business as usual scenario, associated negative impacts of fuel combustion on local air quality, which already experiences frequent occurrences of the "Brown Haze"<sup>11</sup> phenomenon, are only likely to get worse. The constraints of the transportation system prior to 2010 left little room for sustainable development.

### **2.3.4 The Integrated Rapid Transit (IRT) network**

#### **City of Cape Town - Integrated Transport Plan (ITP)**

Aligning itself with the priorities of Cape Town's 2006 – 2011 Integrated Transit Plan (ITP), the Integrated Development Plan stresses the need to link transport goals with spatial development frameworks to

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<sup>11</sup> The "Brown Haze" phenomenon in Cape Town is a visible smog which occurs over the Cape Flats area, often extending from the Northern Suburbs to False Bay, south of CBD. According to the Brown Haze Study (1997), 65% of the air pollutants comprising the haze effect come from vehicle emissions, predominantly commercial diesel (City of Cape Town 2009c, p. 12).

facilitate a 9% modal shift from private transport<sup>12</sup> by the year 2020 (City of Cape Town 2009b, p. 17; City of Cape Town 2010c, p. 27). The ITP identifies key sustainability indicators for measuring its provision of sustainable<sup>13</sup> transport. To achieve a modal shift of 9% from private transport by the year 2020, the ITP enforces a range of strategies, including a “substantial investment in the rail system; major improvement to the road-based public transport system; enhancement of safety and security to and on public transport; investment into walking and cycling environments; provision and enforcement of public transport priority lanes and dedicated lanes” (City of Cape Town 2009b, p. 17). Ultimately, the priorities identified in the ITP culminated in the four-phased expansion of Cape Town’s public transportation network, discussed in detail in the following section.

### **IRT concept and general implementation timeframe**

The City has proposed an integrated public transport system that is “economically viable, environmentally responsible, and which promotes social equity” (City of Cape Town 2010a, p. 8). Cape Town’s Integrated Rapid Transit (IRT) network<sup>14</sup> refers not just to the BRT, but rather stresses the integration and linkages between its various modes of public transport, including its existing electric rail system. To be implemented in four separate phases, the IRT envisions a comprehensive public transport network with “high-quality rail and road services” positioned within 500 m of “at least 75% of Cape Town’s population” (City of Cape Town 2010a, p. 8). Along with the existing rail lines, the new BRT trunk routes are intended to serve as the central transport corridors in the system, with lower-capacity bus feeder services to provide access the remaining areas of the city<sup>15</sup>. The city has projected a 10% modal shift from private vehicle use to the new IRT system (City of Cape Town 2010a).

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<sup>12</sup> As referred to previously, the Phase 1A Business Plan has projected a 10% modal shift from private transport. This projection was used for calculations in Scenario A, as presented in Chapter 4: Findings.

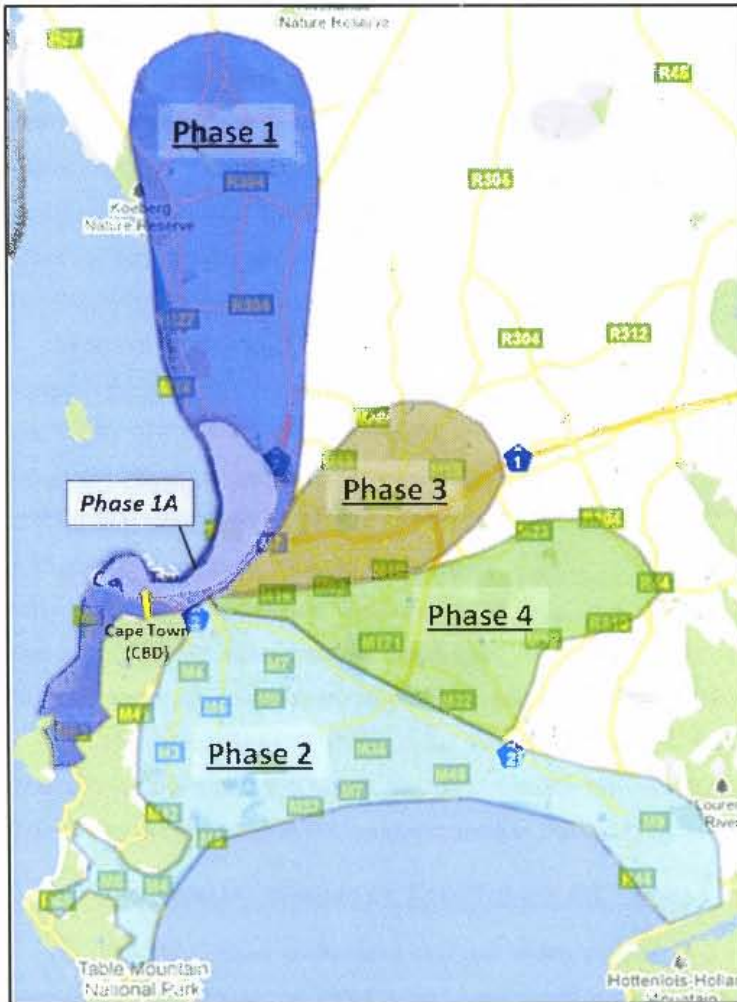
<sup>13</sup> Key indicators are separated by economic, social and environmental objectives.

<sup>14</sup> The full network has been dubbed the Integrated Rapid Transit network, however the bus component has been branded as “MyCiTi”, as it will be known to the public.

<sup>15</sup> The feeder service routes are highly flexible, as they will operate on existing roads in mixed traffic. The routes are not indicated in this figure as they are outside the scope of this study, and are subject to change.

*Phased implementation break down (IRT Phases 1-4)*

According to the Phase 1A Business Plan, the IRT network will be rolled out in four phases, with a tentative timeframe of 15 to 20 years to complete. The IRT Phase map, adapted from the Phase 1A Business Plan, is shown in Figure 2-4.



*Figure 2-4: Overview Map of Cape Town IRT Phases 1-4  
Adapted from: Phase 1A Business Plan (City of Cape Town 2010a)*

Phase 1 (indicated in purple) was originally proposed to be complete by 2015. This phase will connect the CBD to the Northern Suburbs along the Atlantic Coast (upper portion of Phase 1), as well as with Hout Bay to the South (indicated at the lower portion of Phase 1). The motivation for beginning with this route is twofold. First, the City's main growth node is located north of the Phase 1A area. Secondly, this area is not currently equipped with a rail service and has limited access to public transportation.

Phase 1A forms the initial segment of Phase 1, and is the focus of this study. The preliminary segment of Phase 1A consists of the BRT starter trunk route<sup>16</sup>, as indicated in Figure 2-5. The starter trunk route extends from Victoria & Alfred Waterfront (near Granger Bay stop) to the greater Table View area in the North (Bayside stop). The Civic Centre stop is the flagship BRT station, providing a pedestrian link to the main Cape Town railway station and Metrorail services. The Woodstock BRT stop also features a link to Metrorail services, “providing good connectivity with the rest of the metropolitan area” (City of Cape Town 2010a, p. 20). The completed Phase 1A, including feeder services to Hout Bay (southernmost portion of Phase 1 in Figure 2-4) and trunk route to the northern areas of DuNoon and Atlantis, were originally expected to be fully operational by September

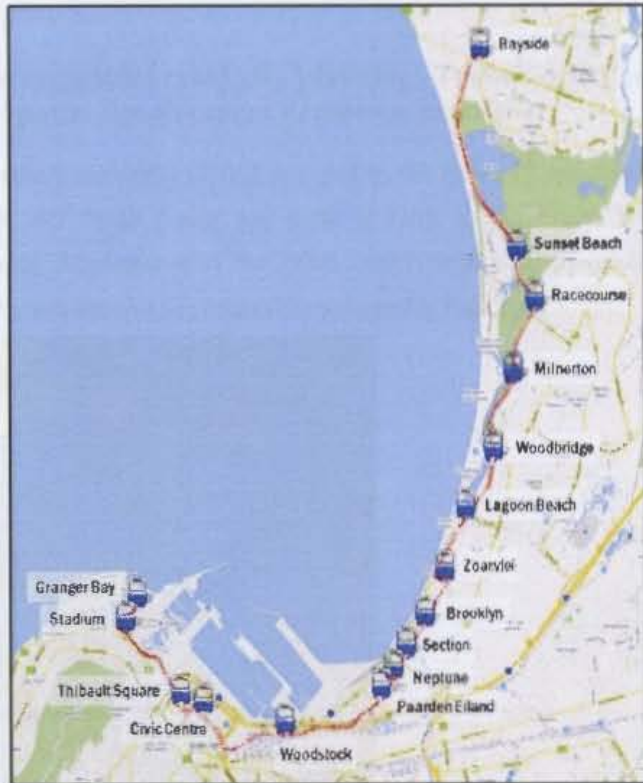


Figure 2-5: IRT Phase 1A – BRT starter service

2013. However, given delays in roll-out of the starter trunk route, the completion date is likely to be extended.

The remainder of the IRT roll-out, shown in Figure 2-4, will eventually extend to, among others, low-income township areas of Khayelitsha and Mitchell’s Plain in Phase 2; extension to Durbanville in Phase 3; followed by the township of Delft and surrounds in Phase 4 (City of Cape Town 2010a, p. 8).

### Technical information on Cape Town’s BRT buses

The BRT buses to be used in Cape Town consist of a customized body built by the company, Marcopolo. The Phase 1A -BRT trunk service will operate predominantly using a 18 m articulated bus, consisting of two main structures, joined by a flexible, articulated seam. These buses are constructed using a Volvo B12M articulated chassis, equipped with a DH12 model diesel engine (Volvo Buses 2011a, p. 2). The electronically-controlled engine contains an intercooler to regulate temperature and optimize fuel combustion efficiency, operating according to EURO 4 emissions requirements<sup>17</sup> (Volvo Buses 2011a, p.2; Volvo Buses 2011b, p. 14). Each 18 m articulated bus has the capacity to carry 146 passengers (City of Cape Town 2010a, p. 30). Off-peak operations, feeder services and the airport route will operate predominantly using 12 m buses mounted on a Volvo B7R chassis, equipped with Volvo D7 diesel engines which also comply with Euro 4

<sup>16</sup> Phase 1A also includes a BRT service running from Cape Town Civic Centre to Cape Town International Airport. This route runs predominantly in a bus-dedicated HOV lane, however does not have a segregated trunk route.

<sup>17</sup> Euro standards regulate the emissions of air pollutants such as nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter (PM) (Uherek et al. 2010). Euro standards are relevant for improving local air quality; however, they do not regulate greenhouse gas emissions.

standards (Volvo Buses 2011c, p. 2). These models have a capacity of 92 passengers (City of Cape Town 2010a, p. 41).

### 2.3.5 Supporting the IRT network through integrated city planning: Transit-oriented development and Cape Town's Spatial Development Frameworks (SDFs)

According to the eight spatial development frameworks (SDFs) prepared by the City of Cape Town (2011), the main new growth node is located in IRT Phase 1 area, just north of Table View. Figure 2-6 highlights key areas identified for transit-oriented development in the Table Bay (southern portion) and Blaauwberg (northern portion) district plans. The study area for this research is indicated in light blue.

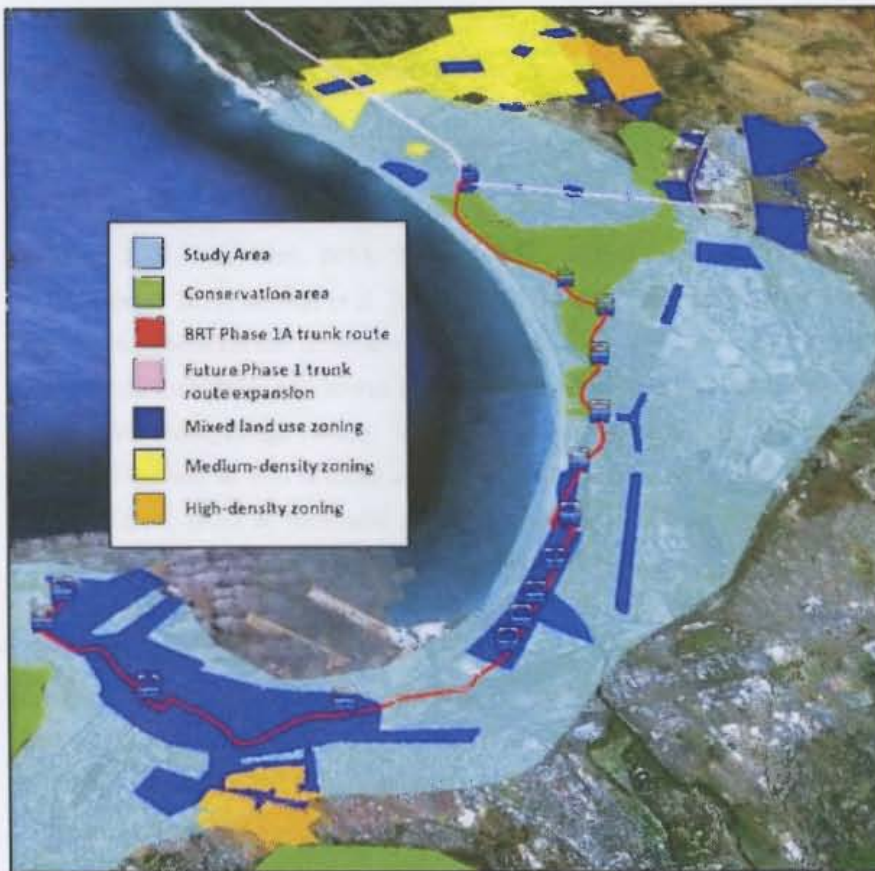


Figure 2-6: Key attributes for Cape Town SDF in relation to BRT Trunk Routes  
Adapted from: City of Cape Town (2011) Spatial Development Frameworks

The SDFs have identified potential areas for new growth, concentrating north of the greater Table View area (top of Figure 2-6). Currently consisting of mostly undeveloped land, optimal uses for this land have been identified as medium-density (yellow), high-density (orange) and mixed-use (dark blue). Also worth noting is that the District Six area (bottom left) has also been identified for potential high-density development, as most of this area is undeveloped<sup>18</sup>. Various portions of the mixed-use zoning indicated in Figure 2-6 contour main (road-based) transportation corridors. The existing corridor for Phase 1A - BRT trunk route traverses two existing medium-density areas in the southern portion of the study area, namely the CBD/Woodstock area

<sup>18</sup> Through the mid-1900s, District Six was a predominantly colored neighbourhood. Under the Apartheid regime, this high-value real estate was designated as a whites-only area. Subsequently, the residents were forcibly removed and relocated to areas in the Cape Flats. Given its sensitive and complex political past, as well as ongoing land restitution claims, this area has remained largely vacant for decades.

Hensher, Louviere & Swait 1998). This section discusses the benefits and shortcomings of each approach and how to optimize statistical predictions.

#### **2.4.2.1 *Revealed preference survey: a method for gathering data on observed (actual) behavior of respondents***

The RP survey method gathers data by documenting the observed (actual) behavior of respondents, or rather, determining their preferences based on choices they have made in reality (Hensher, Barnard & Truong 1988; Hensher, Louviere & Swait 1998; Hensher, Bradley 1993). Using RP methods involves asking respondents to recall their actual behavior, for example, by asking direct questions such as, 'How often do you take the bus to work?' or, 'How much do you pay to commute to work on a daily basis?' While the RP method has clear advantages (namely, that it provides specific and direct answers to research questions), it has also shown to be problematic in accurately predicting behavior. The reason for this is that respondents may answer a question without considering the real-life variables that would affect their *in situ* decision-making (Kroes, Sheldon 1988, p. 13). Ultimately, respondents may have completely different preferences in reality. Given the complexity of choice, it can be difficult for a respondent to take these real-life variables (such as the convenience associated with a personal car) into account when indicating their preference (Hensher, Bradley 1993, p. 139). Kroes and Sheldon (1988, p. 13) further describe limitations of RP methods in analyzing transport behavior, ranging from difficulty in obtaining "sufficient variation . . . to examine all variables of interest" to their inability to incorporate "secondary travel variables (such as seat design and station facilities)" in their data analyses. Most importantly for this study, "revealed preference methods cannot be used in a direct way to evaluate demand under conditions which do not yet exist" (p. 13). As the BRT starter service in Cape Town was still in the construction phase at the time of conducting field work for this research, using RP methods alone to determine the probability of user uptake would have been inadequate.

#### **2.4.2.2 *Stated preference survey: A method for predicting future behavior of respondents***

Development of SP methods advanced in the 1970s and became widely used by the end of the decade (Kroes, Sheldon 1988, p. 12). SP techniques typically involve a combination of hypothetical and real variables to present "a set of mutually exclusive alternatives", also known as choice sets or scenarios (Hensher, Bradley 1993). This type of survey asks respondents to either rank/rate the alternatives presented in each scenario, or simply asks them to choose which alternative (set of variables) they would prefer. In essence, an SP survey examines individuals' preferences based on "the trade-offs they are willing to accept" (Albern Kahn 2006, p. 156). The advantage of using the SP technique is that it allows for efficient "study of preference and choice contexts which may or may not be observed in the market place" (Hensher, Barnard & Truong 1988, p. 50). In other words, an SP survey allows for the normative analysis of relative preferences, as well as hypothetical consideration of respondent behavior, regardless of whether the variables in question exist in reality (Carlsson 2010). By providing a hypothetical scenario through which respondent behavior can be observed, responses regarding travel behavior are hypothetical by nature, and are not be limited to existing services. Kingham et al. (2001, p. 153) explain that, "while stated preference questions are open to criticism that stated preferences will not be adhered to if the transport situation were to change, research suggests that they can be a reliable indicator of likely travel behavior."

There are various forms of SP methods that can be used in analysis of choice<sup>19</sup>. For this research, conjoint analysis (or discrete choice) was used, which refers to the method of making comparisons across a combination of goods or services<sup>20</sup> (Alberni, Kahn 2006, p. 154). In a discrete choice survey, respondents are given a number of choice sets in which they are asked to indicate a preferred scenario. Each choice set comprises at least two scenarios to choose from, each containing a set of attributes at different levels. The term ‘attributes’ refers to different categories of variables (such as cost, time and mode of transport); each of these attributes have different levels. For example, for the attribute of time, each choice set would be constructed using different levels, or increments, of that attribute (5 minutes, 15 minutes, 30 minutes, . . .). The same would be true for the attribute of cost (R5, R10, R15, . . .). An example of a choice set is shown below in Figure 2-7, with the attributes of transport mode, travel time and cost of trip, each at different levels in the respective scenarios.

<b>Scenario A:</b>	<b>Scenario B:</b>
<b>Transport mode:</b> Bus	<b>Transport mode:</b> Car
<b>Travel time:</b> 30 minutes	<b>Travel time:</b> 15 minutes
<b>Cost of trip:</b> R10	<b>Cost of trip:</b> R12

Figure 2-7: Example of a stated preference choice set

Note that the levels used in Scenarios A and B are different for each attribute. However, in some cases one or more attribute levels can be the same (i.e. same cost and time). By indicating the preferred option in several different choice sets, respondents’ answers inform a statistical model about their underlying preferences. The most commonly used model for analyzing SP data is a multinomial logit model, a type of random utility model. An MNL model gives the probability of the outcome (i.e. probability in choosing a mode of transport), the utility (level of satisfaction) derived from each independent variable, as well as a respondent’s willingness to pay (WTP) for a particular outcome (Swait 2009; Street, Burgess 2007).

The attributes and their associated levels inform an algorithm, such as the following shown in Figure 2-8, which suggests the overall utility derived from the scenarios (Kroes, Sheldon 1988):

$U$	=	$\alpha_1x_1 + \alpha_2x_2 + \dots + \alpha_nx_n$
Where $U$	=	total utility
$x_1$ to $x_n$	=	values of factors 1 to $n$
$\alpha_1$ to $\alpha_n$	=	utility weights for factors 1 to $n$

Figure 2-8: Utility function used in SP data analysis (Kroes and Sheldon 1988b, p. 14)

The independent variables, such as journey time, cost of travel or level of comfort, are indicated as  $x_n$ ,  $n$  being the number of choice sets. The values attributed to these variables are based on a respondent’s answers. The coefficient  $\alpha_n$  indicates the weight attached to these values, or how much the respondent cares about one factor versus another. Random utility methods identify the values for the  $\alpha_n$  coefficients, facilitating

<sup>19</sup> the most well-known forms of the stated preference method are “conjoint analysis, functional measurement, trade-off analysis, and the transfer price method” (Kroes, Sheldon 1988, p. 11)

<sup>20</sup> The term ‘discrete choice’ refers to respondents choosing between two or more discrete (different) alternatives.

construction of the model for probability of choice. In aggregate, the utilities derived from the various scenarios suggest a relative demand for a particular good or service (Kroes, Sheldon 1988, p. 14).

The design of the SP survey is a critical component to the data collection process, and the literature consistently refers to difficulties in SP design (Hensher, Barnard & Troung 1988, p. 50; Street, Burgess 2007; Kroes, Sheldon 1988; Carlsson, Martinsson 2003). The main issue that arises in the survey design is how to combine attributes in particular choice sets to ensure optimal data collection for accurate modeling, or prediction of behavior (Carlsson, Martinsson 2003, p. 282; Street, Burgess 2007). Danthurebandara and Manohara (2011, p. 2277) argue that choice complexity must be adequately represented when designing the SP survey. In other words, they stress the importance of including all significant attributes in the scenarios which may affect decision-making. If significant attributes are omitted, the data obtained will be “inconsistent with estimation model”, and result in a bad model fit. In such cases, they argue, “the experimental design obtained cannot be optimal”. On the contrary, however, Aretze et al. (2003) point out that including too many attributes, can increase respondent burden and negatively impact the validity of their responses. By increasing the task complexity for a respondent to choose a preference, it may lead to general fatigue and responses which are not representative of their true preferences. Finding a balance that acknowledges the complexity of choice, but does not overwhelm the respondents is crucial. Best practices for ensuring optimal survey design include conducting pre-screening exercises with the target groups to identify significant attributes in decision-making. This can be followed by use of a statistical design method, referred to as ‘orthogonal<sup>21</sup> factorial design’, which enables a researcher to construct optimal choice sets that extract maximum information from respondents with as few attributes/levels as possible (Kroes, Sheldon 1988; Carlsson, Martinsson 2003; Street, Burgess 2007).

#### ***2.4.2.3 Using revealed preference and stated preference in tandem***

In summary, neither RP nor SP methods have escaped criticism in their abilities to accurately predict choice behavior. RP methods have been criticized for relying too heavily on existing services and observed behavior, while SP methods are far more complex and difficult to implement. Despite the shortcomings of both, it is important to note that, when used correctly in combination with one another, they can be complementary in studying and predicting choice behavior (Hensher, Bradley 1993, p. 139).

Earnhart (2001, p. 14) explains,

“By combining the stated and revealed preference methods, the joint model enhances the strengths and diminishes the drawbacks of each individual method . . . The stated preference questions generate additional observations for uncommon attributes in the revealed data. Third, inclusion of revealed preference data ensures that estimation is based on observed behavior to some degree.”

Pursuant to these recommendations, the survey described in Chapter 3 incorporated both RP and SP elements to obtain the best model fit possible.

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<sup>21</sup> The term ‘orthogonality’ refers to the presence of independent variables in the choice sets, allowing for the “separate effects they have on choice [to be] estimated” (Aretze et al. 2003, p. 234; Street, Burgess 2007, p. 16; Hensher, Barnard & Truong 1988, p. 50).

## 3 Research Methodology

Primary data gathered for this study was conducted in the form of an SP Survey to determine the demand of car users to switch to the BRT as their preferred mode of transport. The second method used in this study included an analysis of traffic count data obtained from the City of Cape Town - Department of Transportation. This data was used in conjunction with the SP survey to predict the percentage of car users who would switch to the BRT. Using a scenario-based approach, the study compares the changed carbon footprint according to projections from the City, as well as to the findings from the SP survey.

### 3.1 Methods for determining demand for the Phase 1A - BRT starter service

The survey conducted in this study included nine SP choice sets, followed by six RP questions. The RP portion of the survey gathered information about respondents' travel behavior, such as how many days per week they drive their car, how long it typically takes them to get from home to work, and if they work in or near the CBD. Further, observed data was gathered regarding demographical characteristics of the survey sample to assist in predicting the behavior of participants. For a complete list of questions, please refer to the survey template contained in Appendix A. The remainder of Section 3.1 focuses on designing and conducting the SP survey, including identifying attributes, assembling choice sets, and conducting the survey.

#### 3.1.1 SP Design

##### 3.1.1.1 Determining attributes and subsequent levels

The researcher compiled a list of possible attributes that might affect respondents' incentives to choose the BRT over private transport. Understanding the importance of including all significant variables in the survey, the preliminary list of attributes became quite extensive: *travel time, comfort level in transit, cost, distance from place of residence to nearest BRT stop, distance from final destination to nearest BRT stop, waiting time on platform, time of day, weather conditions, level of security on-site, and availability of parking facilities*. To minimize respondent burden and to design a survey that could be administered in a limited timeframe, the number of attributes for the survey were significantly reduced<sup>22</sup>. The attributes that were considered to be the most significant for decision-making<sup>23</sup> were included in the final SP survey, namely *mode of transport, pure travel time (one-way), total travel cost (return), and comfort*. It is important to not that reducing the number of attributes does produce some further limitations, as described in Section 3.2.2.

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<sup>22</sup> It should be noted that the best practices (described in Section 2.4.2.2) of pre-screening to determine significant attributes, as well as constructing the choice sets by using the 'orthogonal fractional design' method, were not used in the design process. This is discussed in more detail in Sections 4.4.2 and 5.1.

<sup>23</sup> The initial design process described in Section 3.1.1.1 was conducted in direct consultation with Dr. Marianne Vanderschuren, Senior Lecturer, Centre for Transport Studies at the University of Cape Town. Dr. Vanderschuren assisted in simplifying the subsequent attributes and levels used for constructing the choice sets.

Each attribute was broken down into different levels for inclusion in the choice sets. The attributes and subsequent levels used in the survey are presented below in Table 3-1.

Attributes	Levels
Mode of transport	BRT
	Car
Comfort	No Traffic
	Traffic (stop-and-go)
Cost of return fare	R 10
	R 25
	R 35
Time required for travel one-way	15 minutes
	30 minutes
	45 minutes

Table 3-1: Attributes and corresponding levels for SP choice sets

To determine appropriate levels for the attribute of time in Table 3-1, the researcher first needed a rough estimate of time required to complete a journey from one end of the BRT route to the other. To obtain this figure, a round trip was made by car during off-peak hours, originating at the first BRT stop (Granger Bay) near the V&A Waterfront shopping center in CBD, to the other end of the route, terminating at the last BRT stop (Bayside) in the greater Table View area<sup>24</sup>. Reproduced in this section for easy reference, the Phase 1A starter route is shown in Figure 3-1.

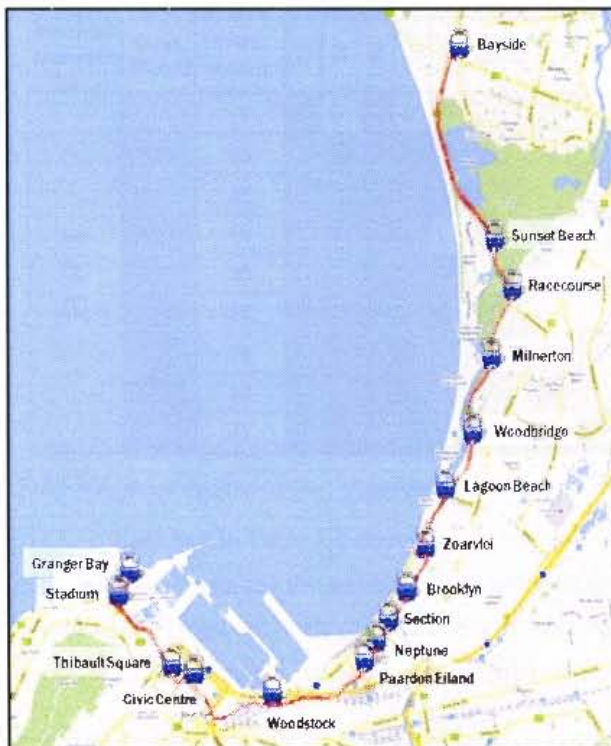


Figure 3-1: IR3 Phase 1A – BRT starter service

A stopwatch was used to measure the time between subsequent BRT stops, and an estimated loading and unloading time of 30 seconds was assumed for each BRT stop. Time measurements were recorded for both segments of the return trip, and were later averaged. Under off-peak conditions, a short trip via private transport from Lagoon Beach to the Civic Centre was observed to take approximately 17 minutes; a full trip from Bayside to Waterfront was determined to take approximately 35 minutes. These levels were simplified at intervals of 15 minutes and were used for both modes of transport (see Table 3-1). To establish appropriate levels for the attribute of cost, the cost to passengers was

<sup>24</sup> It is important to note that for the purposes of the survey, it was not required to obtain precise travel times, as the levels included for the travel time attribute would be simplified to reduce respondent burden.

estimated depending on their mode of transport. To estimate fees for using the BRT service, a base fare of R5 was used, along with a subsequent fare of R0.30 per kilometer traveled, as proposed in the Phase 1A Business Plan (City of Cape Town 2010a, p. 19). Using an average of distance traveled along the 19.63km corridor, the return fare cost range for the BRT<sup>25</sup> was determined to be between R11.20 and R35.70. It is important to note that fares were based on available information at the time, as the BRT service was not in operation during the survey design phase<sup>26</sup>. For the survey, the fares were simplified to R10, R25 and R35. The minimum cost for car travel was estimated based on an average fuel efficiency of 9.5 L/100 km a South African vehicle (Letete et al. 2010) and the observed cost of petrol in South Africa at the time of conducting the survey (R7.50/L). The maximum cost for petrol of a round trip was determined to be approximately R28. For the sake of managing task complexity, the estimated cost of driving a car was assumed to include the cost of petrol and parking<sup>27</sup>. As the levels presented in the SP survey are by nature hypothetical, the figures for both modes of transport were simplified to increments of 5 for the ease of respondent comprehension (see 'Cost' in Table 3-1).

### 3.1.1.2 Constructing the choice sets by combining the attribute levels in each of the alternatives

Once the attributes and levels had been determined, they were inserted into Table 3-2 to identify choice sets to include in the survey.

		Mode of Transport		C A R																	
				Off peak - No Traffic									Peak hours - Stop and Go								
				R 10			R 25			R 35			R 10			R 25			R 35		
Mode of Transport	Cost (Rand)	TIME (mins)	Cost (Rand)																		
			15	30	45	15	30	45	15	30	45	15	30	45	15	30	45				
BRT	R 10	15			Q1		Q2														
		30																Q4			
		45																			
	R 25	15												Q5		Q5			Q7		
		30									Q3										
		45																	Q8		
	R 35	15																			
		30																			
		45																	Q9		

Table 3-2: Stated Preference Survey Design

Each box in Table 3-2 represents a choice set to be included in the survey, allowing for 162 possible combinations. To reduce the number of questions required for respondents to answer, it was necessary to omit choice sets that were not likely to occur in reality. Omitted choice sets are indicated in dark grey. For example, during off-peak hours, it is not likely that a 45-minute trip in a car could be achieved in only 15 minutes with the

<sup>25</sup> The Phase 1A Business Plan indicates that trips will be capped at R16 one-way (or R32 return) (City of Cape Town 2010a, p. 24).

<sup>26</sup> According to an article published in *TimesLIVE* on 08 May 2011, approximately one month after conducting the survey, the fares for the newly operational BRT service were announced to be R10 for the trunk routes, as well as R5 for feeder routes (maximum of R10 per single one-way trip) (SAPA 2011).

<sup>27</sup> As is shown in Table 3-2 on the following page, petrol/parking was only written for the scenario using private transport. However, respondents were informed that the costs included in the choice sets should be assumed to be the total for both modes of transport.

BRT. The assumption in this case is that a car will be able to travel at close to, if not more than, the speed of the BRT during periods of low traffic. Choice sets were also omitted based on unlikely combinations of time and cost. For example, it is not likely that a 45 minute trip (each way) on the BRT will only cost R10 return fare, as the BRT will likely travel well over 15 kilometers in this period of time (at R5 base fare, plus R0.30 per kilometer). Others were omitted based on assumptions for user preference (refer to Assumption and Limitations in Section 3.2 for more details). For example, it was assumed that if cost and time were exactly the same, people would prefer to drive their car (these choice sets are indicated in black in Table 3-2). To test this assumption, however, one such choice set was included in the survey (refer to question #9 in Appendix A; represented in Table 3-2 as 'Q9').

As the main benefit of the BRT service (reduced travel time) is likely to be observed during peak hours, the majority of choice sets selected for the survey occur during peak hours when congestion and reduced speed in car traffic is more likely to occur<sup>28</sup>. After omitting all choice sets that were unlikely to occur in reality or that were believed to offer little insight into identifying travel preferences, the researcher selected nine choice sets from the remaining cells in Table 3-2.

An example of the SP choice sets presented to respondents is shown in

Figure 3-2, below. The attribute of *comfort* was not displayed within each scenario; rather, questions pertaining to *no traffic* were all grouped together, as well as those pertaining to *stop-and-go traffic*. This is shown at the top of Figure 3-2, and can be seen in its entirety in Appendix A.

Imagine you are commuting to work and there is **little or NO traffic**. Which of the following would you prefer:

**(CHOOSE ONE OPTION FOR EACH QUESTION ONLY)**

<p style="text-align: center;"><b><u>OPTION A:</u></b></p> <p style="text-align: center;"><b>Take the BRT</b></p> <p>⇒ Cost of return ticket:      <b>R10</b></p> <p>⇒ Travel Time:                      <b>15 mins</b></p>	<p style="text-align: center;"><b><u>OPTION B:</u></b></p> <p style="text-align: center;"><b>Drive your car</b></p> <p>⇒ Total cost (petrol/parking): <b>R10</b></p> <p>⇒ Travel Time:                      <b>30 mins</b></p>
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Figure 3-2: Stated Preference Choice Set from the survey (refer to Appendix A)

<sup>28</sup> The logic behind omitting the majority of off-peak choice sets was that the BRT would have a bigger impact during peak hours, and that this period should be examined more closely. As discussed in Chapters 2, 4 and 5, using an orthogonal factorial design method, as well as pre-screening process, would have improved the survey design.

### 3.1.2 Conducting the survey

#### 3.1.2.1 Target group and survey location

The target group for this study included car users who live and work within the Phase 1A study area, indicated in light blue in Figure 3-3.



*Figure 3-3: Location for conducting the survey: Civic Centre - MVRLO*

To target car users specifically, the survey was conducted at the Motor Vehicle Registration & Licensing Office (MVRLO) located in the Cape Town Civic Centre Building in the CBD. The MVRLO is also located adjacent to the flagship Civic Centre BRT stop in the CBD. By conducting the interviews in this location, it increased the likelihood that respondents would not only be familiar with the BRT service, but that they may also live or work within the study area.

### 3.1.2.2 Conducting face-to-face interviews

Interviews were conducted during business hours from the period of 19 March, 2011 – 1 April, 2011. Respondents for the survey were interviewed while they stood in a queue to renew their driver license or vehicle registration at the MVLRO. Interviews began by asking participants if they were familiar with the BRT, and providing a brief explanation from the quick reference guide (reproduced below in Figure 3-4) according to their level of knowledge<sup>29</sup>.

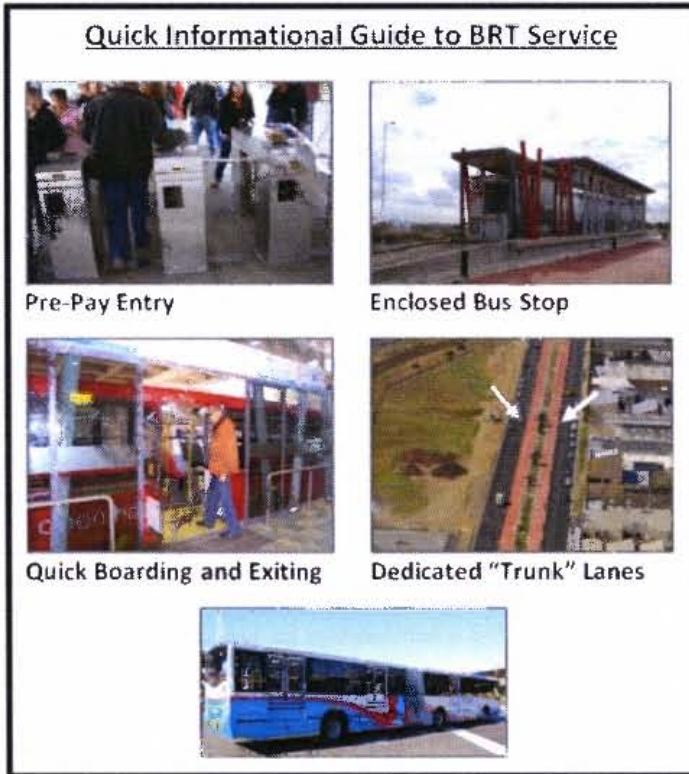


Figure 3-4: Quick reference guide for respondents (shown in Appendix A)  
Images sourced from the Phase 1A Business Plan (City of Cape Town 2010a)

Interviews lasted between three to five minutes. Immediately after conducting each interview, the researcher noted demographic data of the respondent, as well as any comments that might be used for qualitative analysis.

## 3.2 Assumptions and Limitations of designing and conducting the survey

### 3.2.1 Assumptions

As discussed in detail in Section 3.1.1, reducing the number of choice sets was essential to designing a survey that could be concise enough to be conducted in five to ten minutes. To assist in reducing choice sets,

<sup>29</sup> While describing the components of the BRT concept from the quick reference guide, the interviewer was cognizant of potentially influencing respondent bias. As such, effort was taken to clarify that explanation of BRT was for informational purposes only to assist respondents in answering the questions. The interviewer explained that the study was intended to identify how public transportation can best meet the needs of Capetonians. Lastly, he asked that respondents answer the questions as honestly as possible, and that there was no right or wrong answer.

the researcher made the assumption that if the time and cost were the same in both alternatives, respondents would prefer to drive their car over taking the BRT. As mentioned previously, all choice sets with equal cost and time (indicated in black in Table 3-2) were omitted from the survey, with the exception of Q9. Further, the researcher assumed that in conditions of heavy traffic, the BRT would travel more quickly than an automobile in mixed-traffic. Accordingly, for the comfort level of heavy traffic, only choice sets were included in which the travel time for BRT was equal to or less than the car option.

## **3.2.2 Limitations**

### **3.2.2.1 Time constraints and subsequent reduced capacity to accommodate choice complexity**

To account for choice complexity and the various attributes that affect choice behavior, the researcher would have had to include additional attributes to the survey. Expanding the survey even by one additional attribute would have doubled the number of questions required to conduct the experiment, as well as time required to conduct the interviews<sup>30</sup>. Given time constraints for brief, five-minute interviews, the capacity for the survey to accommodate for choice complexity was reduced significantly. Further, best practices for SP design, described in Section 2.4.2.2, include pre-screening and pilot surveys, as well as statistical methods to optimize survey design. Unfortunately, the researcher did not have the requisite experience in statistical and finite mathematics to carry out the experimental design without further technical assistance<sup>31</sup>. Subsequently, the six-month timeframe for conducting this study only allowed for an abbreviated design process<sup>32</sup>, thereby reducing its statistical validity.

### **3.2.2.2 Bias**

Respondent and interviewer bias could have affected the overall findings of the survey. Firstly, the interviewer could have exhibited bias in the selection of respondents, thus skewing the input for the survey based on the respondent demographic represented. As well, respondents could have exhibited bias in their responses to questions. For example, respondents could have thought the researcher's desired objective was to prove people would use the BRT. In some cases, they could have chosen a response to help him meet his desired outcome, known as affirmation bias (Street, Burgess 2007, p. 12). Strategic bias (or policy response bias) could have also influenced how respondents answered the questions. This form of bias refers to a respondent providing an answer which they think will influence the actual *in situ* outcome (Street, Burgess 2007, p. 12). In other words, if respondents wanted the BRT to move forward, they may have exaggerated their willingness to use it, regardless of their actual preference.

### **3.2.2.3 Language barriers**

Language barriers between the interviewer and potential respondents played a role in the selection of participants for the survey. As the demographical composition of Cape Town comprises a variety of

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<sup>30</sup> Another approach for accommodating complexity and additional attributes would be to present only a portion of the choice sets to each respondent, thereby reducing individual respondent burden. To administer this approach, a larger sample size would have been needed.

<sup>31</sup> Despite various attempts to secure support for the factorial design process, he was unable to obtain input beyond the initial design and data analysis phases.

<sup>32</sup> The duration of the 'abbreviated' survey design process still exceeded ten full weeks of preparation prior to conducting the interviews.

socioeconomic, ethnic and cultural backgrounds, not all potential respondents were comfortable or able to communicate in English. As the interviewer was not fluent in any other South African languages, several respondents were prevented from participating in the survey. This omission could have skewed the input for data analysis.

### 3.3 Calculating the carbon footprint for passenger transport in the study area: determining baseline emissions from private transport, the added footprint from BRT starter service, and subsequent net greenhouse gas emissions reductions

The following section discusses methods used to calculate the carbon footprint from private transport in the study area (reproduced below in Figure 3-5 for easy reference). Greenhouse gas emissions were calculated using a scenario-based approach, first determining the baseline carbon footprint of private transport using car vehicle kilometers traveled (VKT) according to their origin and destination. In two scenarios, car VKT were reduced according to projections for a modal shift from private transport to the BRT. Scenario A uses the projected modal shift as stipulated in the Phase 1A Business Plan, while Scenario B uses the modal shift projected in the findings of the SP survey. The total reduction in emissions from car trips were calculated in each scenario according to subsequent reduced VKT. Net reductions were determined by subtracting the added carbon footprint of the BRT starter service from the projected reductions in car VKT.

#### 3.3.1 Calculating greenhouse gas emissions from car users in the Phase 1A study area



Figure 3-5: Location of origin/destination zones in the Cape Town's IRT Phase 1A study area

The City of Cape Town Department of Transport provided passenger transport traffic data for the Cape Town Metropolitan Municipality area, divided into 38 zones. This data was provided in the form of an origin/destination (OD) matrix (City of Cape Town 2010d), which indicates the number of average car trips occurring during one workday peak hour. The matrix represents car trips based on their point of origin and their destination. The researcher extracted all data pertaining to car trips originating and terminating within the study area, resulting in traffic data for five zones in total. Their locations in relation to the general study area are indicated in Figure 3-5. The five zones from which peak-hour car trip data was obtained are Sea Point, Gardens, CBD, Woodstock, Milnerton and Table View. The

Phase 1A starter trunk route is indicated in red. It is important to note the precise boundaries used for each location were not indicated in the OD matrix. For this reason, the study area, indicated in light blue, is only representative of the general location and area to which this data pertains. For the purposes of this research, car traffic data associated with these five zones was assumed to be representative of all car VKT originating and terminating within the general study area.

The researcher mapped out the distances between locations by averaging the length of routes suggested in 'Google Maps - Get Directions' feature (Google 2011). To calculate vehicle kilometers traveled (VKT) for car users per peak morning hour, the average distance for each origin/destination subset was multiplied by number of trips per peak morning hour. The car VKT for baseline and Scenarios A and B were multiplied by an average fuel efficiency for cars in South Africa, as well as the emissions factor (EF) associated with petroleum fuel. This process is discussed in more detail in Chapter 4.

### **3.3.2 Calculating greenhouse gas emissions from Phase 1A – BRT starter trunk service**

The City of Cape Town - Department of Transport provided lifecycle carbon footprint calculations, conducted according to UNFCCC-approved guidelines, for the full IRT network implementation (Lopez 2008). Based on this data, the researcher identified fuel efficiency that the City used to calculate the full Phase 1 project emissions from fuel combustion. To downscale this data to the Phase 1A starter service, it was necessary to determine VKT from the BRT. To calculate this figure, an approximate distance for the trunk route was determined through use of Google Earth software, coupled with the proposed frequency of BRT trips contained in the Phase 1A Business Plan (City of Cape Town 2010a). The VKT from BRT was multiplied by its fuel efficiency, and well as the associated emissions factor for diesel fuel combustion.

### **3.3.3 Assumptions and Limitations**

The main assumptions for the greenhouse gas calculations in this study include using average figures and constant values for vehicle fuel efficiency, trip frequency, VKT and the percentage of the population projected to shift from car transport to the BRT. It was assumed when calculating CO<sub>2</sub> emissions from car trips that 100% of cars operate on petrol. Further, as data was only available for car peak-hour traffic per origin/destination, this figures were scaled up off-peak travel, including non-work days. The assumed average speed for BRT trips was taken from an international average and may differ from the actual speeds observed in the City of Cape Town. The main limitation of calculations for BRT efficiency, in comparison with baseline data for car emissions, is that no observed data is available. Therefore, all calculations for the BRT are based on assumptions for number of trips per day, as well as total VKT. Further, due to the limited scope of this study, it does not incorporate other modes of passenger transport that contribute to the carbon footprint, such as existing city bus services, minibus taxis, electric rail and future IRT feeder services. In addition, figures for BRT and car emissions do not take into account capacity of vehicles or their predicted carrying loads.

## 4 Findings

### 4.1 Introduction

The following chapter presents the overall findings of this research. The first section will discuss the results of the stated preference survey, followed by a section presenting the corresponding greenhouse gas calculations for the study area. The reliability of these findings as well as the general implications for Cape Town's carbon footprint are explored in the Discussion section.

### 4.2 Characteristics of the survey sample

A total of 79 respondents, chosen randomly, were interviewed at the Motor Vehicle Registration & Licensing Office in the City of Cape Town Civic Centre Building (CBD). Figure 4-1 below indicates details pertaining to the survey sample, according to their place of residence and place of employment. This information is presented as an overlay to the IRT Phase 1-4 Map (City of Cape Town 2010a, p. 9). A total of 56 participants interviewed (71% of the sample) currently work in or near the CBD, which forms part of the Phase 1A study area (shown in relation to IRT Phases 1-4 in Figure 2-4). Further, 84% of respondents *work* within the Phase 1A study area (indicated in green), followed by 51% of respondents who *live* within the Phase 1A study area (indicated in blue).

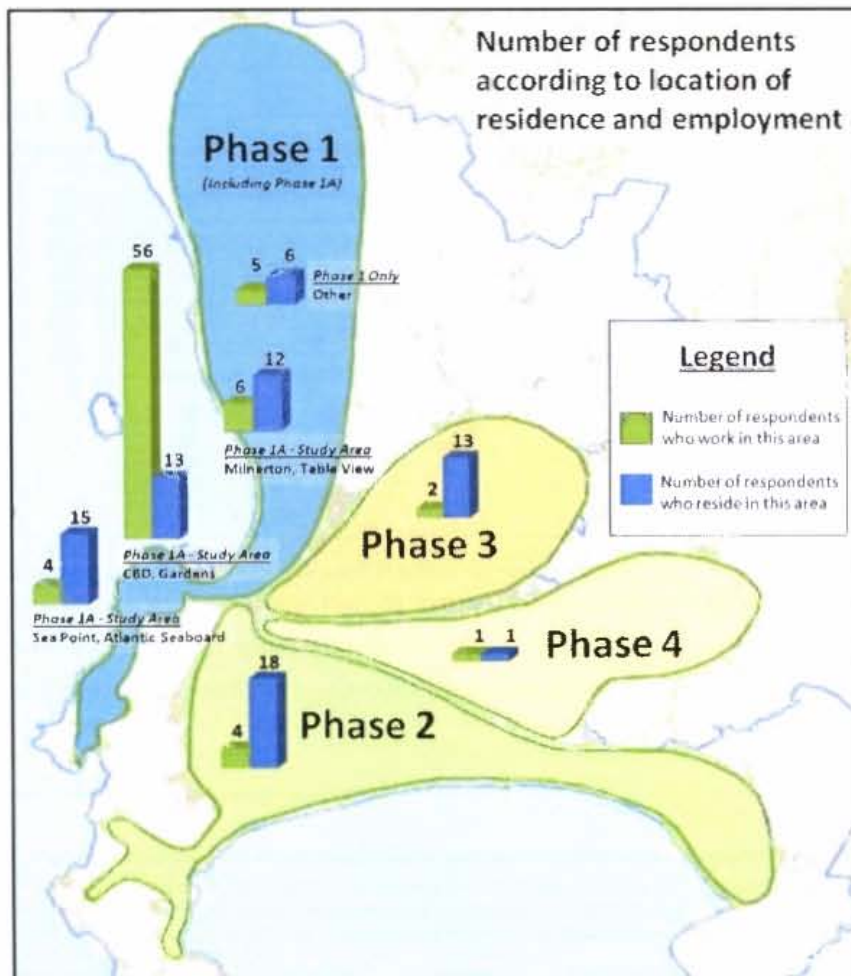


Figure 4-1: Number of respondents according to place of residence and employment, Adapted from: Phase 1A Business Plan (City of Cape Town 2010a, p. 9)

### 4.3 Demographical composition of survey sample

Demographic indicators such as race, socioeconomic status, gender and age can strongly influence travel behavior (SADoT 2005). To determine if these factors had an effect on travel preferences (and a modal shift), demographic data was gathered during the interview process to further inform the data analysis. The findings are presented below in Figure 4-2. Respondents comprised 48 males and 31 females. From the total survey sample, 54% of respondents were white, followed by 33% 'colored' or mixed race, and 13% black. The age range of respondent was approximately 20 to 70 years old<sup>33</sup>, with a mean of 35 and median of 36. This data was obtained to measure any correlation between socio-demographic indicators and travel behavior, as was measured in the National Household Travel Survey (2003) discussed in Section 2.1.2. As will be discussed further in Section 4.4.2, the survey did not measure a correlation between demographic indicators and travel preference.

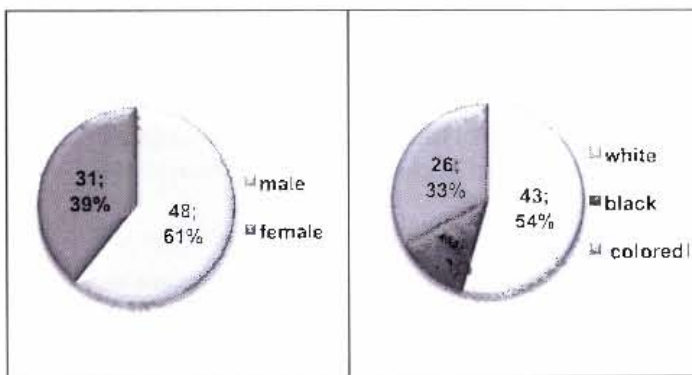


Figure 4-2: Demographic composition of sample

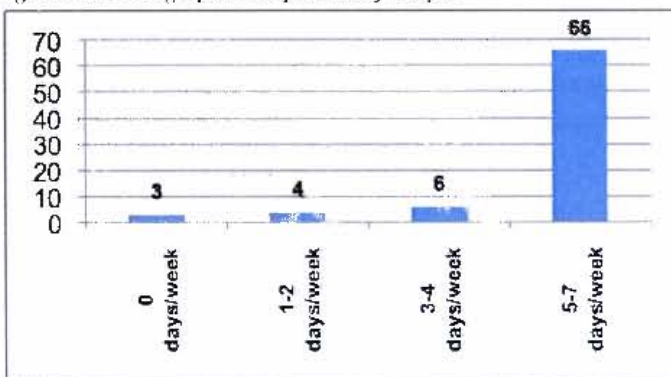


Figure 4-3: Number of days per week in which respondents drive a car

indicated it takes them less than 20 minutes, followed by 40% who take between 20-40 minutes. Lastly, approximately 20% of respondents take over 40 minutes to get to work. The demographic information and revealed travel behavior of respondents<sup>35</sup> is discussed further in Sections 4.4.1 and 4.4.2.

In addition to basic demographic information, respondents were asked in a revealed preference question how often they drove their car<sup>34</sup>. As shown in Figure 4-3, 84% of respondents indicated that they drove their car five to seven days per week, followed by 8% of respondents who drive three to four days per week. Only 9% of respondents used private transportation less than two days per week, which comprises the two columns on the left in Figure 4-3. Responses from respondents who indicated they drive two days or less per week were excluded from the SP analysis, as they were not considered as the target group. Regarding the time it takes for them to get to work, 40% of respondents

<sup>33</sup> Due to the sensitive nature of personal questions, estimates of age and race were simply based on observation and estimation.

<sup>34</sup> The survey questions did not specify the purposes for which they used their car. The purpose of this question was strictly to determine a respondent's revealed preference for private or public transport. As car users were the focus of this study, answers from respondents who drove more than three days per week were placed in the model for data analysis (discussed in Section 4.4.2) to determine the likelihood of their switching to the BRT.

<sup>35</sup> Question 15 in the survey asked participants how long their commute to work lasted. The findings from this question had no significant impact on the model fit, and has therefore been excluded from the discussion. Of respondents, 40% took less than 20 minutes to get to work, followed by 40% who took between 20 and 40 minutes. Roughly 20% of participants took 40 minutes or longer.

## 4.4 Stated Preference Survey analysis

### 4.4.1 Preliminary Results

Of the 72 respondents who drove their car more than three days per week, referred to hereafter as 'car users'<sup>36</sup>, 42% of their answers indicated a preference for taking the BRT over their car in the nine hypothetical scenarios. Of public transit users (representing the seven respondents who drove less than two days per week), a more predictable 84% of answers were in favor of taking the BRT as preferred mode of transport.

As described in Chapter 3, Question 9 in the survey<sup>37</sup> tested the assumption that car users would prefer to take private transport over the BRT if the levels for cost and time were the same. In response to this question, 88% of car users answered in favor of private transport.

Further data analysis was conducted for responses from car users. The results of the econometric analysis are discussed below.

### 4.4.2 Probability of a modal shift from car users to the BRT as preferred mode of transport, using (Discrete Choice) Multinomial Logit (MNL) Model

To analyze the data gathered from the SP Survey, the LIMDEP econometric software was used to generate a multinomial logit model (MNL). MNL is a commonly used discrete choice model, based on the theoretical underpinnings of Random Utility Modeling (Henscher, Bradley 1993), and is a useful method for estimating preferences in situations of choice (Alberni, Kahn 2006). Discrete choice analysis seeks to determine the utility that a respondent attaches to each alternative according to the attributes (or variables) (Earnhart 2001). The data analysis was conducted by Ms Dorothy Kobel, Doctoral student in the Transportation Studies program at the Department of Civil Engineering and Architecture, Planning & Geomatics, University of Cape Town<sup>38</sup>. The relevant information pertaining to understanding the model is presented below (Kobel 2011):

The model 'goodness of fit' refers to how well the model explains the data gathered from the interviews. The model fit was tested using the log likelihood (LL) test, as well as the pseudo-rho index. The LL test was used to indicate the overall significance of the model. The test compared the model results from the populated model with the results of the model fitted as if there were no explanatory variables (i.e. base model results). The populated model passes the overall significance test if the LL of the populated model is an improvement on that of the base model.

Explanatory variables are used in this analysis to explain the choices that individuals make. Inclusion of different explanatory variables can further clarify why certain choices are made over others. If an explanatory variable does not contribute to the respondent's choice, the weight attached will be zero ( $\beta=0$ ) and is considered to be statistically insignificant to choice behavior. If the explanatory variable is statistically significant (i.e. contributes to explaining the respondent's choice), the weight attached will not equal zero ( $\beta\neq 0$ ).

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<sup>36</sup> Regular car drivers/commuters have the most significant, consistent and measurable impact on the carbon footprint from passenger transport. Their consistent behavior allows for more accurate analysis of trends and their revealed preference for shifting to public transport. As such, data analysis considers those who drive at least four days per week as 'car users'.

<sup>37</sup> Refer to: 'Q9' in Table 3-2, Section 3.1.1.2; Question #9 in Appendix A

<sup>38</sup> The findings contained in Section 4.4.2 were provided by Ms Kobel, as well as the relevant information pertaining to model parameters and outputs. The information presented in the following three paragraphs of this section was obtained through direct consultation with Ms Kobel. For reference, the LIMDEP MNL model outputs to which these paragraphs refer are contained in Appendix B.

To check the results of the model and ascertain whether the explanatory variables are indeed significant, a Wald statistic test is carried out. This test generates a value represented as '*b/St.Er.*' in the model outcome<sup>39</sup>. This value is compared to a critical value set at 1.96 (similar to the t-test, the critical value taken at a 95% confidence level represents the value at which there is a 5% chance that the result is wrong. If the Wald value is greater than the critical value, then the explanatory variable can be said to contribute significantly to the respondent's choice, and the reverse is true. The probability (p- value), represented as '*P[|Z|>z]*' in the output table, compares the Wald value to the 95% confidence level that the parameter  $\beta$  is statistically equal to zero. If the value is less than 5%, (100-95), the parameter can be said to be statistically significant, and the reverse is true (Hensher, Rose & Greene 2005, p. 343).

To achieve the strongest relationship between the variables, the model was run several times, selectively including different independent variables. Initial analysis included main explanatory variables only (mode of transport, time, cost and comfort), which did not result in a good fit<sup>40</sup>. This lack of model fit indicated possible flaws in the design of the survey, specifically relating to omission of statistically significant explanatory variables (refer to Chapter 5 for further discussion).

To compensate for the lack of model fit, the insignificant variables were excluded from the model, as well as including select demographic data discussed in Section 4.3 as additional explanatory variables. Specifically, including the variables for number of days per week that car users drove, as well as the length of time respondents observe in their daily commute, the overall model fit achieved was within statistically acceptable parameters. The variables of age, race and gender of respondents did not seem to significantly impact decisions pertaining to travel behavior and were therefore excluded from the final analysis. It is important to note that the National Household Travel Survey (2003) discussed in Section 2.4.1 measured a correlation between these socio-demographic indicators and travel behavior. The fact that this survey did not find this same correlation, contrary to the findings from the National Household Travel Survey, is mostly likely due to small sample size as well as SP survey design flaws. The explanatory variables shown in Table 4-1 were included in the final analysis, as they were found to have a significant impact on choice:

SP data	RP data
<ul style="list-style-type: none"> <li>• <i>transport mode</i></li> <li>• <i>cost</i></li> <li>• <i>time</i></li> </ul>	<ul style="list-style-type: none"> <li>• <i>how many days per week respondents drive</i></li> <li>• <i>how long it takes to get to work</i></li> <li>• <i>whether or not respondent works in CBD</i></li> </ul>

**Table 4-1: Explanatory variables which have a significant impact on choice**

After excluding all insignificant variables, the average probability among car users to choose the BRT as preferred mode of transport was determined to be 0.35. This value has been equated to a 35% modal shift from private transport to BRT, represented hereafter in Scenario B.

<sup>39</sup> Refer to Appendix B.

<sup>40</sup> The results from this analysis are shown in page 1 of Appendix B.

## 4.5 The impact of a modal shift on the carbon footprint

This section details the process and findings from carbon footprint calculations associated with car VKT within the study area. All figures regarding emissions factors and fuel efficiency are based on available literature. While fuel efficiency of vehicles is dependent on load and capacity, these fluctuations were not considered for the purposes of these calculations.

### 4.5.1 Total number of peak-hour car trips within the study area: using data from the City of Cape Town origin/destination matrix

The five origin/destination (OD) zones, indicated in Figure 4-4 for easy reference, are Sea Point, Gardens, Central Business District (CBD), Woodstock, Milnerton and Table View.



Figure 4-4: Location of origin/destination zones in relation to Cape Town's Phase 1A starter trunk route for BRT

Peak-hour car trips per origin and destination, as provided by City of Cape Town (2010d), are shown in Table 4-2, rounded to the nearest whole number.

		Destination						Total
		CBD	Woodstock	Gardens	Sea Point	Milnerton	Table View	
Origin	CBD	304	118	195	190	160	251	1,219
	Woodstock	269	263	64	67	84	77	823
	Gardens	648	163	377	154	106	26	1,474
	Sea Point	673	174	61	482	110	112	1,512
	Milnerton	513	189	37	80	954	363	2,135
	Table View	940	262	37	76	723	4,109	6,147
	Total	3,346	1,169	771	1,048	2,137	4,938	13,409

Table 4-2: Cape Town's Origin/Destination Matrix reduced to study area only - number of car trips per peak hour

The left-hand column in Table 4-2 shows the point of origin for each car trip; each subsequent column represents a destination point. Car trips originating and terminating within the same zone (for example, beginning in CBD and ending in CBD) are indicated in grey. The total number of car trips per peak morning hour (2010) is about 13,400. Table View had a relatively large number of peak-hour car trips contained within its zone, with roughly 4,100 per peak hour. Given its relatively large land-area, it is not especially surprising that more trips would occur than in other areas. However, the number of car trips within the Table View area seemed to be unusually high, especially in comparison to Milnerton, with a larger land area. While it is reasonable to assume that there would be a large number of car trips originating in Table View during peak traffic hours, one would assume that the majority of these trips would terminate in areas of higher commercial activity.

As car traffic data from these locations would form the basis of carbon footprint calculations for this study, the researcher wanted to verify the plausibility of such high car traffic volumes occurring in Table View, to ensure that the information provided was accurate. Using 2008 socioeconomic data obtained from the City of Cape Town (2008b, 2008d), the researcher cross-referenced population size and income-levels for different zones in the metropolitan area. Durbanville, a zone located outside the study area with comparable car traffic and population to Table View, was used for the purpose of comparison (City of Cape Town 2010d, 2010e). While residents of Durbanville had generally higher income levels than those in Table View, the percentage of population earning above R36,000 per year was approximately the same, at roughly 85%. This threshold is significant, according to the NHTS (2003), as 68% of South African households earning above R36,000/year<sup>41</sup> have access to a car (SADoT 2005). Further, households above this income level make 23% more trips per day than those below the threshold (SADoT 2005, p. 18). More importantly, almost 2/3 of residents in Table View and Durbanville areas earn at least four times that much (City of Cape Town 2008d). This significantly increases the likelihood that residents in these locations would drive a car for their daily travel needs.

<sup>41</sup> The salary threshold from 2003 NHTS has not been adjusted to 2008 values, despite a five-year gap in data between the socioeconomic figures and Travel Survey findings. This is not believed to cause a significant influence the findings, as this exercise was used solely to determine if traffic counts from Table View were erroneous or reliable. To do so, salary ranges were compared for residents in two suburbs with similar traffic counts and number of residents, namely Table View and Durbanville. The important finding from this exercise is that the income distributions within the two suburbs were nearly identical to one another (slightly lower income in Durbanville). Adjusting the salary threshold to 2008 figures did not significantly change the similarity in income distribution, nor did it affect the overall outcome of this finding.

Further data from the National Household Travel Survey (2003) assists in determining plausibility of Table View traffic counts. In the Western Cape, for example, 41% of daily trips in metropolitan areas are for travel to work. However, a sizeable portion of these trips are to travel to educational facilities (33%) and shopping centers (26%) (SADoT 2005, p. 10). Taking these transport statistics into consideration, it is reasonable to assume that a sizeable portion of car trips originating and terminating within Durbanville and Table View, predominantly residential areas, are for taking family members to and from school, as well as to go shopping. Given the relatively high income level of residents in both areas, as well as their similar, low-density urban form, it is likely that the vast majority of daily trips are made by car. Further, as 59% of car trips in Western Cape metropolitan areas are made for non-work purposes, a high number of trips originating and terminating relatively close to one's place of residence is likely to occur. Taking into consideration the relevant transportation statistics, similar traffic counts<sup>42</sup>, as well as income-levels from the two locations, this suggested that the data provided for Table View in Table 4-2 was feasible, and would be used accordingly.

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<sup>42</sup> Durbanville car trips originating and terminating within its zone total above 5,000.

#### 4.5.2 Peak-hour vehicle kilometers traveled from car trips

To estimate the number of VKT associated with the origin/destination matrix, it was necessary to determine distances between each zone. These figures are indicated below (rounded to the nearest 100 m) in Table 4-2.

		Destination					
		CBD	Woodstock	Gardens	Sea Point	Milnerton	Table View
Origin	CBD	1.5	3.4	2.7	4.9	18.1	22.2
	Woodstock	3.4	1.5	5.7	7.8	14.6	19.3
	Gardens	2.7	5.7	1.0	5.8	18.6	20.8
	Sea Point	4.9	7.8	5.8	1.5	19.0	22.5
	Milnerton	18.1	14.6	18.6	19.0	22.5	11.8
	Table View	22.2	19.3	20.8	22.5	11.8	3.0

Table 4-3: Average length of trip between each location (in km)

As indicated in Chapter 3, the distances between locations were calculated by averaging the length of routes suggested in 'Google Maps – Get Directions' feature (Google 2011). The origins and destinations used for calculating distances between locations were placed in the center of each respective location, as suggested by Google destination search. For this reason, the distance from Table View to CBD, for example, and the distance from Table View to Sea Point, only differs by 200 meters. The reason for this is that the distance calculated to CBD is not to its perimeter, but rather its center. For trips contained within each zone, for example from CBD to CBD, an approximate length was used, based on the relative size of each location and an average length of trips contained therein.

To calculate the total car VKT (per peak hour), the matrices from Table 4-2 (number of car trips) and Table 4-3 (distance traveled) were multiplied. The total car VKT per peak-hour (2010) came to approximately 103,000 VKT, as indicated in the lower right-hand cell of Table 4-4.

		Destination						Total
		CBD	Woodstock	Gardens	Sea Point	Milnerton	Table View	
Origin	CBD	457	397	517	932	2,892	5,573	10,767
	Woodstock	901	394	363	522	1,225	1,486	4,890
	Gardens	1,716	926	377	886	1,967	541	6,414
	Sea Point	3,295	1,357	352	723	2,086	2,519	10,333
	Milnerton	9,280	2,755	682	1,507	2,863	4,283	21,370
	Table View	20,871	5,065	776	1,703	8,527	12,326	49,268
	Total	36,520	10,895	3,068	6,272	19,559	26,727	103,042

Table 4-4: Car VKT within the study area per peak traffic hour

### 4.5.3 Scaling up peak-hour car VKT to represent total yearly VKT

To calculate yearly car VKT from peak-hour estimates, it was necessary to determine what portion of the total car VKT was associated with peak-hour traffic. City of Cape Town - Department of Transport provided observed bus and minibus taxi traffic counts taken in 2010 at three bus stations in the metropolitan area. The traffic counts, while not specifically including private transport, do provide a good indication of peak travel times. Using this assumption, the ratio of off-peak to peak-hour traffic was measured according to traffic volume per 15-minute interval. This data is presented below in Figure 4-5. It is important to note that while traffic counts were not taken for late night hours, these numbers were assumed to be negligible and were not considered for this study.

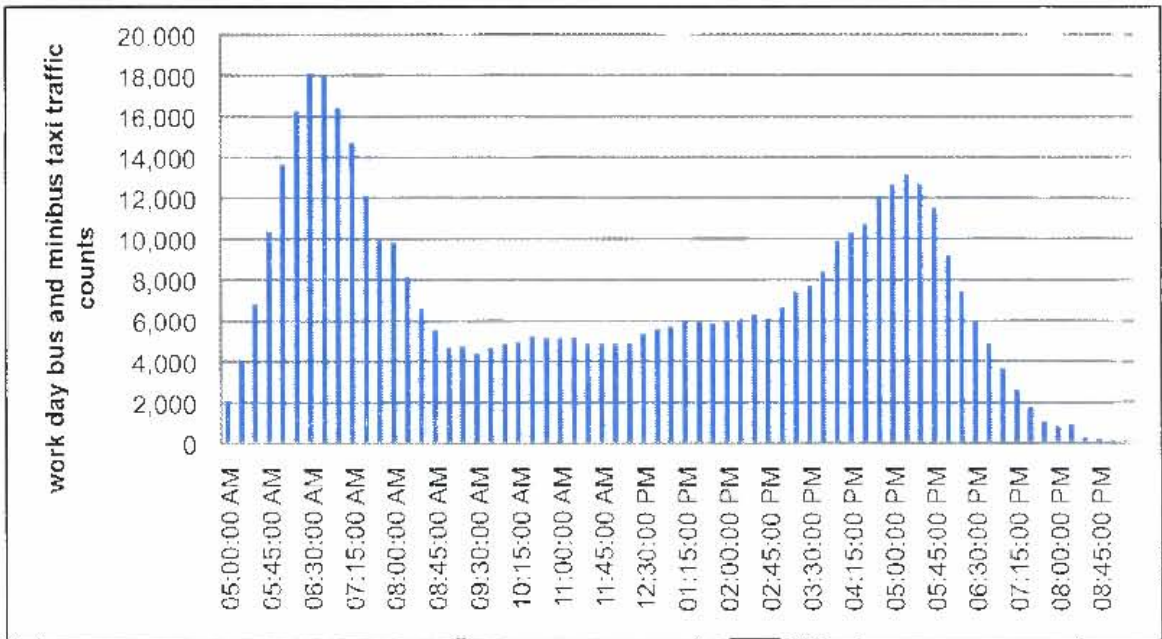
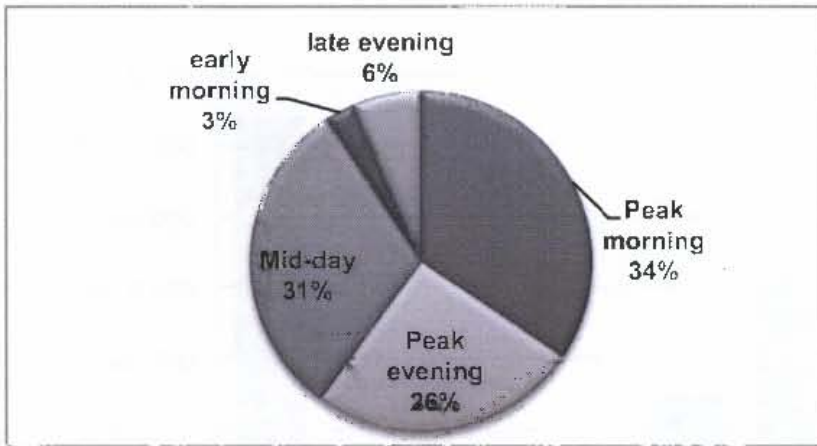


Figure 4-5: Workday traffic count (buses and taxis) taken from three bus stations in Cape Town (City of Cape Town 2010e)

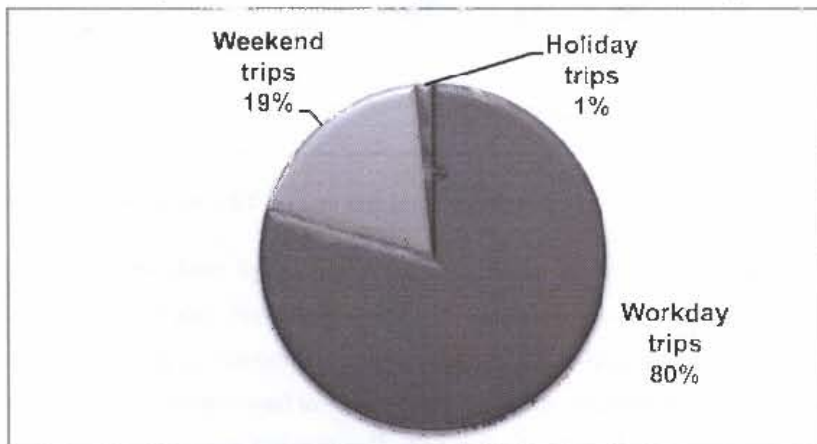
From the data in Figure 4-5, the researcher determined that peak traffic conditions (considered roughly at 8,000 traffic counts per 15-minute interval) exist for approximately 5.5 hours per work day<sup>43</sup>. Assuming that trends for bus and taxi traffic in Figure 4-5 can be directly correlated to transport demand among car users, peak-hour car VKT were multiplied by 5.5 hours to determine the total peak-hour car VKT per work day, for a total of 566,729 peak-hour car VKT per work day. Further, according to data presented in Figure 4-5, peak-hour traffic accounted for 60% of the total workday traffic volume. Off-peak car VKT per day represented the remaining 40%, as shown below in Figure 4-6. Off-peak workday traffic came to 377,819 VKT, for a total of 944,548 car VKT per workday in the study area.

<sup>43</sup> The traffic counts presented in this figure which reach >8,000 per 15-minute interval actually work out to 5.25 hours per work day. However, peak conditions change slightly (higher or lower) depending on which traffic data from three stations are included. Rather than underestimating the number of peak hours and subsequent emissions from car trips, it was decided to use the maximum 5.5 peak hours per work day.



**Figure 4-6: Workday road traffic volume in Cape Town - according to time of day**  
*Data source: Bus and minibus taxi traffic counts (City of Cape Town 2010e)*

To determine the ratio of workday car trips per year to weekend car trips per year, the corresponding traffic counts for Saturdays and Sundays (not pictured) were analyzed along with the workday traffic data shown in Figure 4-5. It was assumed that there are a total of 250 workdays per year (just under 21 per month), 52 Saturdays and Sundays, as well as 11 public holidays. As there were no traffic counts attributed to public holidays, these were assumed to be similar to Sunday traffic data. Data from Saturdays and Sundays were combined to represent total weekend trips. The results are shown in Figure 4-7.



**Figure 4-7: Percentage of yearly car traffic volume in Cape Town**  
*Data source: Bus and minibus taxi traffic counts (City of Cape Town 2010e)*

As seen above, the total number of workday trips accounted for 80% of the yearly total, followed by 19% on weekends and 1% from public holiday travel. Total yearly VKT, based on the ratio shown above, are indicated below in Figure 4-8.

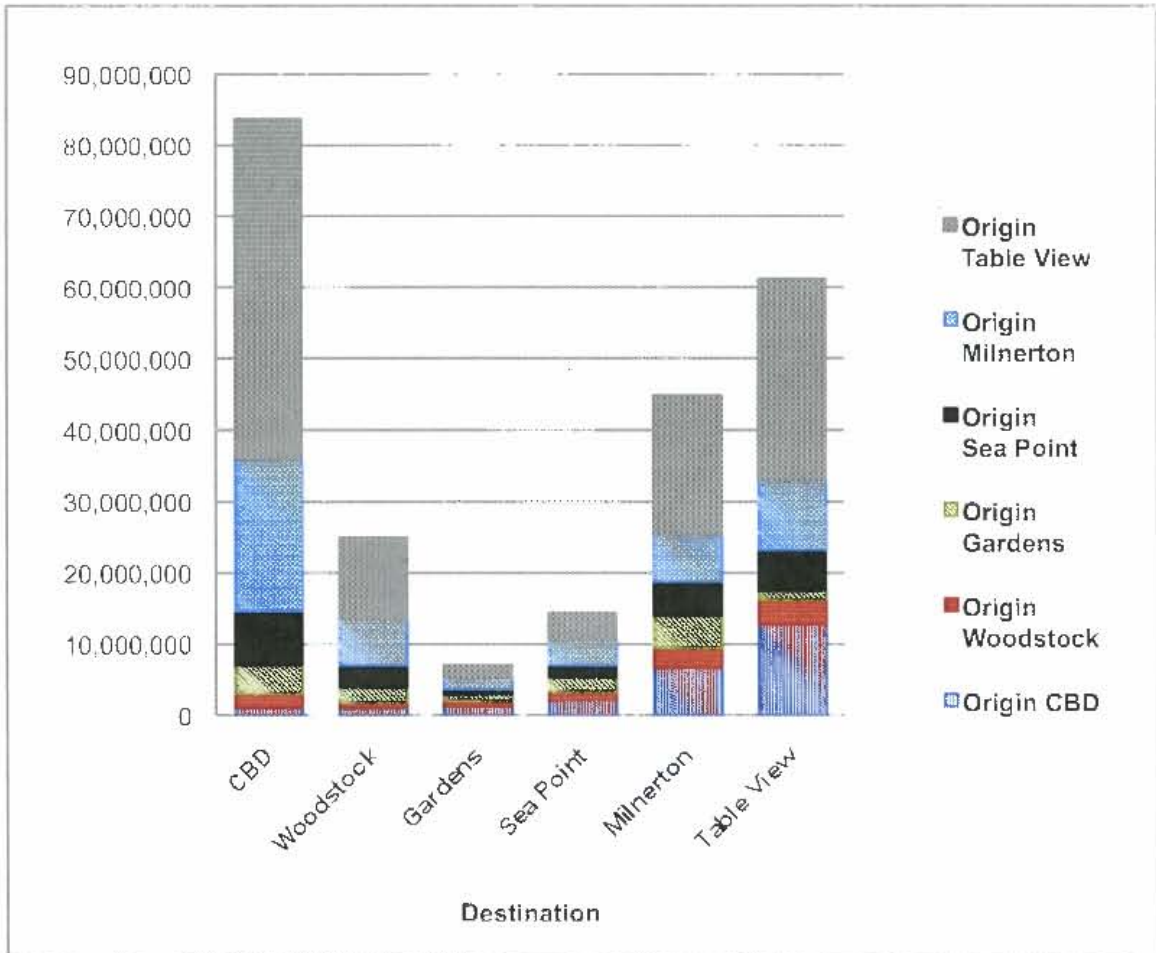


Figure 4-8: Total car VKT per year (per origin/destination)

In the above figure, trips originating from each location are indicated according to color coding in the legend on the right. For example, car trips originating in Sea Point are shown in black. The x-axis (bottom) indicates the trip destination. Trips originating and terminating in Gardens represent the smallest portion of total VKT, which is proportional to its relatively small size and population. The total VKT per year in the study area came to approximately 295 million<sup>44</sup>. The majority of car VKT originate in Table View, with 48% of the total, followed by 21% originating in Milnerton. Car trips terminating in CBD account for 35% of the total VKT, followed by Table View (with 26%) and Milnerton (19%).

<sup>44</sup> The *City of Cape Town Integrated Transport Plan* (2009b) and the *City of Cape Town Five-Year Plan* (City of Cape Town 2010c) state that the total yearly traffic on the City's road network totals to just 90 million VKT per annum. This statement is believed to be erroneous, based on the following information: the 2010 passenger transport carbon footprint was approximately 4.2 million tCO<sub>2</sub>e (UCT, SEA 2011), the average efficiency for petrol-operated vehicles in South Africa is 9.5 L/100 km (Letete et al. 2010); the emissions factor for petrol is 2.3307 kgCO<sub>2</sub>e/L (DEFRA 2010). If only 90 million VKT are travelled per year in Cape Town, that amounts to less than 20,000 tCO<sub>2</sub>e. Even if all 90 million VKT were conducted by diesel buses (with 66.7 L/100 km fuel efficiency and emissions factor of 2.6694 kgCO<sub>2</sub>e/L), this still only amounts to just over 160,000 tCO<sub>2</sub>e, a small fraction of the total passenger transport carbon footprint in Cape Town.

#### 4.5.4 Translating car VKT (2010) to baseline carbon footprint

Using an average car efficiency in South Africa of 9.5 L/100 km (Letete et al. 2010) and an emissions factor of 2.3307 kg CO<sub>2</sub>e/liter for petroleum combustion<sup>45</sup> (DEFRA 2010), the researcher determined the baseline CO<sub>2</sub>e from car trips within the study area to be 65,356 tCO<sub>2</sub>e/year, as shown in Table 4-5.

Day of the week	Total car vehicle kilometers travelled (in VKT/y)	fuel efficiency (in L/1km)	emissions factor (in kg CO <sub>2</sub> e/L)	Net Emissions (in tCO <sub>2</sub> e/q)	Percentage of car emissions
Weekday peak hour	141,682,225	0.095	2.3307	31,371	48%
Weekday off-peak	94,454,817	0.095	2.3307	20,914	32%
weekends	56,082,548	0.095	2.3307	12,418	19%
holidays	2,951,713	0.095	2.3307	654	1%
<b>Total baseline (2010) carbon footprint from car trips</b>				<b>65,356</b>	

Table 4-5: Baseline carbon footprint (2010) from car trips within the study area

#### 4.5.5 Projected emissions for starter BRT trunk route operation in year one

Data for estimating BRT emissions in the City of Cape Town was provided in the Phase 1A Business Plan, as well as the baseline greenhouse gas calculations commissioned by the City for their CDM application (Lopez 2008). As estimated in the City of Cape Town CDM calculations, the 18 m articulated buses have an average fuel efficiency of 0.667 L/km<sup>46</sup> (Lopez 2008). Further, Phase 1A BRT vehicles operate at a frequency of 14 buses per peak hour (City of Cape Town 2010a). To downscale the CDM calculations for the Phase 1A study area during peak hours, the researcher used the previous assumption of 5.5 peak hours per workday and 250 work days per year. Using an approximate length of 19.63 km for the Phase 1A BRT starter route, as measured using the Google Earth software, and an average BRT speed of 37.5 km/hr<sup>47</sup> (USDOT 2004, pp. 3-7), it was determined that one starter route BRT bus can make approximately 1.91 trips per hour. Based on this information, the yearly peak-hour VKT from the Phase 1A - BRT starter route came to 721,875, as indicated below in Table 4-6.

<sup>45</sup> It was assumed that all cars in the study area operate on petroleum (rather than diesel).

<sup>46</sup> It is worth noting that newer fleets of BRT vehicles have achieved much better fuel efficiency than 0.667 L/km, among other reasons, due to fuel type (compressed natural gas or CNG) as well as hybrid diesel/electric fuel combustion (Levinson et al. 2003; Wright and Fulton 2005; Vincent, Jerram 2006). The City of Cape Town used the fuel efficiency of 0.667 L/km for its BRT carbon footprint calculations based on the observed fuel efficiency of the *Transmilenio* fleet in Bogota (Lopez 2008). *In situ* fuel efficiency data was not available at the time of conducting this research for the 18 m buses to be used in Cape Town (consisting of a Marcopolo-assembled frame on a Volvo chassis, powered by Volvo DHI2 engine) (Volvo 2011a; 2011b). For a conservative estimate on net reduction of the carbon footprint, 0.667 L/km was assumed for BRT fuel efficiency, as per Cape Town CDM calculations.

<sup>47</sup> USDOT indicates that average BRT speeds are between 48 and 27 km/h. Much higher speeds of 80 km/h have been observed in some Australian BRT networks such as Adelaide (Levinson et al. 2003; Currie 2006). As stated above, the BRT starter route is projected to utilize a frequency of 14 BRT vehicles per peak hour at four-minute intervals at each stop (City of Cape Town 2010a). Given the relatively short distance between each stop, it was assumed that Cape Town's BRT vehicles will not achieve such high speeds. Subsequently, the average speed from USDOT figures was used for these calculations.

Day of the week	Total BRT vehicle kilometres travelled (in VKT/y)	fuel efficiency (in L/1km)	emissions factor (in kg CO <sub>2</sub> e/L)	Net Emissions (in tCO <sub>2</sub> eq/y)	Percentage of yearly BRT emissions
Weekday peak hour	721,875	0.667	2.6694	1,285	48%
Weekday off-peak	481,250	0.667	2.6694	857	32%
weekends	285,742	0.667	2.6694	509	19%
holidays	15,039	0.667	2.6694	27	1%
<b>Total yearly carbon footprint from Phase 1A – BRT starter route</b>				<b>2,678</b>	

Table 4-6: Added carbon footprint from Phase 1A – BRT starter route (in tCO<sub>2</sub>eq/y)

Using the same scaling ratio from calculating car VKT in Section 4.5.3, it was assumed that peak-hour VKT from the BRT represented 60% of workday VKT. Off-peak BRT VKT per year, representing the remaining 40%, came to 481,250 VKT/ year. As with car trips, workday VKT for BRT was assumed to represent 80% of the yearly total. The yearly percentages are indicated in the far right column in Table 4-6. The same break down of 250 workdays, 52 Saturdays and Sundays, and 11 holidays was used for this estimate. Using an emissions factor of 2.6694 kg CO<sub>2</sub>e/liter for diesel fuel (DEFRA 2010) the total carbon footprint from the Phase 1A – BRT starter route came to 2,678 tCO<sub>2</sub>eq/y.

#### 4.5.6 The net reduction in carbon footprint as a result of BRT implementation

Calculations for the impact of the BRT on the carbon footprint of the study area are presented using a scenario-based approach. To calculate the change in emissions in each scenario, the researcher reduced the total number of peak-hour car trips by 10% (Scenario A) and 35% (Scenario B), respectively. Trips that originated and terminated within the same zone (for example, beginning in Woodstock and ending in Woodstock) were assumed to be relatively unaffected by implementation of the BRT. That is, there was assumed to be no modal shift for these trips, as the BRT starter route has limited stops within each zone, with the exception of Milnerton<sup>48</sup>. As such, car transport emissions contained within each zone were kept at baseline levels for both scenarios. The net CO<sub>2</sub> emissions for each scenario are shown below in Figure 4-9, followed by descriptions for the respective Scenarios A and B.

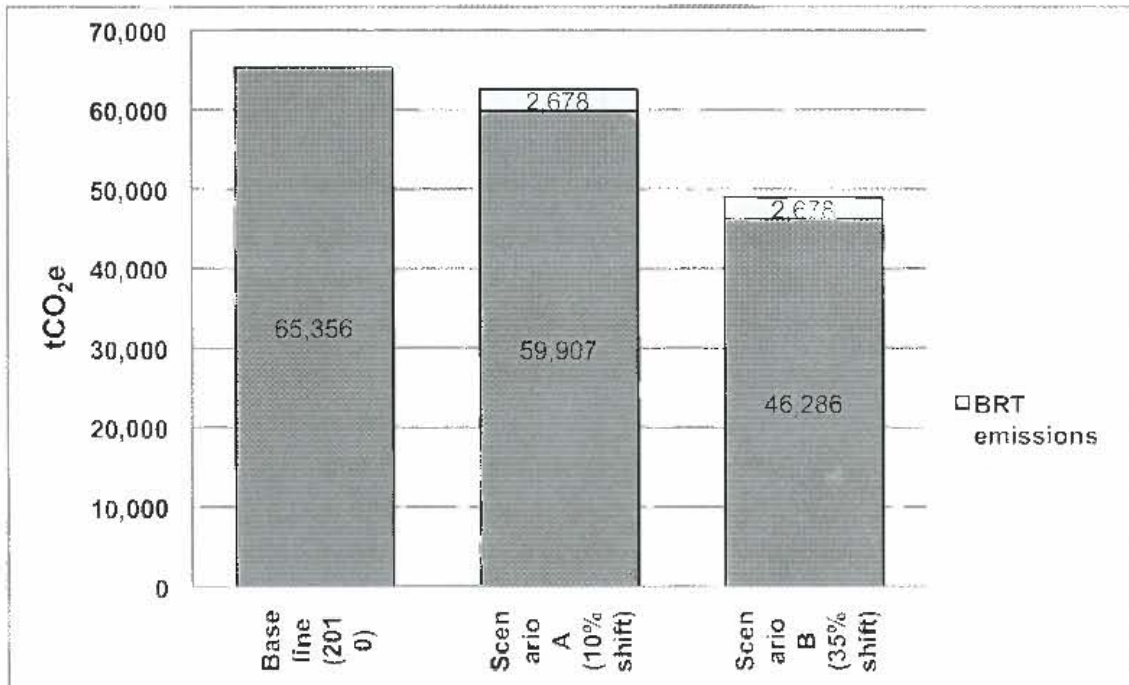


Figure 4-9: Net CO<sub>2</sub> emissions from a modal shift to BRT

<sup>48</sup> While the BRT may be useful for some residents traveling within Milnerton, there are still several square kilometers that are not within walking distance to the BRT. This scope of this study does not take into account existing and future feeder services. For this reason, as well as for the sake of consistency, the modal shift pertaining to car trips contained within each zone was considered to be zero. Further, while it is likely that some BRT users will drive their car and park near a BRT station, these added car trips were not considered for this calculation.

#### 4.5.7 Scenario A: Reduced emissions from a 10% modal shift from cars to BRT

Scenario A represents the net reduction in car-related carbon emissions according to the City's projection of a 10% modal shift from private transport to the IRT system (City of Cape Town 2010a). To calculate this reduction, the baseline number of peak-hour car trips from the origin/destination matrix (Table 4-2) were reduced by 10%. The results are shown below in Table 4-7.

		Destination						Total
		CBD	Woodstock	Gardens	Sea Point	Milnerton	Table View	
Origin	CBD	304	107	176	171	144	226	1,127
	Woodstock	242	263	57	60	75	69	767
	Gardens	583	146	377	139	95	23	1,364
	Sea Point	605	157	55	482	99	101	1,499
	Milnerton	461	170	33	72	954	327	2,017
	Table View	846	236	34	68	650	4,109	5,943
	Total	3,042	1,079	732	992	2,018	4,855	12,717

Table 4-7: Scenario A - Origin/Destination matrix after 10% modal shift from cars to BRT

With exception, as explained previously in this section, trips originating and terminating in the same location remained the same as the baseline figures (indicated in grey in Table 4-7). The total peak-hour VKT in Scenario A were subsequently reduced by only 5% from the baseline of 13,409 in Table 4-2 to 12,717 VKT/peak hour. The same process of scaling from Section 4.5.3 was used to determine total yearly VKT and subsequent CO<sub>2</sub>e under a 10% modal shift.

If 10% of car trips within the study area were to shift to the BRT, the net carbon footprint from cars would decrease by 2,771 tCO<sub>2</sub>e from 2010 levels, as shown in Figure 4-9. The net emissions of 62,585 tCO<sub>2</sub>e for Scenario A (Figure 4-9) represent only a 4% net reduction in car-related emissions.

#### 4.5.8 Scenario B: Reduced emissions from a 35% modal shift from cars to BRT

The SP survey conducted for this study indicated a probability of 0.35 that car users would take the BRT starter service, equating this to a 35% modal shift. The same process conducted for Scenario A was followed to reduce the baseline VKT from the origin/destination matrix (maintaining baseline levels for intra-zonal car trips). The resulting car peak-hour VKT after a 35% modal shift are shown in Table 4-8.

		Destination						Total
		CBD	Woodstock	Gardens	Sea Point	Milnerton	Table View	
Origin	CBD	304	77	127	124	104	163	899
	Woodstock	175	263	41	43	55	50	627
	Gardens	42	106	377	100	69	17	1,090
	Sea Point	437	113	40	482	72	73	1,216
	Milnerton	333	123	24	52	954	236	1,722
	Table View	611	17	24	49	470	4,109	5,433
	Total	2,281	852	633	850	1,723	4,647	10,987

Table 4-8: Scenario B - Origin/Destination matrix after 35% modal shift from cars to BRT

Peak-hour car VKT were reduced by a total of 18% from the baseline of 13,409 to 10,987. Following the same scaling process, the total net emissions for Scenario B (shown in Figure 4-9) were 48,964 tCO<sub>2</sub>eq/y. The subsequent net reduction from baseline levels would be 16,392 tCO<sub>2</sub>eq, or a 25% decrease in emissions.

## 5 Discussion

The City of Cape Town has proposed the expansion and integration of existing public transport services to, among other deliverables, mitigate the impacts of carbon emissions from passenger transport. Naturally, for any such system to be effective in reducing car-related emissions, its implementation must provide incentive for a sizeable portion of the car-driving population, estimated at 43% of Capetonians in 2006 (City of Cape Town 2008d) and increasing at 3.4% per annum (City of Cape Town 2009b), to choose public transport options instead. One of the aims of this research was to predict how many of those car-drivers would switch to the new BRT service, which was achieved through conducting an SP survey. Based on this prediction, this study sought to determine the impact of their mode switch on the carbon footprint of the City of Cape Town. This chapter first discusses the results of the SP survey, including its efficacy as a research method and the implications of its findings. The latter portion of this section analyzes the results from the carbon footprint calculations for Scenarios A and B, followed by their larger implications for mitigation of passenger transport emissions in Cape Town.

### 5.1 SP Survey as a research method: Reliability of the findings

As discussed in Chapter 2, a large body of literature praises the stated preference method in market research, particularly in predicting travel behavior. Certainly this method has considerable potential in predicting respondents' behavior and has been credited with achieving far more accurate results than traditional, revealed-preference methods (Hensher, Barnard & Truong 1988; Carlsson 2010). There are, however, some significant shortcomings of this technique, particularly to an unseasoned researcher. It appears in retrospect that proper execution of the SP survey would have required a longer timeframe than was available to conduct the research. In the six-month period of time available for this study, it was simply not possible to sufficiently master the statistical design procedure, conduct a suitable public participation process to identify all relevant variables, administer a pilot survey and fine-tune the scenarios prior to conducting the interviews. All of these design elements are essential to constructing a statistically valid survey and for producing a reliable model for predicting behavior. Not using statistical experimental design for developing the survey is thus recognized as responsible for introducing flaws in the design process. Achieving more certainty from the survey projection of travel behavior would require correcting flaws in the design and re-administering the survey according to preferred methodology. Therefore, while Scenario B was based on a 35% modal shift, it is difficult to ascertain whether or not this is a sensible and reliable projection. For this reason Scenario A (based on the City's conservative projections of a 10% modal shift) was retained in the analysis for comparison.

#### 5.1.1 Potential flaws in stated P survey process

Data analysis of the survey indicated that while the main attributes were mostly significant, the results in the initial model run did not indicate a strong *rho*-squared<sup>49</sup>. This implied that some attributes significantly contributing to respondent choice may have been omitted from the model (Kobel 2011). There are several possible reasons why the model fit was not optimal, in addition to design flaws. First, it is likely that the

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<sup>49</sup> Refer to "R-sqrd" on page 1 of Appendix B.

quickly-paced, five-minute interview (conducted while respondents stood in the queue for vehicle registration) was not an ideal survey technique. This could have contributed to respondent bias/fatigue. Thus, it is difficult to determine if respondents' answers were well-considered, true representations of their travel behavior in relation to the hypothetical BRT scenarios. A way to overcome possible bias to re-administer the survey in the future would be to dedicate more time to individual interviews to enable proper explanation of the survey methodology and to allow respondents adequate time to fully consider their responses in the context of each scenario.

As highlighted in Chapter 2, travel behavior is complex and difficult to predict, as it depends on a number of variables. In addition to the attributes of cost, time and comfort, other possible attributes affecting respondents' choice behavior likely include convenience/flexibility, proximity of transport mode to origin/destination of traveler, how many transfers are needed for the trip, waiting time on the platform, security, as well as availability of parking facilities. Further, feeder routes were excluded from this study given their added complexity and an associated lack of data available. While it was necessary for the scope of this research to reduce the number of attributes included the SP survey, identifying pertinent attributes through a pre-screening/pilot process and including them in the scenarios through statistical design would improve the reliability of this data.

## **5.2 Reducing the carbon footprint from passenger transport in Cape Town**

Through its international commitments as a Party to the UNFCCC and a signatory under the Kyoto Protocol and Copenhagen Accord, the South African government has indicated that it recognizes the importance of climate change mitigation, as well as its role in reducing its contribution to global greenhouse gas emissions. Informed by, amongst other drivers, the National Climate Change Response Strategy, the City of Cape Town has compiled a series of plans and policies to implement a response to climate change, as discussed in Chapter 2. Emphasizing holistic and integrated approaches to reducing emissions, the City's transport goals highlight the implementation of a reliable public transportation system, including infrastructure for non-motorized transport (NMT), as well as encouraging an efficient urban form. Acknowledging the role of sustainable transportation in improving local air quality and reducing global emissions, the IRT network is the City's keystone effort to curb the growth in car ownership. While utilizing existing transport infrastructure, such as LRT and minibus taxis, BRT will be integrated as the newest mode of transport in Cape Town. Scores of cities around the world, each with unique planning challenges, have proven that BRT can be a cost-effective tool for reducing the number of VKT and associated greenhouse gas emissions from passenger transport (McManus 2006, p. 48; Satterthwaite 2007; Currie, Wallis 2008; Santos, Behrendt & Teytelboym 2010; Hensher, Golob 2008; Levinson et al. 2002; Jarzab, Lightbody & Maeda 2002). In particular, BRT has proven to be financially viable in areas of low density, where other forms of transport, such as rail-based options, are too expensive to operate (Levinson et al. 2003; Carey 2002; Falbel et al. 2006). Specifically, BRT infrastructure can cost up to 20 times less than an LRT equivalent, and between 10 to 100 times less than a metro rail-based system with the same coverage (Hensher, Golob 2008, p. 502).

While the SP survey findings were an attempt to predict travel behavior, the scenarios presented in this study should not be considered as predictions of the future. Rather, scenarios are best used to "analyze the consequences of certain policies or measures" (Uherek et al. 2010). With this in mind, the accuracy of modal shares projected in Scenarios A and B is less important. Instead, the scenarios are used as a tool to examine the

impact of the IRT network on the carbon footprint. Reproduced below in Figure 5-1 for easy reference, the total carbon footprint of the City of Cape Town in 2010 was approximately 17 million tCO<sub>2</sub>eq (UCT, SEA 2011, p. 14). Of the total footprint, roughly 4.2 million tCO<sub>2</sub>eq in 2010 came from passenger transport emissions, or approximately 25% of the total emissions.

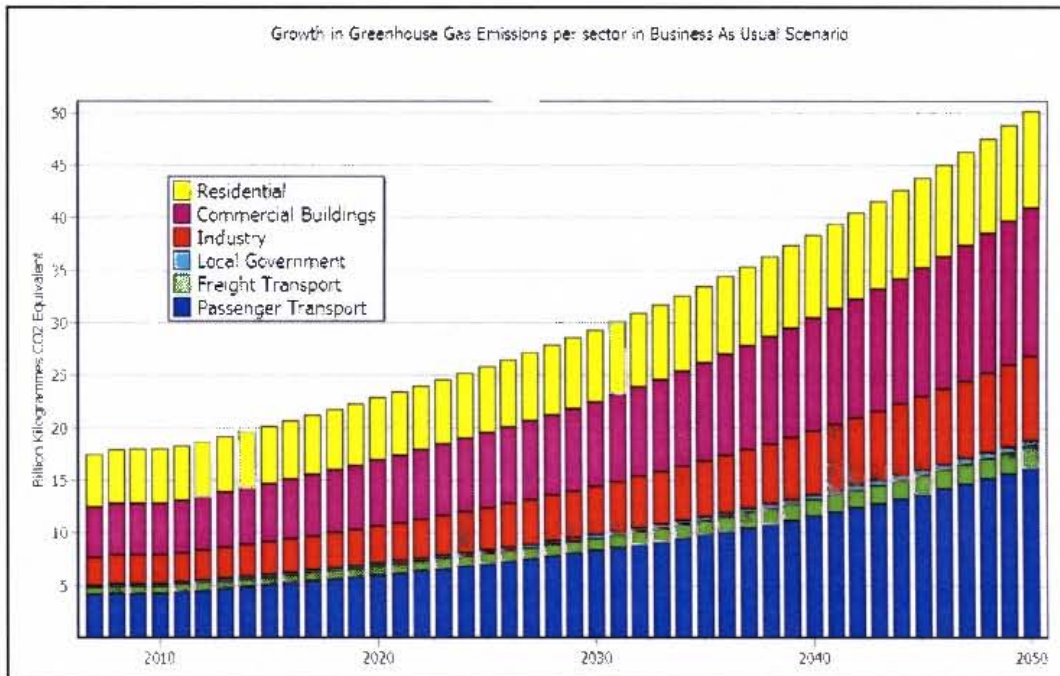


Figure 5-1: 'Growth in Greenhouse Gas Emissions per sector in Business as Usual Scenario' (UCT, SEA 2011, p. 14)

The study area baseline figure of 65,356 tCO<sub>2</sub>eq therefore accounts for less than 2% of the total 2010 passenger transport emissions in Cape Town. Subsequently, Scenario A (10% modal shift) accounts for an approximate net reduction of 0.07% of the total passenger 2010 transport emissions. Scenario B (35% modal shift) represents about 0.39% net reduction in passenger transport emissions. Given that the car trips analyzed within study area only represent a small fraction of traffic volume in Cape Town, this insignificant impact on the total carbon footprint of passenger transport is not surprising. To speculate how a system-wide modal shift might impact the carbon footprint, the net emissions were scaled up to represent the entire footprint of passenger transport. The results from this exercise are discussed below.

### 5.2.1 The significance of Scenarios A and B for mitigation of carbon emissions and the broader implications for sustainability

To get a better idea of the impact a city-wide modal shift after completion of IRT Phase 4 could have on the city's carbon footprint, the baseline emissions from the study area, as well as projections from Scenarios A and B, were simply extrapolated to the whole of Cape Town. This exercise was conducted for the sake of comparison and should not be considered as representative of actual net reductions under a completed IRT system. The very nature of the integrated, multi-modal IRT system will include minibus taxis, feeder bus routes and light rail transit, all of which have different fuel efficiencies and carbon emissions per VKT. This exercise was intended strictly to speculate how a modal shift might affect the overall carbon footprint if Scenarios A and B were representative of the entire City of Cape Town.

The calculations for this exercise involved multiplying the study area baseline emissions by 64 (rounded here to the nearest whole number), which effectively scaled up the study area footprint to represent 100% of the total 4.2 million tCO<sub>2</sub>eq from passenger transport in the City of Cape Town. The baseline figure only included emissions from private cars, and does not include buses, minibus taxis, metrorail, or any other type of transport. Scaling the emissions associated with Scenario A accordingly would still only achieve a 4% net reduction in passenger transport emissions (approximately 178,000 tCO<sub>2</sub>eq), or a 1% net reduction of Cape Town's total 2010 carbon footprint. Scenario B, on the other hand, would achieve a far more significant net reduction of 25% of the total passenger transport emissions (or roughly 1.1 million tCO<sub>2</sub>eq). Despite the loose implications for Scenarios A and B discussed above, it is important to note that once IRT Phases 1-4 are complete, there will not be a one-to-one relationship with BRT emissions when scaling up. While scaling up according to this method would unjustly increase the carbon footprint of the BRT, it also does not adequately take into account the higher emissions factor from coal-powered rail transport.

Assuming that the results of this simple extrapolation are indicative of the impact on the passenger transport carbon footprint upon completion of IRT Phase 4, this raises important questions. First, would either respective modal shift make a significant impact on the carbon footprint? The impact of Scenario A suggests that a 10% modal shift will make a fairly insignificant impact on passenger transport emissions. Considering projections for growth in car ownership and the total carbon footprint in 2050, a 4% net decrease in transport emissions would not bring the carbon footprint even close to the sustainable level of 1 tCO<sub>2</sub>eq per capita. In fact, this rough calculation shows a per capita carbon footprint of almost 10 times as much<sup>50</sup>. A 35% modal shift in Scenario B, on the other hand, suggests a far more significant outcome for transportation emissions in Cape Town, mitigating roughly one fourth of (2010) passenger transport emissions. It is important to note, however, this net reduction still only accounts for only 6% of the total 2010 carbon footprint. Recognizing Scenario B as a significant impact at current emissions levels, the question remains whether a 35% modal shift would result in sustainable emissions levels in the future.

As the total carbon footprint is projected to increase almost threefold in the next 40 years, the long-term impact of Scenario B seems less optimistic. As shown in Figure 5-1, passenger transport is projected to emit 17 million tCO<sub>2</sub>eq by the year 2050, four times the amount in 2010. Further, 2050 passenger transport emissions would be almost equal to the total 2010 carbon footprint. By 2050, the passenger transport sector would make up the largest emitter of greenhouse gases in Cape Town, at roughly 30% of the total footprint. Even maintaining a 35% mode share from private transport to the IRT would not be effective as the only mitigation measure to reduce emissions. The impact of a 35% modal shift, as suggested by this rough estimate, would result in a net decrease of only 4 million tCO<sub>2</sub>eq in 2050 (or 8% of total emissions). The remaining emissions from passenger transport would still be more than three times the 2010 levels. In fact, even if all other sectors in Cape Town achieved carbon neutrality by 2050, including housing, industry and commerce<sup>51</sup>, the net emissions in the City after a 35% modal shift would still be well over double the sustainable level suggested in the Copenhagen Accord. Assuming that comprehensive and drastic climate change mitigation measures are not put in place across all sectors (including transport), neither modal shift from Scenarios A or B is likely to be sufficient in mitigating the City's long-term carbon footprint to sustainable levels.

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<sup>50</sup> Assuming no other mitigation measures are put in place

<sup>51</sup> This scenario is, of course, extremely unlikely.

## 5.2.2 How to get people out of their cars: making the IRT a more attractive option than private transport

The findings from this research suggest that, among other conclusions, to achieve sustainable emissions from passenger transport in the future, Cape Town must ultimately target a smaller mode share for private transport. It should be noted that this study assumed that relatively short trips beginning and ending in the same zonal area would be unaffected by implementation of the IRT system<sup>52</sup>. While this assumption could be challenged, it is not unreasonable to assume that people who own cars will continue to use them for non-work related trips. As discussed previously, the National Household Travel Survey (2003) indicates that approximately 59% of daily trips in the Western Cape were for non-work purposes. Further, it points out that South Africans with higher incomes are more likely to own and operate a private vehicle for their daily transportation needs. Compared to lower income populations, wealthier South Africans are particularly concerned with security from crime and flexibility of transport mode, and perceive their private vehicles as a more attractive option to public transit. As the majority of cars are owned by people in the higher-income brackets, the logical conclusion is the following: to reduce the number of cars on the road to a sustainable level, the City of Cape Town must identify and address the concerns of this group in particular. This does not imply that the needs of lower-income groups should not be addressed, of course<sup>53</sup>. From a strictly environmental perspective, however, if the IRT network is intended as a viable alternative to the automobile, then city planners must find a way to make public transit the more attractive option for car owners.

### Complementary policies and practices to optimize IRT mode share

There are several complementary methods that are likely to change travel behavior and preferred mode of transport. Using a more econometric, demand-based approach, the following transport solutions consider choice behavior under a particular set of constraints. By adding constraints to private vehicle use, for example, more car-drivers will find the IRT to be the most attractive option. Restricting car access into the key commercial areas (CBD) would make public transport the more convenient option, as they would not be able to complete their trip via private transportation. This could be done through financial constraints, such as congestion pricing. This method could be administered in a variety of ways, including toll roads in congested areas, as well as issuing permits for inner city car traffic. This would effectively increase the cost of private car trips. Admittedly, this method has proven to be politically difficult to implement, and would certainly face many legislative and administrative hurdles to successfully implement in Cape Town. Another method for restricting car traffic, as is the case in Bogota, is to designate some streets exclusively for pedestrian use in commercial areas, and improve general infrastructure for NMT (Wright, Fulton 2005, p. 697). The City has begun expanding corridors for NMT along key CBD streets, including some segregated bicycle lanes and

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<sup>52</sup> Maintaining baseline levels for intra-zonal car trips (e.g. CBD to CBD) resulted in modal shifts that were actually less than their indicated totals of 10% and 35%, respectively. These reduced VKT were applied only to inter-zonal trips (e.g. Table View to Sea Point), effectively reducing the aggregate modal shifts presented in the respective calculations. Another way to have approached this issue would have been to simply apply the reductions to the total VKT within the study area, rather than to each respective origin-destination. In this case, either *a*) all trips in the study area would be assumed to have decreased by the same amount (implying that inter-zonal trips *would* be affected by the BRT as well); or *b*) intra-zonal trips would still remain at or near baseline levels, while inter-zonal trips (e.g. Table View to Sea Point) would compensate with higher modal shifts to achieve the aggregate reductions of 10% and 35%, respectively. Neither of these options seemed representative to the literature or findings from the SP survey, so this method was not used.

<sup>53</sup> This is the main sustainability issue in developing countries. To 'develop', there needs to be an increase in consumption for lower income brackets and a drastic reduction in consumption from high income brackets.

exclusive pedestrian zones. As the City continues towards its sustainability targets, this option should be considered for other areas of CBD and key business districts throughout the metropolitan area.

Perhaps the most important constraint in transportation modes, particularly for frequent car drivers, is that of time/convenience. To market the BRT (and IRT in general) as an attractive option the car-driving population, the speed at which it travels must be optimized through careful and reiterative design. If travelers were able move from origin to destination more quickly than with their car, in particular during peak hours, this could make the IRT a more appealing option for making these trips. In essence, if the constraints on speed were greater in car traffic than with the IRT, more car drivers would be likely to switch modes. To achieve the optimal design, BRT trunk and feeder vehicle speeds should be monitored on an on-going basis to identify possible bottlenecks and other obstacles that reduce their operating speeds. As BRT routes are considered to be more 'flexible' in comparison to fixed rail transport, the City should commit ongoing resources to identifying and making route/infrastructure revisions where necessary and reasonable. While financing such revisions may be problematic, it is essential to maintain the highest quality of service possible to maximize IRT mode share in the future, as well as its financial viability.

### **5.2.3 The limitations of the IRT network as mitigation measure for transport emissions: emphasizing integrated, holistic approaches to reducing the carbon footprint**

Assuming the IRT network were able to achieve optimal efficiency, there are still limitations for its capacity to reduce the carbon footprint of passenger transport. As discussed in Chapter 2, Zegras (2007, p. 5137) referenced the key elements of transport-related energy use as being "a function of total activity (A), mode share (S), fuel intensity (I) and fuel type (F)". This research has focused largely on the role of the mode share (S) of private vs. IRT system as a mitigation measure for carbon emissions. Even if the IRT were able to maximize its capacity of total mode share, the existing urban form of Cape Town still provides incentives for travelers to make some daily trips with their car, as they would be out of the scope of the IRT. Even car owners who use IRT network for commuting to school or work will likely not be able to satisfy all of their travel needs through public transport. This is particularly true for non-work related trips, as they often require more flexibility than a fixed route can offer, especially when the predominant urban form is low-density sprawl. The IRT is thus more likely to gain mode share for necessary (work or school related) trips, than for leisure and non-work related trips. Ultimately, this limits the potential number of cars the IRT can take off the road. Given projections for car ownership increases, this limitation of the IRT network suggests other mitigation measures should be taken.

To reduce emissions to sustainable levels in the long term, The City must holistically consider the other key elements of transport-related energy consumption. For example, further innovation in the transport sector can complement reduced transport emissions through improved fuel intensity (I)<sup>54</sup> of vehicle fleets across all means of transportation. Cape Town and South Africa in general must take fuel efficiency of vehicles more seriously and impose gradual restrictions not only on air pollutants, but also on global greenhouse gas emissions (through better fuel efficiency). Further, the country must impose standards for producing and operating

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<sup>54</sup> Fuel efficiency

vehicles that use alternative, more efficient fuel types (F)<sup>55</sup>. In particular as car ownership increases in Cape Town, the efficiency and emissions factors for the respective fuels must continue to improve to reduce transport emissions. Above all, however, planning policies must implement solutions to reduce overall transport activity (A), or total number of VKT. This requires a particularly integrated, comprehensive approach to recognize the relationship between urban form and travel behavior. Specifically, to improve transport efficiency, the City must continue to integrate its land-use planning policies with transport objectives.

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<sup>55</sup> Such as petroleum, diesel, as well hybrid/electric, CNG, solar or hydrogen-powered vehicles

## 5.2.4 Transit-oriented development and urban densification for improved transport efficiency

Using examples from Chapter 2, the BRT network in Curitiba has been widely praised as a model transport system, with 70% of its population using the BRT to commute to work (Goodman, Laube & Schwank 2006, p. 75). Much of its success is due to its high level of integration with land-use planning policies, including transit-oriented development and a two-block, high-density zone along the trunk route corridors (p. 76). Transit-oriented zoning can improve the efficiency of the IRT, by placing housing and commercial activities closer to public transport corridors. Further, urban densification and mixed-use zoning can reduce the total number of VKT all together. These practices further reduce energy consumed from travel, by placing people closer to one another and commercial/retail establishments. Redeveloping low-density areas of Cape Town into a more sustainable urban form, in which origins and destinations were closer together, would reduce the overall distance and need for people to travel with motorized transport.

Enforcing an integrated, holistic approach to city planning in Cape Town is the only long-term path for reducing total activity of work and non-work related car trips. According to the eight SDFs for City of Cape Town (2011), the main new growth node is located in IRT Phase 1 area, just north of Table View. This area is indicated predominantly in yellow at the top of Figure 5-2, reproduced below (from Chapter 2) for easy reference.



*Figure 5-2: Key attributes for Cape Town SDF in relation to BRT Trunk Routes*  
*Data Source: City of Cape Town (2011) Spatial Development Frameworks*

While key areas have been identified for further medium-density development (yellow), as well as mixed use (dark blue) and high-density (orange), much of the remaining portions of the study area, especially

north of the CBD, still remain as low-density areas. The urban form for most existing residential areas is not likely to change in the near future, but the City has identified key areas for incorporating transit-oriented development. In particular, the SDF highlights potential land for mixed-use purposes, shown along the future Phase 1A - BRT extension to DuNoon (upper right corner; future BRT routes are shown in pink). The greatest potential for medium and high-density development exists in undeveloped areas such as District Six (bottom left – pictured in orange) and Atlantis areas to the North (pictured in yellow/orange at the top of Figure 5-2) (City of Cape Town 2011). This leaves little immediate opportunity for high and medium density land-use zoning in the already developed, low-density areas of Milnerton and Table View, as well as similar areas across the City.

If the City wishes to play a serious role in reducing South Africa's emissions to sustainable levels, it will likely be faced with drastic measures to prevent the business as usual trajectory shown in Figure 5-1 (UCT, SEA 2011). With this in mind, city planners ultimately have little choice but to adopt more aggressive urban densification and transport-oriented development policies in low-density areas along IRT routes in the greater Cape Town area. The land-use zoning purposes proposed in the SDFs are a step in the right direction, but have a long way to go to fulfill the City's commitment to developing an efficient urban form.

## 6 Conclusion

As presented in this study, the transport sector in the City of Cape Town comprises 27% of its carbon footprint (UCT, SEA 2011). Given the trajectory for increased car ownership in Cape Town, emissions will continue to increase well above sustainability targets if no mitigation measures are put in place by 2050. Recognizing the potential for improved efficiency in the transportation industry, the City has begun implementing its Integrated Rapid Transit network as a means to reduce traffic volume from private vehicles. Drawing from the multitude of successful and increasingly numerous bus rapid transit systems across the world, the IRT shows potential for inducing a considerable modal shift from private vehicle use to more efficient, public transport options. The modal shift achieved from the Phase 1A - BRT starter service can provide insight to the broader implications of the fully-implemented IRT network.

Thus, this research aimed to predict the modal shift from private transport to the BRT starter service. By using a combination of revealed and stated preference techniques, the researcher interviewed 79 people at the Motor Vehicle Licensing & Registration Office in the CBD to assess their willingness to take the BRT. Using the multinomial logit model, the data gathered from car users suggests a 0.35 probability for taking the BRT, or a 35% modal shift from private transport to BRT. As highlighted in this research, the complexity of choice behavior makes it notoriously difficult to predict. Further, as there are flaws in the SP survey design, its ultimate 'prediction' cannot be said to be optimal. However, as discussed by Uherek et al. (2010, p. 4798), scenario-based projections are best considered not as 'predictions' of the future, but rather as 'projections' to "analyze the consequences of certain policies or measures".

With this in mind, respective modal shifts were considered in two scenarios to determine how they would impact the carbon footprint. Scenario A features a 10% modal shift from private transport, as projected by the City; and Scenario B features a 35% modal shift, as projected by the SP survey. Baseline emissions from private transport were calculated using a distance-based approach, scaling up car VKT from a peak-hour origin/destination matrix provided by City of Cape Town Department of Transport to represent total yearly car VKT in the study area. Added emissions from the BRT service were calculated using specifications explained in the Phase 1A Business Plan (City of Cape Town 2010a), as well as from the IRT Clean Development Mechanism Project Description Document (Lopez 2008). The baseline carbon footprint (2010) from private transport in the study area comes to a total of 65,356 tCO<sub>2</sub>eq. Further, the added emissions from the BRT starter service totals 2,678 tCO<sub>2</sub>eq. For Scenarios A and B, the car VKT were reduced according to the projected modal shift from private transport. The net reductions in passenger transport emissions were calculated by subtracting the avoided emissions from car trips from the added emissions from the BRT starter service.

With a 10% modal shift, the net reduction in Scenario A comes to 2,771 tCO<sub>2</sub>eq, or a 4% net reduction from baseline emissions. When compared to the total carbon footprint of Cape Town in 2010, this accounts for a 0.07% net reduction in the total carbon footprint. A rough calculation was made to scale up the study area figures to represent the whole of 2010 passenger transport emissions in Cape Town. This loose estimation suggests that a 4% net reduction on the total passenger transport emissions from a 10% modal shift still places

per capita<sup>56</sup> emissions in 2050 at approximately ten times the sustainable targets of the Copenhagen Accord. Net reductions from a 35% modal shift in Scenario B, on the other hand, come to 16,392 tCO<sub>2</sub>eq, or a 25% net reduction from baseline levels. The amounts to approximately a 0.39% net reduction in the total 2010 carbon footprint. Scaled up, loose calculations suggest that a sustained 35% mode share in 2050 would account for an 8% net reduction in the total carbon footprint. From this rough estimate, per capita emissions would still equal nine times the sustainable target of 1 tCO<sub>2</sub>eq per capita.

The City has demonstrated its commitment to sustainable development through its planning policies for improving energy efficiency across all sectors. The five-year IMEP targets to reduce per capita emissions from 6.21 tCO<sub>2</sub>eq in 2009 to 5 tCO<sub>2</sub>eq in by 2014 are ambitious, and would set a precedent for moving towards sustainability. Further, the City's bold commitment to the IRT network is a significant milestone in mitigating greenhouse gas emissions from the transportation sector. While the scaled up estimates are only very general projections for their respective impacts on the carbon footprint, they highlight key issues to take into consideration moving towards a sustainable future. First, they point out that 2050 per capita emissions in both scenarios are significantly higher than IMEP 2014 targets. Secondly, they stress the importance of a holistic, integrated approach to improve energy efficiency across all sectors. This includes integrating transportation needs with spatial development frameworks. Further, the findings from this research highlight the need for significant mitigation measures to optimize the key components of transport energy consumption: total transport activity (A), public transportation mode share (S), the fuel efficiency/intensity (I) of vehicles, and low-emissions, alternative fuel types (F). This study suggests that if no additional mitigation measures are put in place, neither modal shift will be sufficient to achieve sustainability by the year 2050. It is fair to say that even with complementary measures to reduce emissions, the City's projection of a 10% modal shift will not be sustainable. While the City of Cape Town has shown a bold commitment to achieving sustainable development across all sectors, including transport, the current outlook on achieving 2050 emissions targets is far from optimistic.

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<sup>56</sup> This calculation used a high estimate of a population of 5 million in Cape Town by the year 2050, which is not supported by statistical estimations. This figure was used purely for the sake of argument, and would imply that the City will grow by 1 million inhabitants from 2021 population estimates (City of Cape Town 2008c). The City of Cape Town growth trajectory suggests it will likely be less than this figure. However, by over-estimating the population, per capita emissions described here are actually less than they would be with a smaller population estimate. This suggests that if the population is less than 5 million in 2050, per capita emissions will be higher than the figures discussed here.

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## Appendix A: Stated Preference Survey **WHICH WOULD YOU CHOOSE?**

**Bus Rapid Transit  
(BRT)  
OR**

The following is a survey to determine the travel behaviour of residents in the City of Cape Town. This survey will inform my research in composing a Master's Dissertation at the University of Cape Town.

This survey is completely anonymous, and the information obtained will be used solely for the purpose of research to inform the process for developing transportation solutions.

Your participation in this travel study is greatly appreciated.

Thank you.

### Quick Informational Guide to BRT Service



**Pre-Pay Entry**



**Enclosed Bus Stop**



**Quick Boarding and Exiting  
Lanes**



**Dedicated "Trunk"  
Lanes**



In each of the following questions, you will be offered two scenarios. Each option will indicate the pure travel time (time spent in the vehicle) to get from your starting point to your desired destination. Each option will also indicate the cost for travel with the mode of transport.

**Option A** will feature the **Bus Rapid Transit (BRT) MyCiti bus** as the main mode of transportation. Costs included refer to purchasing a return (roundtrip) ticket. Please assume for this exercise that you live within 10 minutes of a BRT stop, and that your place of employment is within a 10 minute walk from the nearest stop.

**Option B** will involve using **your own car** as the main mode of transport and that your current parking facilities apply. If you do not have a car, please assume for this exercise that you do. The costs listed for Option B refer to petrol use for a return (roundtrip) drive to and from work.

**For each of the nine questions below, please circle either "Option A" or "Option B" as your preferred option.**

---

### QUESTIONS 1-3:

Imagine you are commuting to work and there is *little or NO traffic*. Which of the following would you prefer:

**(CHOOSE ONE OPTION FOR EACH QUESTION ONLY)**

1)

<b><u>OPTION A:</u></b> <input type="checkbox"/>	
<b>Take the BRT</b>	
⇒ Cost of return ticket:	<b>R10</b>
⇒ Travel Time:	<b>15 mins</b>

<b><u>OPTION B:</u></b> <input type="checkbox"/>	
<b>Drive your car</b>	
⇒ Total cost (petrol/parking):	<b>R10</b>
⇒ Travel Time:	<b>30 mins</b>

2)

<b><u>OPTION A:</u></b> <input type="checkbox"/>	
<b>Take the BRT</b>	
⇒ Cost of return ticket:	<b>R10</b>
⇒ Travel Time:	<b>15 mins</b>

<b><u>OPTION B:</u></b> <input type="checkbox"/>	
<b>Drive your car</b>	
⇒ Total cost (petrol/parking):	<b>R25</b>
⇒ Travel Time:	<b>15 mins</b>

3)

<u>OPTION A:</u>		<input type="checkbox"/>
<b>Take the BRT</b>		
⇒ Cost of return ticket:	<b>R25</b>	
⇒ Travel Time:	<b>30 mins</b>	

<u>OPTION B:</u>		<input type="checkbox"/>
<b>Drive your car</b>		
⇒ Total cost (petrol/parking):	<b>R35</b>	
⇒ Travel Time:	<b>45 mins</b>	

=====

**QUESTIONS 4-9:**

Imagine you are commuting to and from work and there is ***stop-and-go, heavy traffic.***  
Which of the following would you prefer:

**(CHOOSE ONE OPTION FOR EACH QUESTION ONLY)**

4)

<u>OPTION A:</u>		<input type="checkbox"/>
<b>Take the BRT</b>		
⇒ Cost of return ticket:	<b>R10</b>	
⇒ Travel Time:	<b>30 mins</b>	

<u>OPTION B:</u>		<input type="checkbox"/>
<b>Drive your car</b>		
⇒ Total cost (petrol/parking):	<b>R25</b>	
⇒ Travel Time:	<b>45 mins</b>	

5)

<u>OPTION A:</u>		<input type="checkbox"/>
<b>Take the BRT</b>		
⇒ Cost of return ticket:	<b>R25</b>	
⇒ Travel Time:	<b>15 mins</b>	

<u>OPTION B:</u>		<input type="checkbox"/>
<b>Drive your car</b>		
⇒ Total cost (petrol/parking):	<b>R25</b>	
⇒ Travel Time:	<b>30 mins</b>	

6)

OPTION A:

**Take the BRT**

⇒ Cost of return ticket: **R25**

⇒ Travel Time: **15 mins**

OPTION B:

**Drive your car**

⇒ Total cost (petrol/parking):  
**R10**

⇒ Travel Time: **30 mins**

7)

OPTION A:

**Take the BRT**

⇒ Cost of return ticket: **R25**

⇒ Travel Time: **15 mins**

OPTION B:

**Drive your car**

⇒ Total cost (petrol/parking):  
**R35**

⇒ Travel Time: **45 mins**

8)

OPTION A:

**Take the BRT**

⇒ Cost of return ticket: **R25**

⇒ Travel Time: **45 mins**

OPTION B:

**Drive your car**

⇒ Total cost (petrol/parking):  
**R35**

⇒ Travel Time: **45 mins**

9)

**OPTION A:**

**Take the BRT**

⇒ Cost of return ticket:       **R35**

⇒ Travel Time:                   **30 mins**

**OPTION B:**

**Drive your car**

⇒ Total cost (petrol/parking):  
   **R35**

⇒ Travel Time:                   **30 mins**

=====

=====

**Follow up questions for research purposes only:**

10. In which part of town do you stay? (Please specify neighbourhood / general area)

11. Do you normally drive a car to work/school?

- a. Yes
- b. No
- c. Occasionally

12. On average, how many days per week do you drive your car?

- a. 5-7
- b. 3-4
- c. 1-2
- d. 0

13. Do you in work in or near CBD Central Business District (CBD)?

- a. Yes
- b. No

14. If not, in which part of town do you work?

15. On average, how long does it take you to get from home to work?

- a. 10-20 minutes
- b. 20-40 minutes
- c. 40-60 minutes
- d. Over 60 minutes

## Appendix B: Stated Preference Survey data analysis: LIMDEP software multinomial logit (MNL) model output

```
--> RESET
--> Reset$
--> Read;file=C:\Ryan.csv
    ;nobs=1422; nvar=24
    ;names= RESP , Pair, nij, MODE, COST, TIME, COMF, CHOICE, DRIVE,
DRIVE0, ...
    DRIVE2, DRIVE3, LOC, TTW1, TTW2, TTW3, TTW4, MALE, FEM, WH, BL, CO,
AGE $
--> CREATE; IF(MODE=0)ALT=1; IF(MODE=1)ALT=2$
--> CREATE; IF(MODE=0)BRT=1; IF (MODE=1) CAR = 1$
```

### 1. Main attributes only

```
--> NLOGIT
    ;lhs=CHOICE, nij, ALT
    ;choices= BRT, CAR
    ;Model:
    U(BRT)=PBRT*BRT+PTIME*TIME+PCOST*COST/
    U(CAR)=PTIME*TIME+PCOST*COST+PCOMF*COMF$
Normal exit from iterations. Exit status=0.
```

```
+-----+
| Discrete choice (multinomial logit) model
| Maximum Likelihood Estimates
| Dependent variable           Choice
| Weighting variable           ONE
| Number of observations        711
| Iterations completed          4
| Log likelihood function       -466.1557
| Log-L for Choice model =     -466.1557
| R2=1-LogL/LogL* Log-L fncn  R-sqrd  RsqAdj
| No coefficients   -492.8276  .05412  .04877
| Constants only.  Must be computed directly.
|                   Use NLOGIT ;...; RHS=ONE $
| Response data are given as ind. choice.
| Number of obs.=   711, skipped  0 bad obs.
+-----+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[ Z >z]	Mean of X
PBRT	-.7553792844	.17795364	-4.245	.0000	
PTIME	-.5071682639E-01	.87022524E-02	-5.828	.0000	
PCOST	-.3908736285E-01	.89417643E-02	-4.371	.0000	
PCOMF	.8008059596E-01	.16939635	.473	.6364	

3. Excluding insignificant attributes:

```
--> NLOGIT
;lhs=CHOICE, nij, ALT
;choices= BRT, CAR
;Model:
U(BRT)=PBRT*BRT+PTIME*TIME+PCOST*COST/
U(CAR)=PTIME*TIME+PCOST*COST
+FEM*FEM+DRIVE*DRIVE
+DRIVE1*DRIVE1 + DRIVE2*DRIVE2 + DRIVE3*DRIVE3
+LOC*LOC + TTW1*TTW1 + TTW2*TTW2 + TTW3*TTW3 + BL*BL$
Normal exit from iterations. Exit status=0.
```

```
+-----+
| Discrete choice (multinomial logit) model
| Maximum Likelihood Estimates
| Dependent variable           Choice
| Weighting variable           ONE
| Number of observations        711
| Iterations completed          7
| Log likelihood function       -380.2719
| Log-L for Choice model =     -380.2719
| R2=1-LogL/LogL* Log-L fncn  R-sqrd  RsqAdj
| No coefficients   -492.8276  .22839  .21402
| Constants only.  Must be computed directly.
|                   Use NLOGIT ;...; RHS=ONE $
| Response data are given as ind. choice.
| Number of obs.=  711, skipped  0 bad obs.
+-----+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[ Z >z]	Mean of X
PBRT	7.771219398	1.2336101	6.300	.0000	
PTIME	-.6321651569E-01	.98882541E-02	-6.393	.0000	
PCOST	-.5142947078E-01	.10075579E-01	-5.104	.0000	
FEM	-.3437736509	.18928479	-1.816	.0693	
DRIVE	2.325811133	.41507814	5.603	.0000	
DRIVE1	5.338286509	1.1592929	4.605	.0000	
DRIVE2	2.945513888	.96423352	3.055	.0023	
DRIVE3	5.474478523	.90442924	6.053	.0000	
LOC	-.3943777439	.21137689	-1.866	.0621	
TTW1	2.192339433	.46745184	4.690	.0000	
TTW2	1.834173021	.46585789	3.937	.0001	
TTW3	1.957800600	.49574085	3.949	.0001	
BL	-1.174133185	.27245738	-4.309	.0000	

4. Excluding all insignificant variables

```
--> NLOGIT
;lhs=CHOICE, nij, ALT
;choices= BRT, CAR
;Model:
U(BRT)=PBRT*BRT+PTIME*TIME+PCOST*COST/
U(CAR)=PTIME*TIME+PCOST*COST
+ DRIVE*DRIVE
+DRIVE1*DRIVE1 + DRIVE2*DRIVE2 + DRIVE3*DRIVE3
+ TTW1*TTW1 + TTW2*TTW2 + TTW3*TTW3 + BL*BL$
Normal exit from iterations. Exit status=0.
```

```
+-----+
| Discrete choice (multinomial logit) model
| Maximum Likelihood Estimates
| Dependent variable             Choice
| Weighting variable             ONE
| Number of observations         711
| Iterations completed           7
| Log likelihood function        -383.3619
| Log-L for Choice model =      -383.3619
| R2=1-LogL/LogL* Log-L fncn R-sqrd RsqAdj
| No coefficients -492.8276 .22212 .20989
| Constants only. Must be computed directly.
|                               Use NLOGIT ;...; RHS=ONE $
| Response data are given as ind. choice.
| Number of obs.= 711, skipped 0 bad obs.
+-----+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[ Z >z]	Mean of X
PBRT	8.197438497	1.2359101	6.633	.0000	
PTIME	-.6252960140E-01	.98257487E-02	-6.364	.0000	
PCOST	-.5087236834E-01	.10015517E-01	-5.079	.0000	
DRIVE	2.383350303	.42460676	5.613	.0000	
DRIVE1	5.181511884	1.1773088	4.401	.0000	
DRIVE2	3.101225270	.94082542	3.296	.0010	
DRIVE3	5.457175210	.89564839	6.093	.0000	
TTW1	2.151464153	.46643395	4.613	.0000	
TTW2	1.832307086	.46479452	3.942	.0001	
TTW3	1.835666154	.49231832	3.729	.0002	
BL	-1.185737738	.27060987	-4.382	.0000	

### 5. Descriptive Statistics

--> DSTAT;Rhs=MODE,COST,TIME,COMF,CHOICE,DRIVE,DRIVE0,DRIVE1  
,DRIVE2,DRIVE3,LOC,TTW1,TTW2,TTW3,TTW4,MALE,FEM,WH,BL,CO,AGE\$

#### Descriptive Statistics

All results based on nonmissing observations.

```
=====
```

Variable	Mean	Std.Dev.	Minimum	Maximum	Cases
-----					
All observations in current sample					
MODE	.500000000	.500175902	.000000000	1.000000000	1422
COST	23.61111111	9.40270914	10.00000000	35.00000000	1422
TIME	29.16666667	11.7005055	15.00000000	45.00000000	1422
COMF	.666666667	.471570362	.000000000	1.000000000	1422
CHOICE	.500000000	.500175902	.000000000	1.000000000	1422
DRIVE	.949367089	.386574875	.000000000	2.000000000	1422
DRIVE0	.379746835E-01	.191202291	.000000000	1.000000000	1422
DRIVE1	.506329114E-01	.219324069	.000000000	1.000000000	1422
DRIVE2	.759493671E-01	.265010281	.000000000	1.000000000	1422
DRIVE3	.835443038	.370910657	.000000000	1.000000000	1422
LOC	.708860759	.454447375	.000000000	1.000000000	1422
TTW1	.405063291	.491076991	.000000000	1.000000000	1422
TTW2	.354430380	.478508627	.000000000	1.000000000	1422
TTW3	.189873418	.392338823	.000000000	1.000000000	1422
TTW4	.506329114E-01	.219324069	.000000000	1.000000000	1422
MALE	.607594937	.488457895	.000000000	1.000000000	1422
FEM	.392405063	.488457895	.000000000	1.000000000	1422
WH	.544303797	.498208515	.000000000	1.000000000	1422
BL	.126582278	.332621420	.000000000	1.000000000	1422
CO	.329113924	.470056732	.000000000	1.000000000	1422
AGE	35.9367089	10.2305686	20.00000000	70.00000000	1422

```
=====
```

6. Showing correlation between Gender and Location

```
--> NLOGIT
;lhs=CHOICE, nij, ALT
;choices= BRT, CAR
;Model:
U(BRT)=PBRT*BRT+PTIME*TIME+PCOST*COST/
U(CAR)=PTIME*TIME+PCOST*COST
+FEM*FEM+DRIVE*DRIVE
+DRIVE1*DRIVE1 + DRIVE2*DRIVE2 + DRIVE3*DRIVE3
+ TTW1*TTW1 + TTW2*TTW2 + TTW3*TTW3 + BL*BL$
Normal exit from iterations. Exit status=0.
```

```
+-----+
| Discrete choice (multinomial logit) model |
| Maximum Likelihood Estimates             |
| Dependent variable                       | Choice |
| Weighting variable                       | ONE   |
| Number of observations                   | 711   |
| Iterations completed                     | 7     |
| Log likelihood function                  | -382.0375 |
| Log-L for Choice model =                 | -382.0375 |
| R2=1-LogL/LogL* Log-L fncn R-sqrd RsqAdj |
| No coefficients -492.8276 .22481 .21150 |
| Constants only. Must be computed directly. |
| Use NLOGIT ;...; RHS=ONE $              |
| Response data are given as ind. choice.  |
| Number of obs.= 711, skipped 0 bad obs. |
+-----+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[ Z >z]	Mean of X
PBRT	7.941829543	1.2435616	6.386	.0000	
PTIME	-.6280667722E-01	.98508898E-02	-6.376	.0000	
PCOST	-.5109692433E-01	.10039727E-01	-5.089	.0000	
FEM	-.3059426676	.18802957	-1.627	.1037	
DRIVE	2.394382951	.42415486	5.645	.0000	
DRIVE1	5.107815146	1.1726240	4.356	.0000	
DRIVE2	2.803017234	.95773948	2.927	.0034	
DRIVE3	5.278012487	.90143587	5.855	.0000	
TTW1	2.182697892	.46714417	4.672	.0000	
TTW2	1.861330210	.46546253	3.999	.0001	
TTW3	1.879270416	.49347992	3.808	.0001	
BL	-1.191492336	.27124838	-4.393	.0000	

```

--> NLOGIT
    ;lhs=CHOICE, nij, ALT
    ;choices= BRT, CAR
    ;Model:
    U(BRT)=PBRT*BRT+PTIME*TIME+PCOST*COST/
    U(CAR)=PTIME*TIME+PCOST*COST
    + DRIVE*DRIVE
    +DRIVE1*DRIVE1 + DRIVE2*DRIVE2 + DRIVE3*DRIVE3
    +LOC*LOC + TTW1*TTW1 + TTW2*TTW2 + TTW3*TTW3 + BL*BL$
Normal exit from iterations. Exit status=0.

```

```

+-----+
| Discrete choice (multinomial logit) model
| Maximum Likelihood Estimates
| Dependent variable           Choice
| Weighting variable           ONE
| Number of observations       711
| Iterations completed         7
| Log likelihood function      -381.9233
| Log-L for Choice model =    -381.9233
| R2=1-LogL/LogL* Log-L fncn  R-sqrd  RsqAdj
| No coefficients -492.8276 .22504 .21173
| Constants only. Must be computed directly.
|                               Use NLOGIT ;...; RHS=ONE $
| Response data are given as ind. choice.
| Number of obs.= 711, skipped 0 bad obs.
+-----+

```

Variable	Coefficient	Standard Error	b/St.Er.	P[ Z >z]	Mean of X
PBRT	8.082672254	1.2257627	6.594	.0000	
PTIME	-.6285241774E-01	.98551255E-02	-6.378	.0000	
PCOST	-.5114100776E-01	.10045659E-01	-5.091	.0000	
DRIVE	2.320867085	.41657072	5.571	.0000	
DRIVE1	5.395135947	1.1667873	4.624	.0000	
DRIVE2	3.259149518	.94895440	3.434	.0006	
DRIVE3	5.651414961	.90037115	6.277	.0000	
LOC	-.3523387422	.20893955	-1.686	.0917	
TTW1	2.165979807	.46851610	4.623	.0000	
TTW2	1.814773145	.46682979	3.887	.0001	
TTW3	1.912510192	.49673486	3.850	.0001	
BL	-1.169902190	.27157684	-4.308	.0000	