ACCESSIBILITY AND SOCIAL WELFARE: A STUDY OF THE CITY OF JOHANNESBURG

MADALENA NAHUNGU LIONJANGA

A dissertation submitted in partial fulfilment of the requirements for the degree of

MASTER OF ENGINEERING (TRANSPORTATION ENGINEERING)

In the

FACULTY OF ENGINEERING

UNIVERSITY OF PRETORIA

February 2018

DISSERTATION SUMMARY

ACCESSIBILITY AND SOCIAL WELFARE: A STUDY OF THE CITY OF JOHANNESBURG

M.N. LIONJANGA

Supervisor: Professor Christo Venter

Department: Civil Engineering

University: University of Pretoria

Degree: Master of Engineering (Transportation engineering)

Within the corpus of accessibility measures is the Net Wage After Commute which describes the potential wage earnable less the transport costs incurred to commute to work from a particular location. This study examines the time-series development of accessibility, using this poverty-relevant metric, from townships in the City of Johannesburg, biennially from 2009 to 2013 when accessibility patterns were altered as a result of major investment in the Bus Rapid Transit (BRT) system Rea Vaya. Furthermore, a difference-in-differences methodology was adopted to explore the effect of access to the BRT on the welfare of lower-income households, investigating the premise that transport related benefits brought about by such investments translate to social welfare improvements. The results suggest that significant time-series changes in accessibility patterns are driven by improved affordability of public transport against the backdrop of decentralisation, particularly for low-income areas in the peripheries of the city. However, the marginal benefits of improving accessibility from regions with already high levels of accessibility are relatively low. The BRT improved accessibility to jobs from Soweto, but only minimally, suggesting that in polycentric regions like Johannesburg which grapple with poor modal integration, investment in improving accessibility to an already well accessible CBD could potentially result in only minimal improvements in accessibility. The difference-in-differences model revealed that implementation of the BRT did not result in any significant welfare improvements for the served community. However, an increase in the accessibility to jobs offered by the BRT resulted in a larger increase in the social welfare of those in close proximity to the service than it did for the wider community. This suggests that the BRT in Johannesburg is beneficial as a transport project to users within close proximity to the service, but not as a general urban intervention able to uniformly improve the overall amenity of the served community.

Keywords: Accessibility, Social welfare, Public transportation, Johannesburg, Time-series analysis

DECLARATION

I, the undersigned hereby declare that:

- I understand what plagiarism is and I am aware of the University's policy in this regard;
- The work contained in this thesis is my own original work;
- I did not refer to work of current or previous students, lecture notes, handbooks or any other study material without proper referencing;
- Where other people's work has been used this has been properly acknowledged and referenced;
- I have not allowed anyone to copy any part of my thesis;
- I have not previously in its entirety or in part submitted this thesis at any university for a degree.

DISCLAIMER:

The work presented in this report is that of the student alone. Students were encouraged to take ownership of their projects and to develop and execute their experiments with limited guidance and assistance. The content of the research does not necessarily represent the views of the supervisor or any staff member of the University of Pretoria, Department of Civil Engineering. The supervisor did not read or edit the final report and is not responsible for any technical inaccuracies, statements or errors. The conclusions and recommendations given in the report are also not necessarily that of the supervisor, sponsors or companies involved in the research.

Signature of student:

Name of student: Madalena Nahungu Lionjanga

Student number: 11027445

Date: 14/02/2018

Number of words in report: **46000**_words

ACKNOWLEDGEMENT

I wish to express my appreciation to the following organisations and persons who made this dissertation possible:

a) The Southern African Transport Conference for their financial support throughout my Masters programme.

b) The data used in this paper is taken from the Quality of Life survey commissioned by the Gauteng City-Region Observatory, a partnership of the University of Johannesburg, the University of the Witwatersrand, Johannesburg, and the Gauteng Provincial Government.

c) Willem Badenhorst and Johan du Toit for the preparation of transport and land use data, and software development.

d) Professor Christo Venter, my supervisor, for his unwavering guidance and support.

e) My family and friends for their undying encouragement and support during the study.

f) My father, I will continue to "fly the Lionjanga flag high", I hope I have made you proud. May your soul rest in eternal peace.

g) God, for making all of this possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

1 INTRODUCTION

1.1 BACKGROUND

Transport and planning policy is prioritising the improvement of transport accessibility and equity across various regions in the world; it is no different in the Gauteng province (GPG, 2012, CoJ, 2013). Located in the polycentric province is the City of Johannesburg (CoJ) which is South Africa's largest and most dynamic economy (Todes, 2012). However, despite its economic success, the CoJ grapples with relatively high levels of poverty, unemployment and inequality (Todes, 2012, World Bank, 2012, CoJ, 2013). During the apartheid era, non-white groups were relocated to townships which are predominantly located in the peripheries of the CoJ (Todes, 2012). This resulted in low-income, non-white groups residing in areas that were dislocated from the city's economic opportunities (CoJ, 2011), and due to a governance structure assimilated into the racial segregation and discrimination of that era, these areas suffered from poor infrastructure and service delivery (Todes, 2012).

The Reconstruction and Development Programme (RDP) was introduced in 1994 as a poverty alleviation strategy which involved, amongst other things, providing housing to the urban poor. However, RDP housing continues to be developed within or close to townships due to escalating land prices in the urbanised areas of the city (Todes, 2012, CoJ, 2013), perpetuating the spatial exclusion and the financial and travel time burden experienced by low-income groups. Everatt (2014) describes this spatial inequality as the "glaring challenge exacerbated by the resilience of apartheid social engineering". To combat this historic spatial exclusion, the CoJ introduced the "Corridors of Freedom" as an initiative to drive spatial integration through land-use and transport interventions (Venter, 2016). The first of these corridors of freedom was introduced during the study period (2009 – 2013) through the introduction of the Bus Rapid Transit (BRT) system dubbed Rea Vaya (CoJ, 2013, Gotz et al., 2014). The Rea Vaya Phase 1A corridor operates between Soweto and the Johannesburg CBD. Since its implementation, Rea Vaya Phase 1A has resulted in 10% - 20% travel time savings for its users and it has assisted in the transition of minibus taxi drivers from informal to formal employment with Rea Vaya, doubling their annual income (Carrigan et al., 2014). However, the poorest residents of the CoJ are not significant beneficiaries of this project, only receiving 4% of the project benefits (Carrigan et al., 2014).

The question of whether BRT systems deliver equitable and pro-poor outcomes is closely related to the extent to which they enhance the accessibility of poverty-stricken populations (Venter et al., 2017). Despite the body of theoretical and empirical work on accessibility, there still appears to be a poor understanding of the social meaning of accessibility benefits and how such benefits translate into social welfare improvements across different groups of a population. The use of accessibility measures to better understand the wider social benefits of transport investments is hampered by a shortage of empirical studies that examine the relationships between accessibility and social outcomes. Accessibility, its social benefits, and the various forms of exclusion are dynamic concepts which should be thoroughly assessed over time, individually and interactively.

This study will attempt to fill two gaps, the first being the time-series analysis of accessibility in the South African context which could provide a tool to assess the performance of transport and land-use polices such as the White Paper on National Transport Policy (1996) and the National Development Plan (2012) which have called for improvements in accessibility. The second gap being that of deepening the knowledge of the wider social benefits of transport investments by unpacking the effects of the introduction of the Rea Vaya BRT and its associated accessibility on the social welfare of Soweto residents.

1.2 OBJECTIVES OF THE STUDY

Through a case study of randomly selected origin zones in selected townships of the CoJ, the study objectives are as follows:

- To examine the time-series development of accessibility to jobs from selected townships in the CoJ biennially from 2009 to 2013.
- To determine the extent to which investment in public transport, particularly the BRT in the CoJ, contributed to changes in the accessibility patterns of the urban poor.
- To determine the wider social benefits, in terms of subjective welfare, of accessibility improvements driven by public transport investment in the Rea Vaya BRT.

1.3 SCOPE OF THE STUDY

The analysis of transport accessibility was carried out using biennial data from 2009 to 2013 in order to remain congruent with the Gauteng City Region Observatory’s (GCRO) Quality of Life (QoL) surveys, which are conducted biennially since 2009. The 2015 QoL survey data was received towards the latter stages of this study, therefore, accessibility measures for 2015 were excluded from the results. The QoL surveys were used to determine: a) a measure of social welfare and b) a social exclusion index; both of which were limited to the questions contained in the surveys. The GCRO conducts QoL surveys across the Gauteng City-Region (GCR), thus the ideal scenario would have been to determine temporal accessibility developments across the entire GCR, however, due to a limitation of spatial data on the city-region scale, this study was restricted to the City of Johannesburg (CoJ), for which the necessary spatial data was obtained. The job location data was obtained from the 2011 Gauteng transport model and was not altered across the analysis years due to the lack of availability of such data for the other analysis years. This narrowed the focus of the time-series accessibility analysis leg of the study to the effect of changes in the transport component on accessibility, not the land-use component. Due to the poverty relevant nature of the accessibility measure used, this study focused on accessibility to job opportunities using public transport from townships in the CoJ; therefore this excluded accessibility to social services such as educational institutions and healthcare facilities. The public transport modes considered were the minibus taxi, the Metrobus, the Metrorail and the Rea Vaya BRT; the Gautrain was excluded from the study as it predominantly caters for middle to high income groups. This is a quantitative analysis of accessibility, furthermore it uses the generated results to quantitatively approximate wider social benefits of transport investments on a measure of welfare determined using the Quality of Life survey responses. Although stakeholder engagement would add value in such an analysis, it falls outside of the scope of this study.

1.4 METHODOLOGY

The access envelope technique, developed by Venter & Cross (2014), was used for the time-series accessibility measurements. This is a Geographic Information System (GIS) based technique which required mapping of the study surface which was divided into roughly 19000 zones and from each one of the zones, the accessibility measure to every other zone on the study surface could be determined. Eight townships were selected for this study. Thirty or more sample zones were then randomly selected from each township to determine the average accessibility measurement of the corresponding township for each analysis year. Using the generated accessibility measurements and selected data from the QoL surveys, a difference-in-differences Negative Binomial regression model was used to determine the effect of BRT implementation in Soweto on the social welfare of Soweto residents.

1.5 ORGANISATION OF THE REPORT

The report consists of the following chapters and appendices:

- Chapter 1 serves as an introduction to the report.
- Chapter 2 serves as a review of applicable literature and identifies observable gaps in this literature.
- Chapter 3 describes the methodology undertaken to measure accessibility and the wider social benefits (if any) of investment in BRT in the CoJ.
- Chapter 4 serves as the analysis of the results.

- Chapter 5 contains the conclusions and recommendations for future research.
- The list of references follows at the end of the report.
- Appendix A contains raw data from the calibration of minibus taxi fares in the CoJ.
- Appendix B contains summary measures computed from the sample of origin zones from which accessibility to job opportunities was measured.
- Appendix C contains the script and detailed output of the difference-in-difference analysis.

2 LITERATURE REVIEW

This chapter presents a review of the literature pertaining to this study and assists in developing a comprehensive understanding of accessibility, the formation and development of the CoJ, the role and challenges of transportation within the CoJ, the Quality of Life (QoL) concept and other indicators of social welfare.

2.1 ACCESSIBILITY

2.1.1 The definitions and developments of accessibility

Hansen (1959) is one of the pioneers of accessibility measurements (Martin & van Wee, 2011), and he defined accessibility as “the potential of opportunities for interaction”. His research that aimed to further understand the relationship between land use and accessibility resulted in the development of a land use model that was based on an accessibility measurement.

Ingram (1971) defined two types of accessibility, namely, relative accessibility and integral accessibility (Dalvi & Martin, 1976). Relative accessibility determines the extent to which two points on the same surface are connected. Integral accessibility determines the extent to which a single point is connected to all other points on the same surface (Dalvi & Martin, 1976). The formula below was used by Hansen (1959) to estimate the relative accessibility between two zones:

$$\boldsymbol{A_{12}} = \frac{\boldsymbol{S_2}}{\boldsymbol{T_{1-2}^{x}}} \qquad (2\text{-}1)$$

Where:

A_{12} – The relative measure of accessibility from zone 1 to an activity located at zone 2

S_2 – The size of the activity in zone 2; for example, number of employment opportunities

$T_{1\text{-}2}$ – The travel time or distance between the two zones

x – The exponent that describes the effect of the travel time or distance between the two zones

The formula can be adapted to accommodate more than one activity in a zone (Hansen, 1959). Ultimately, the model sums up all the activities in the zone and weighs them based on the travel distance or travel time impedance to reach them, to determine the accessibility to the activities in such a way that activities that are closer are more desirable than those that are farther away; true to the form of gravity models (Burns & Golob, 1976, Foth et al., 2013, Venter & Cross, 2014).

Hansen's accessibility model is classified as a gravity based or potential model (Hansen, 1959); the model most commonly used due to its relative simplicity of computation and interpretation (Iacono et al., 2010). However, Geurs and Wee (2004) and Venter and Cross (2014) beg to differ with Iacono, Krizek et al. (2010). They hold the view that, although gravity-based models are one of the most commonly used methods of measuring accessibility, one of the shortcomings of these models is that they are not easily interpreted and communicated. Geurs and Wee (2004) argue that this may be due to the fact that these models consider both land-use and transport elements, instead of one or the other, over and above that, they also weigh opportunities. An additional shortcoming of gravity models is the unclear determination of the impedance function. Empirical data has revealed that an exponential function (as seen in the equation above) is the most suitable function; however, the value of the exponent can take on a value anywhere between 0.5 and 3, depending on the trip length, trip purpose etc. (Hansen, 1959). Consequently the accessibility measure is not always easily understood by policy and decision makers (Hansen, 1959, Cervero, 2005, Venter & Cross, 2014). This contradicts one of Morris, Dumble et al (1978) criteria for accessibility measures which states that the accessibility measure must be "easy to interpret, and preferably be intelligible to the layman" (Morris et al., 1979). The gravity-type model was applied by Foth, Manaugh et al. (2013), among many others, to determine the transit accessibility to jobs (low skilled and high skilled) in Toronto, Canada to measure the relationship that exists between social disadvantage and accessibility for the years 1996 and 2006. In the South African context, this model has been applied by Venter & Mohammed (2013) to explore a possible relationship between transport energy consumption and accessibility in the Nelson Mandela Bay.

Another common type of measure is the threshold type accessibility measure (Geurs & van Wee, 2004). This type of measure specifies an arbitrary cut-off point (whether in travel time or travel distance) and only considers potential opportunities that fall within the specified threshold (Burns & Golob, 1976, Cervero, 2005, Venter & Cross, 2014). A threshold type measure has been applied by El-Geneidy and Levinson (2006) to measure accessibility changes over time and by van Dijk, Krygsman et al. (2015) to explore the effects of tolls on public transport and private vehicle accessibility across various income groups in the Cape Town metropolitan region, amongst others.

Other types of accessibility measures include the adapted potential measure, the balancing factors measure, logsum benefit measure, space-time measure and the balancing factor benefit measure (Geurs & van Wee, 2004). However, the most widely used approaches to measure accessibility are the gravity-based measures and the threshold type measures (Cervero, 2005).

An accessibility literature review by Geurs and Van Wee (2004) reveals that there are four main components in accessibility analysis, namely:

- *Land use* – reflects the different activities that can be accessed,
- *Transportation* – reflects the transportation systems that are necessary to link the various activities,
- *Time* – reflects the temporal impedance to access some activities, and
- *Individual* – reflects the unique characteristics of the individual travelling, such as, age, income, level of education etc.

Figure 2-1 further describes these components and reflects the relationships that exist between them and accessibility. This figure reveals that the individual component is the only component related to every other component because a person's values and needs determine how much they value time, which activities to participate in and at what time, as well as the appropriate cost and effort of travel (Geurs & van Wee, 2004). Ideally an accessibility measure must incorporate all four of these components, however, a single approach to accessibility analysis cannot be developed due to the large variety of study purposes, each of which will most likely require a different approach. Consequently, there is a wide variety of alternative approaches and components considered for accessibility analysis depending on the perspective taken (Morris et al., 1979, Geurs & van Wee, 2004, Martin & van Wee, 2011, Foth et al., 2013).

There are four different perspectives (listed below) that can be taken, under which the different types of accessibility measures are classified (Geurs & van Wee, 2004):

- *Infrastructure-based measures* - These measures analyse the level of service of transport infrastructure, such as the level of congestion on the road network. They are typically used in transportation planning.
- *Location-based measures* - These are location specific measures that reflect the level of accessibility to spatially distributed activities or opportunities. They are typically used in urban planning and geographic studies. The gravity-based measures and threshold-type measures mentioned earlier fall under this perspective of accessibility measures.
- *Person-based measures* - These accessibility measures determine individual-specific accessibility such as the activities that an individual can participate in at a given time.
- *Utility-based measures* - These accessibility measures determine the economic benefit that is derived from accessibility to spatially distributed activities or opportunities.

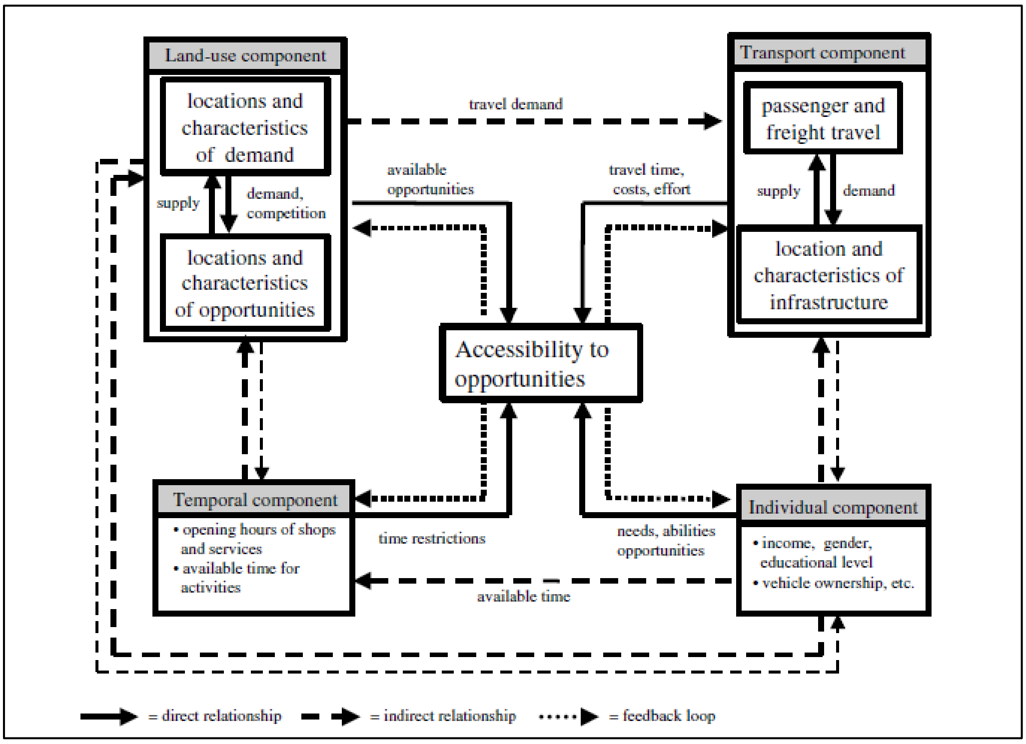

Figure 2-1: The relationship between the components of accessibility (Geurs and Wee, 2004)

Due to the flexible nature of accessibility, it can be used for various activities, modes of transport, individuals and groups, thus it has taken on an array of meanings over the years (Geurs & van Wee, 2004, Martin & van Wee, 2011). Dalvi and Martin (1976) conducted a study in which the data obtained from the 1972 London Travel Survey was used to measure the accessibility offered by private vehicles in the area. They defined accessibility as “the inherent characteristic (or advantage) of a place with respect to overcoming some form of spatially operating source of friction” (Dalvi & Martin, 1976). Morris, Dumble et al. (1979), who conducted an extensive study of accessibility measures, broadly defined accessibility as, “some measure of spatial separation of human activities”. Cervero (2005) who studied the benefits of an accessibility-based approach to planning, defined accessibility as “a product of mobility and proximity, enhanced by either increasing the speed of getting from point A to point B (mobility), or by bringing points A and B closer together (proximity) or some combination thereof”. Venter and Cross (2014) developed an accessibility measure dubbed the Net Wage After Commute (NWAC) which explicitly includes travel cost as a component that impedes accessibility; they defined accessibility as, “the ease of reaching desired destinations from a particular location, given a number of available opportunities and the difficulty (or impedance) of reaching them.”

As stated above, the concept of accessibility has been studied extensively, for various reasons and across various modes over the years. Iacono, Krizek et al. (2010) put forth that although accessibility has been a prevalent concept in transportation planning since the late 1950s, it has developed a stern focus on the automobile and thus accessibility measures are mostly developed for auto-based transport modes. Consequently, they developed a gravity-based accessibility measure for non-motorised transport (NMT) modes, more specifically cycling and walking (Iacono et al., 2010). However, there have been issues hindering the rate of progress of these NMT accessibility measures, particularly in larger metropolitan areas (Iacono et al., 2010). The following issues, specific to NMT access, were the most prominent: a) a lack of travel behaviour data for various trip purposes for NMT users, b) the need for land use data that is provided at a higher resolution, c) the aggregation of census information into zones that are too large for an NMT analysis (zip code area, traffic analysis zones (TAZs) etc.) and the lack of NMT travel networks, and d) the arbitrary impedance functions that are used for NMT accessibility measures (Iacono et al., 2010).

Accessibility measures play a critical role in transportation planning as they can act as evaluation criteria when making a selection between alternative transportation projects or plans (Morris et al., 1979). Accessibility measures also assist in identifying areas subject to transport disadvantage and thus inform the appropriate remedial action, which could either involve modification of the transport system, modification of land use or both (Morris et al., 1979, Cervero, 2005). In identifying areas subject to transport disadvantage, accessibility measures determine the level of accessibility to activities essential for a high quality of life, such as jobs, food, health, social services and interaction; with this application, accessibility measures act as social indicators (Geurs & van Wee, 2004). Accessibility measures can also be utilised as economic benefit indicators, only if they can be linked to an economic theory or they can be used as inputs in an economic benefit formula that determines the economic benefits of land-use or transport changes (Geurs & van Wee, 2004). Ultimately, accessibility plays a crucial role in policy making (Geurs & van Wee, 2004, Axhausen, 2008). Cervero (2005) believes that monitoring the performance of transportation projects from an accessibility point of view provides a more balanced and holistic approach to transportation planning and analysis. He also believes that this approach to transport analysis will provide crucial answers to issues of transport equity because as it stands, the "inattention to the social implications of past transportation investment decisions is particularly troubling" (Cervero, 2005). There is significant social value in accessibility both as a theoretical construct and as a potential spatial planning tool; as Martens (2017) puts it, "the distinct social meaning of the transport good lies in the accessibility it confers to persons".

2.1.2 Accessibility as a benefit and its wider socio-economic benefits

Stewart and Zegras (2016) hold the notion that due to the fact that we understand transport as a derived demand ("rarely do we desire mobility for itself, rather we desire the ultimate access that mobility enables"), accessibility is a benefit in and of itself. This is supported by Gutiérrez et al. (2010) who describe accessibility as "the main 'product' of a transport system". In addition to this, accessibility improvements have been tied to both wider social and economic benefits (Cervero, 2005, Gutiérrez et al., 2010, Delbosc & Currie, 2011a, GPG, 2012, Hensher et al., 2014, Venter & Cross, 2014, Stewart & Zegras, 2016). For example, higher accessibility is associated with reduced car ownership rates, which in turn alleviates some of the severe problems facing the world's cities, namely, traffic congestion and air pollution (Cervero, 2005).

According to Venables (2007), improving the accessibility of a population group expands a city's employment market and subsequently its productivity levels (Stewart & Zegras, 2016). This does not negate the knowledge that there are a number of other factors that affect economic activity in a region - accessibility to the labour market is but one of these (Gutiérrez et al., 2010). With regards to the social fabric of a region, Hensher et al. (2014) speak of social accessibility impacts which are associated with decreased social exclusion resulting from increased potential accessibility to opportunities.

Through a case study of alternative projects, López (2007) revealed that the magnitude of accessibility gains (and its benefits therefore) is dependent on existing accessibility levels. A significant effect of investment in transport infrastructure on accessibility was observed for the scenario in which the initial state of mobility and accessibility were poor; whereas, further transport investment resulted in only marginal accessibility benefits in regions with already high accessibility levels (López, 2007). In concurrence with this finding is Axhausen (2008), who after studying the effects of increased road-based accessibility across 184 districts in Switzerland observed that the marginal gains of increased accessibility were decreasing with time, particularly in the city centres which started off with relatively high levels of accessibility.

2.1.3 Measuring accessibility over time

Amongst others, accessibility changes over time have been measured in studies by El-Geneidy and Levinson (2006); Foth, Manaugh et al. (2013); Koopmans, Groot et al. (2013) and lastly, Condeço-Melhorado, Zofío et al. (2017) who examined the impetus of temporal changes in accessibility.

To elaborate on a few of these studies: El-Geneidy and Levinson (2006) studied the change in accessibility offered by two modes of transport (private vehicles and public transport) over a decade (1990 to 2000) in Minneapolis. A threshold-type measure was used to determine the accessibility to jobs in each Transportation Analysis Zone (TAZ) within a 15 minute travel time threshold. The findings were presented as maps depicting the number of jobs accessible within this threshold travel time in 1990 and 2000, for both modes, as well as the difference in the number of accessible jobs over the decade (see Figure 2-2).

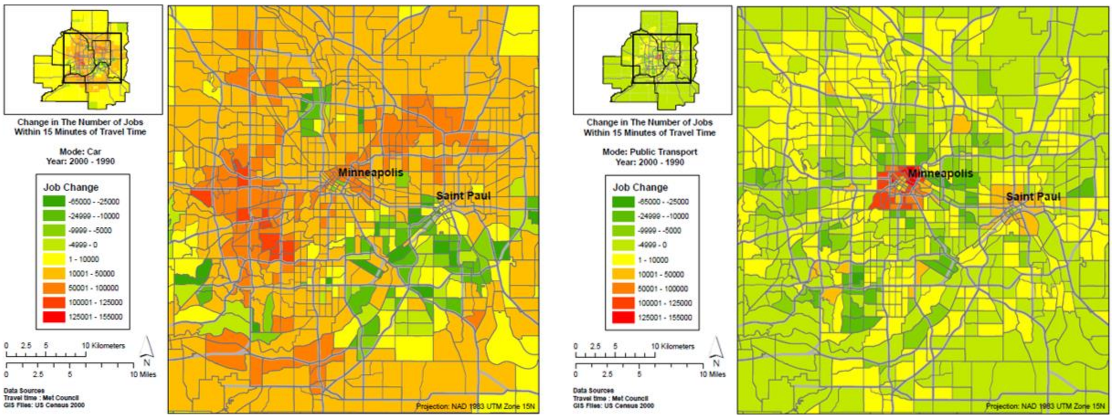

Figure 2-2: Change in the number of jobs within 15 minutes travel time (Car on the left, Public transport on the right) (El-Geneidy and Levinson, 2006)

The green regions are those that experienced a decrease in the number of accessibile jobs over the decade, while the yellow to red regions are those that experineced an increase in the number of accessibile jobs over the decade. It is evident that the number of jobs accessible by car has increased far more than the number of jobs accessible by public transport over the decade.

Foth, Manaugh et al. (2013), on the other hand, used census tract data to compare the social disadvantage, job accessibility and transit travel times of 1996 to those of 2006 in Toronto, Canada. Socially disadvantaged individuals in terms of travelling to work were identified through a social indicator which comprised of the following four variables:

- Median household income,
- Percentage of labour force that is unemployed,
- Percentage of population that has immigrated within the last 5 years, and
- Percentage of households that spend more than 30% of income on housing rent.

A gravity-based measure was used to determine the transit accessibility to jobs for the various census tracts. The same negative exponential function, derived from the Toronto area origin-destination survey data, was used to determine the travel impedance for both 1996 and 2006. The findings, displayed in Figure 2-3, reflect that the socially disadvantaged groups continue to enjoy the highest levels of accessibility to jobs in that area. This was found to be consistent with the policy objectives of Canada as the accessibility increased for all residents in the study area while the range between those experiencing the most and least accessibility narrowed over the decade. With this in mind, it was concluded that Toronto's transit systems are becoming more equitable in terms of accessibility to jobs.

El-Geneidy and Levinson (2006) stress the importance of measuring accessibility changes over time as this could provide a tool that can be used to assess the performance of land-use and transportation planning and policy.

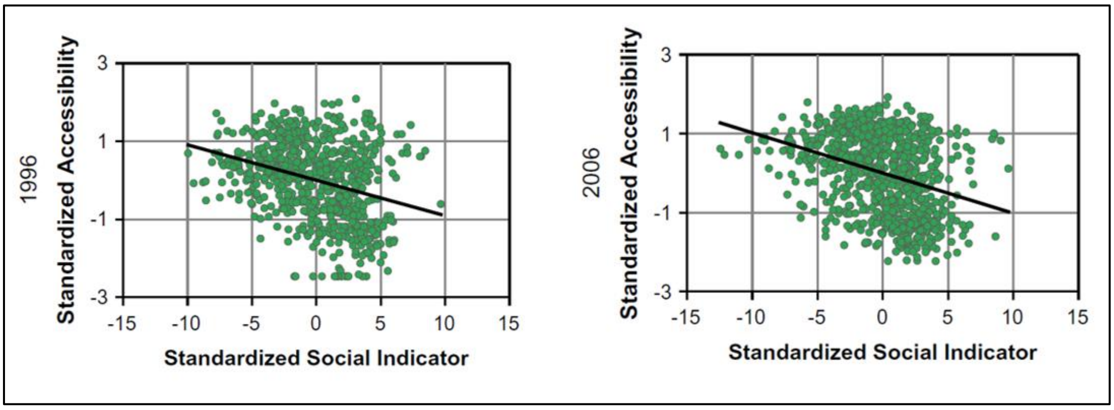

Figure 2-3: The relationship between accessibility and the social indicator, 1996 and 2006 (Foth, Manaugh et al., 2013)

2.1.4 Measuring accessibility in the developing world

In recent accessibility literature in the developing world, where affordability of transport is a significant challenge, there has been an increase in research exploring the effect of affordability of transport services on the accessibility afforded to residents. This has been executed with particular interest in low-income residents who tend to experience the financial burden of travel that is often attached to residing in the peripheries of cities, significantly dislocated from the centres of economic activity (Bocarejo S. & Oviedo H., 2012, Venter & Cross, 2014, Falavigna & Hernandez, 2016, Guzman et al., 2017). According to Falavigna and Hernandez (2016), who analysed the affordability of public transport services by the urban poor in two cities in Latin America found that for the poorest residents of each city to achieve the same mobility as the corresponding middle-income group, it would require them to increase their transport expenditure by upwards of 30%.

Litman (2016), who has carried out extensive research on transport affordability, defines it as “the financial burden households bear in purchasing transportation services, particularly those required to access basic (also called essential) goods and activities such as healthcare, shopping, school, work and social activities.” Therefore, transport expenditure alone, does not adequately depict transport affordability (Venter, 2011). This is acknowledged in the accessibility measure developed by Bocarejo & Oviedo H. (2012) in which they explicitly account for transport affordability as the percentage of income spent on transportation. The results revealed that, in certain instances, dependent on the population group, its location and purchasing power, the improvement of affordability can have a greater impact on the accessibility to opportunities than the expansion of the public transport system. Although transport expenditure alone does not adequately reflect affordability, transport expenditure data together with objective and subjective data such as mode choice, frequency of trips and perceived affordability can allow for a useful comparative analysis regarding the use and ability to use transport services (Venter, 2011). Ultimately, incorporating cost or affordability as a form of travel impedance in an accessibility measure can incorporate the individual component into the measures, in terms of the financial means to commute to opportunities, ultimately providing an indication of equity across various income groups and areas and potentially informing means to achieve equity (Bocarejo S. & Oviedo H., 2012, Falavigna & Hernandez, 2016).

In the African context, there has been evidence of both qualitative and quantitative measurements of accessibility. In the case study of transport accessibility afforded to the urban poor residing in the peripheries of Dar es Salaam, Tanzania, both a qualitative and quantitative analysis was carried out. The qualitative analysis in particular was carried out due to the absence of previously recorded travel time and speed data for the study regions. The quantitative data regarding travel times between regions were then verified using qualitative data obtained from interviews with the population groups of interest (Andreasen & Møller-Jensen, 2017). A purely qualitative study, through surveys and workshops, was recently carried out in Zimbabwe, to assess the accessibility of children with disabilities to spatially distributed educational opportunities (Kett & Deluca, 2016). In the South African context, there is evidence of more quantitative analyses of accessibility over the years, using traditional accessibility metrics and even the application of newly developed accessibility measures such as the access envelope technique developed by Venter and Cross (2014). What gave rise to this measure was the identification of two main shortcomings of the traditional types of accessibility measurements (more specifically, gravity-type and threshold-type measures) that propelled the development of the access envelope technique for accessibility mapping in developing countries. The first shortcoming identified is the simplistic manner in which travel impedance is accounted for in previous accessibility measures; it is either in terms of travel time or travel distance (Venter & Cross, 2014). The second shortcoming is the failure of these measures to explicitly account for travel costs when estimating travel impedance (Venter & Cross, 2014).

The access envelope technique is a Geographic Information Systems (GIS) based methodology. GIS is an interactive data manipulation, spatial analysis, network analysis and visualisation tool that has been used in transportation planning for quite some time (Ford et al., 2015). Various studies, including that of Venter and Cross (2014), have used GIS software to map accessibility over the years, (see (Miller & Wu, 2000, Delamater et al., 2012, Ford et al., 2015).

Venter and Cross (2014) describe the access envelope technique as "a planning tool for measuring the impact of both transport and job or housing delivery on the location-specific affordability of job access at a community level for poor households". Some of the input data required to determine the accessibility is; a) the spatial distribution of jobs, b) the potential wage levels, c) public transport networks and d) walking times to and from public transport stops, public transport costs, and f) speed of the public transport modes. The accessibility measure is dubbed the Net Wage After Commute (NWAC) and it describes the potential wage earnable less the transport costs incurred to travel from home to the job location on any given day. Essentially, this technique derives the benefit acquired from reaching a particular destination and subtracts the costs incurred in doing so. By explicitly including transport costs as a form of travel impedance, this technique becomes sensitive to these costs as well as operational shortfalls that force commuters to transfer, which usually occurs with the payment of an additional fare and travel delay (Venter & Cross, 2014).

Figure 2-4 reflects how the NWAC is mapped from an origin in Soshanguve in the City of Tshwane. Regions with higher NWAC values (NWAC of R80 or above) are deemed more accessible than those that fall below this mark.

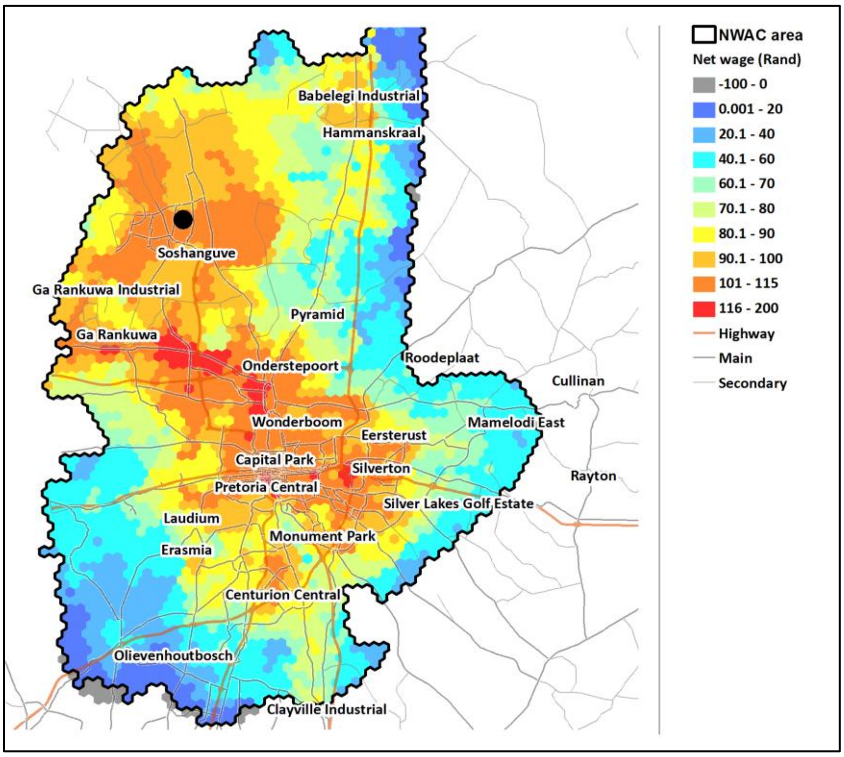

Figure 2-4: Soshanguve wage surface (Venter & Cross, 2014)

In their study of Altos de Cazucá, Soacha, a low-income informal residential area in the peripheries of Bogotá, Hernandez and Titheridge (2014) found that community members operate informal services within the community as an infill of the gaps and shortfalls of formal government systems in serving low-income residents in the peripheries. The inadequacy, in terms of service provision, of formal public transport services in low-income residential areas in the peripheries also gave rise to the informal minibus taxi service in South Africa, which has been the most widely used public transport mode in the country for approximately three decades (CoJ, 2011, CoJ, 2013). Despite the evident risks of operating informal services, such as increased road accidents, costs and potential fatalities as well as the likely poor road-worthiness of the service vehicles (Oviedo Hernandez & Titheridge, 2016), these services remain a necessary measure in such contexts to meet the accessibility needs (to public transport services and subsequently to opportunities) of the urban poor in the peripheries. Therefore, in such contexts, it is likely that measuring the accessibility to opportunities offered by the public transport system as a whole will require the consideration of both formal and informal services.

2.2 THE CITY OF JOHANNESBURG

2.2.1 The making of the "economic hub"

The City of Johannesburg (CoJ), home to South Africa's most dynamic economy, was founded in 1886 when gold was discovered in what was then the South Transvaal (Hart, 1984, Todes, 2012). The discovery of gold had a significant impact on the attractiveness of Johannesburg to international investors, and the subsequent wealth accumulation affected the distribution of economic activity and the populace throughout South Africa (Gotz Wray & Mubiwa, 2014). Johannesburg's population grew at an average annual growth rate of 3.2% per annum from 2001 (3.2 million) to 2011 (4.5 million) and in 2011, the city's residents made up 36% of Gauteng's population and 8% of South Africa's population (CoJ, 2013). The *Joburg 2040: Growth and Development Strategy* predicts that by 2040 the city's population will be between 6 and 8 million (CoJ, 2013). Figure 2-5 displays the boundaries of the Johannesburg metropolitan municipality within the Gauteng province and its location relative to the other municipalities that form part of the province.

Although Johannesburg's economy was initially driven by the mining sector, by 1996, the mining sector contributed only minimally to Johannesburg's economy and total employment. The emerging markets in the period of the mining sector decline were manufacturing, and finally, the service sectors (particularly the finance, insurance, real estate and business services sector) were driving the economy by the mid-1990s. From 1996 to 2011, the Johannesburg economy was growing relatively fast in comparison to the national economy, with a 79% increase in the number of individuals with jobs in comparison to 43% for the entire country. The CoJ unemployment rate also dropped from 29.4% to 25% in this time period (Harrison et al., 2014).

Johannesburg began its transition to a polycentric region from the 1970s with the formation of new economic nodes, such as Midrand, Rosebank and Sandton, towards the north of the city (Todes, 2012). The relocation of former Central Business District (CBD) residents to the northern parts of the city gave impetus to decentralisation as service sectors followed consumers to these suburbs which also allowed for new and safer working spaces away from "the 'crime and grime' of the CBD" (Todes, 2012). The CBD has since been occupied by low-income African and African immigrant populations, which together with factors including overcrowding and poor maintenance of buildings have led to high densities and the dilapidation of some buildings (Beall et al., 2000, Todes, 2012).

The CoJ forms part of a polycentric city-region named the Gauteng City-Region (GCR), in which Johannesburg, Tshwane and Ekurhuleni are the economic, administrative and industry centres of the GCR respectively; see Figure 2-6 (Everatt et al., 2011). The GCR footprint spreads across four provinces, namely; Gauteng, Mpumalanga, North West and the Free State (Wray, 2010).

Figure 2-5: The CoJ in the Gauteng province (Source: https://www.south-africa-tours-and-travel.com/map-of-johannesburg-south-africa.html)

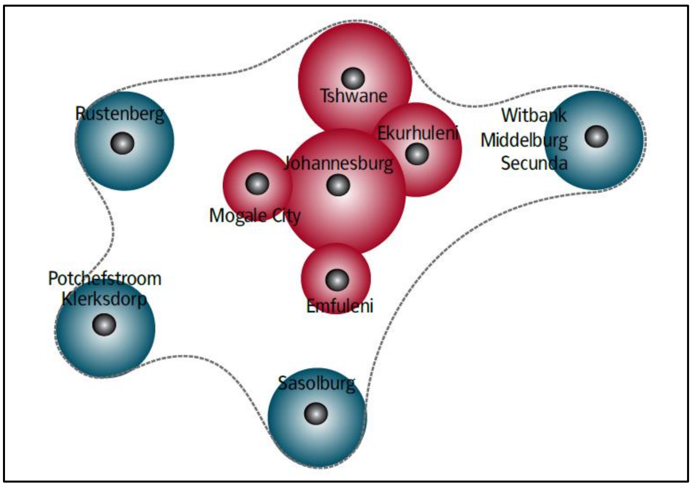

Figure 2-6: Conceptual figure of the GCR (Greenberg, 2010)

The drive towards the formation of the GCR was initiated by the Gauteng Provincial Government (GPG) in 2006 and is the most significant step South African planning has taken towards 'new regionalism'; a concept that has dominated regional studies since the 1980s (Rogerson, 2009). Pike, Rodríguez-Pose et al. (2006) define 'new regionalism' as "the renewed emphasis upon the region as the locus for economic, social and political action and the roles of institutions in local and regional development". In relation to 'new regionalism', Scott (2002) defines a region as "an area of sub-national extent focussed on a central urban agglomeration or agglomerations together with an immediate surrounding hinterland". From the start of the Industrial Revolution, regions played an imperative role in economic growth and development (Scott, 2002). This, amongst other things, was the logic behind the formation of the GCR and Gauteng was also identified as the urban region in South Africa most suited to be advanced to global city-region status (Greenberg, 2010). According to Gotz et al. (2014), the development necessary to form what is now the GCR can distinctly be attributed to the discovery of gold in Johannesburg in 1886.

2.2.2 Challenges in the CoJ

Johannesburg's economic success occurred in tandem with rapid population growth and relatively high levels of poverty and unemployment, all of which pose challenges in the post-apartheid governance of South Africa. The following sub-chapters will elaborate on a few of these challenges and their repercussions.

2.2.2.1 Historic spatial form

The apartheid era resulted in the "fracturing of urban development" in the CoJ, in which there were clear divisions across racial lines (Gotz et al., 2014). There has since been a level of racial integration amongst the middle class residents in the northern region of the city, however, according to the Todes (2012), clear spatial divisions across class lines still exist.

The forceful relocation of non-white racial groups to the peripheries of the city during the apartheid era, what Gotz et al. (2014a) refer to as "township planning", played a significant role in fracturing the city's spatial form. These townships, housing predominantly low-income residents, were far removed from the city's economic and social opportunities and suffered from inadequate services and infrastructure (Everatt et al., 2011, Todes, 2012). In his paper about the "experiences and aspirations" of township residents, Manase (2014) presents literature that suggests that legislations such as 1923 Native Urban Areas Act and the 1936 Land Act which resulted in the spatial segregation of racial groups, were birthed from colonialism. To allow for growth of the colonial economy, particularly after the discovery of gold in 1886, "slum settlements" for workers, predominantly inhabited by black workers, were established along the mining belt. The aforementioned laws were then introduced by authorities with growth of the notion that these settlements and their associated environmental and socio-economic challenges should only be suffered by blacks (Manase, 2014). The Witwatersrand mining belt has been referred to as the "apartheid 'buffer zone'", which separates the CoJ into the wealthier north and the poorer south (Gotz et al., 2014), see Figure 2-7.

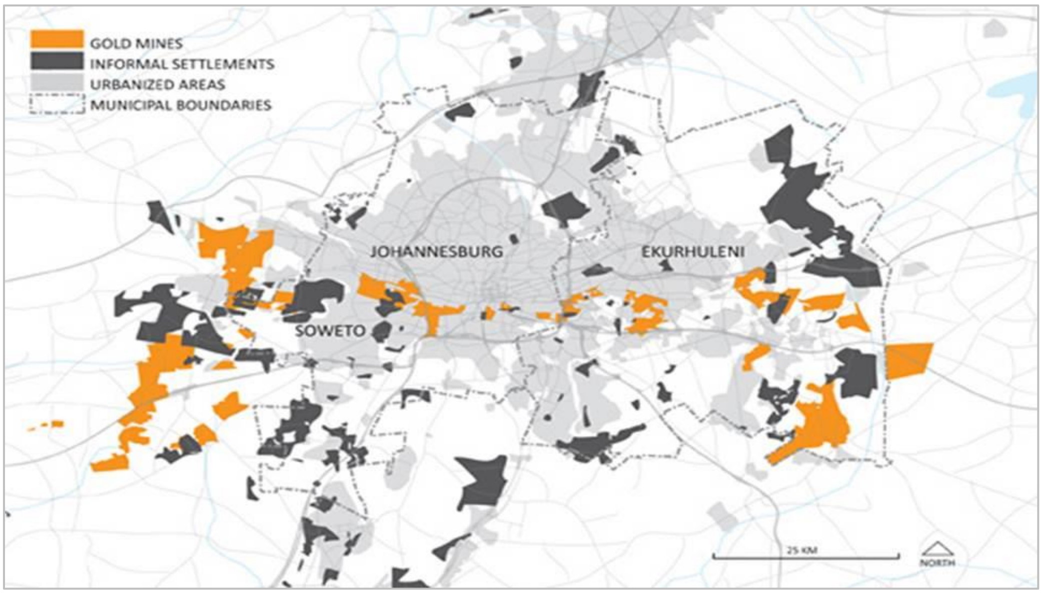

Figure 2-7: Mining belt and settlements in the CoJ (Source: https://www.health-e.org.za/2015/10/15/gautengs-mine-dumps-brimming-with-radioactive-uranium/#lightbox/0/)

This apartheid spatial planning has posed challenges for the re-integration and de-racialisation of space in the cities of post-apartheid South Africa (Gotz et al., 2014). One of these challenges is observed in the administering of housing through the Reconstruction and Development Programme (RDP). This programme was introduced in 1994 as a poverty alleviation strategy which involved, amongst other things, providing housing to the urban poor. Although the programme was well-intentioned, the growth of RDP housing was within or close to existing townships due to escalating land prices in the more urbanised areas of the city, perpetuating the spatial exclusion and the financial and travel time burden experienced by the urban poor (Todes, 2012, CoJ, 2013). The current Integrated Residential Development Programme (IRDP) was introduced to "facilitate the development of integrated human settlements in well-located areas that provide convenient access to urban amenities, including places of employment" (National Department of Human Settlements, 2010). This approach imposes additional costs on the government and/or households due to higher land and housing costs in these "well-located areas"; therefore Venter and Cross (2014) believe that a key consideration in spatial development policy should be trade-offs between housing costs and transport costs, particularly in the metropolitan cities of Gauteng where there is currently significant investment in BRT services which may, in the long-term, result in restructuring urban land use.

2.2.2.2 (Im)migrantion[1]

Due to the perceived relative economic growth and success of Johannesburg, the city became a magnet for work-seekers from both within and outside of South Africa, the latter mostly relocating from southern Africa (Harrison et al., 2014). The CoJ population increased by 68.4% in 15 years, from roughly 2.6 million people in 1996 to roughly 4.5 million people in 2011; (im)migration accounts for nearly 60% of this growth (Harrison et al., 2014). In addition to that, the city experienced a 96% growth in households in the same time period, which posed a challenge to government to meet the increasing demand for accommodation and household services delivery (Harrison et al., 2014).

(Im)migration is not unique to the CoJ, similar trends are evident across the greater Gauteng province. In 2010, Statistics South Africa (StatsSA) estimated that although Gauteng was the smallest province in the country, it was the most populated; it housed 22.4% (11 191 700 people) of South Africa's population, with an approximate population growth rate of just short of 2% per year (Landau & Gindrey, 2008, Everatt et al., 2011, GPG, 2012). Aside from the rapid population growth consequent upon (im)migration, this human mobility creates vibrant and culturally diverse spaces, however, that in itself then acts as an additional magnet for (im)migrants (Everatt et al., 2011).

[1] Immigration refers to the movement of individuals from their country of origin to another country, migration refers to the movement by individuals from one place to another within the same county, (im)migration refers to both these forms of human mobility.

The 2011 QoL survey presented worrying revelations regarding the attitude towards migrants in Gauteng, where 32% of respondents believe that Gauteng is for South Africans only and immigrants must leave. Perdeby (2013) believes that this displays little belief in the concept of diversity and a complete disregard for the immigrant hands that worked and still work at the gold mines to help build the province. Landau and Gindrey (2008) believe this anti-immigrant attitude is a significant institutional barrier in developing the necessary policies to accommodate immigrants. They are of the view that, although catering for immigrants has its associated political risks, they believe that the long-term benefits will out-weigh the immediate costs (Landau & Gindrey, 2008). Over and above their contribution to diversity, entrepreneurial immigrants assist in creating employment opportunities for nationals and thus participate in and contribute to the economy of the province (Landau & Gindrey, 2008, Peberdy, 2013). In fact, data from the Forced Migration Studies Programme (FMSP) revealed that in the inner city of Johannesburg, immigrants create more jobs than they 'take' (Landau & Gindrey, 2008).

Due to the non-uniform nature of human mobility (some people (im)migrate to the metropolitan cities, others to mining towns etc.), investments and the need for housing structures becomes unpredictable; consequently, the government cannot develop a universal response to (im)migration (Landau & Gindrey, 2008).

2.2.2.3 Poverty, inequality and unemployment

According to the World Bank, South Africa is amongst the most unequal countries in the world, with an income Gini coefficient of 0.70 in 2008 and a consumption Gini coefficient of 0.68 in 2009. Exacerbating this reality is the high level of unemployment in the country (25.5%), once again, amongst the highest in the world. As a result, despite the significant growth of the country's GDP, post-apartheid, there has been minimal reduction in poverty since then (World Bank, 2012). StatsSA's 2017 report on *Poverty trends in South Africa* reveals that there has been a decrease in poverty since 2006, however, poverty levels rose again in 2015 with 30.4 million South Africans living in poverty (StatsSA, 2017). The GCRO's QoL surveys revealed that in Gauteng, the income Gini coefficient of Johannesburg (0.74) only comes second to that of Ekurhuleni (0.77). Mushongera et al. (2015) believes that these high levels of income inequality may be contributing to social tensions which are then manifested through violence.

Since 1994, the government has put policies and programmes in place to aid poverty alleviation and combat inequality (Everatt et al., 2011, Mushongera et al., 2015). Some of these include the RDP (1994) and the NDP (2012). The main aim of these programmes and policies was to rectify the injustices of the past (Mushongera et al., 2015), however, according to Beall et al. (2000), the distribution of poverty in the CoJ closely follows the racially segregated spatial form of the past. This is confirmed by Everatt (2014), who states that available poverty studies and data have consistently shown that “Africans are most likely to be poor…”

2.3 TRANSPORT IN THE COJ

2.3.1 The role of transport in shaping the city’s urban form

Literature has revealed that the interaction between transport systems and land use patterns affects the urban form (Hart, 1984, Schiller et al., 2010, Naudé, 2015). In 1886 when the only transport modes available in Johannesburg were the horse buggy, the Hansom cab, the bicycle and walking; the formal part of the Johannesburg settlement was densely developed into a rectangular shape measuring approximately two kilometres from East to West and one and half kilometres from North to South, see Figure 2-8 (Hart, 1984).

Johannesburg grew larger as public transport modes such as the horse tram and electric streetcars were introduced in 1891 and 1906 respectively (Hart, 1984). Transit allowed for faster travel and subsequently bigger cities (Hart, 1984, Schiller et al., 2010). Although cities grew larger, development was kept within walking distance or a bicycle ride to the transit stops which encouraged high density, mixed land use development (Schiller et al., 2010). However, the introduction of the automobile in Johannesburg led to extensive urban sprawl and even longer distances could now be travelled; subsequently, residential areas were located further and further away from working areas, freeways were developed and Johannesburg became a metropolitan city (Hart, 1984), see Figure 2-9.

A more recent example of the effects of transport on urban form would be the Gautrain, the rapid rail link in Gauteng that Naudé (2015) describes as “arguably the most prestigious public transport project ever undertaken in South Africa”. A study conducted by Mushongahande et al. (2014) on the impact of the Gautrain on property development at the Rosebank, Midrand and Pretoria stations revealed that property developers consider the Gautrain a major attraction to develop in station vicinities. Since the announcement of the Gautrain was made in 2000, 47 properties in the vicinity of the Rosebank station went through at least one stage of property development (Mushongahande et al., 2014). Of the three stations studied, the Rosebank station is where the concepts of Transit-Orientated Development (TOD) such as: mixed land-use development, high quality NMT infrastructure and multi-modal integration are the most evident (Mushongahande et al., 2014).

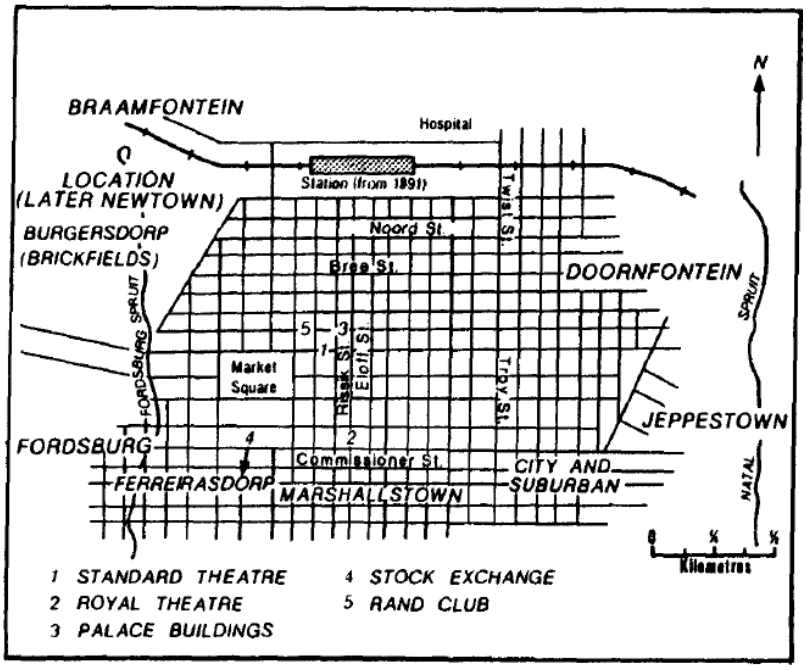

Figure 2-8: Horse and buggy, bicycling and walking era, 1990 (Hart, 1984)

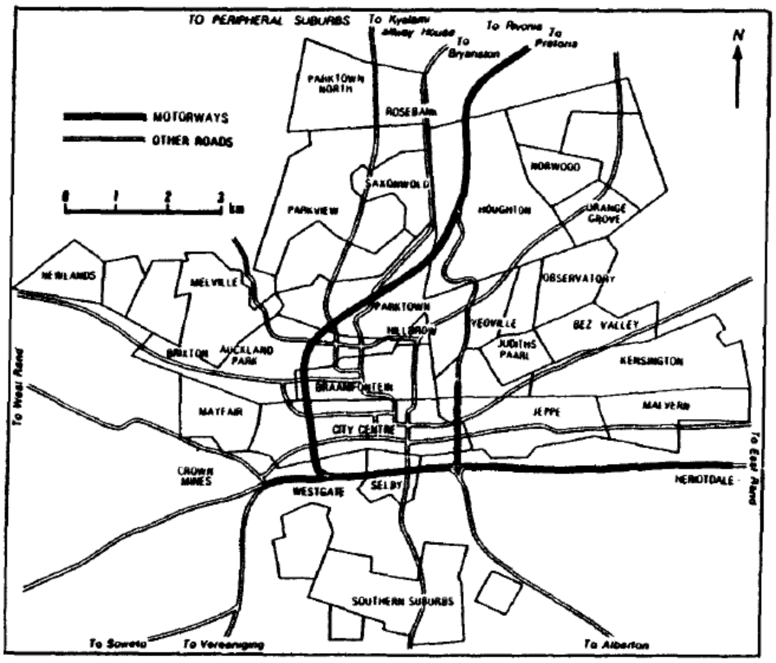

Figure 2-9: Motorways and the automobile (Hart, 1984)

2.3.2 Public transport in the CoJ

During the apartheid era, two public transport modes were available in Johannesburg, namely, the commuter rail and subsidised state busses (CoJ, 2011). As these public transport services were provided by the state, their services and infrastructure were divided across racial lines, with inadequate provision in non-white townships already deliberately dislocated from the city's economic opportunities (CoJ, 2011). This created a gap in the public transport market, which became occupied by privately owned services which, relative to the existing services at the time, sufficiently served the non-white urban poor, resulting in a striking shift from the publicly owned services to privately owned services (see Table 2-1). This rapidly advanced the minibus taxi's public transport modal share and it is currently the most widely used public transport mode in the CoJ (CoJ, 2011, CoJ, 2013).

Table 2-1: Modal shifts in Gauteng from 1975 to 2013 (Gotz, Wray et al., 2014)

Year	Survey	Walk	Rail	Taxi	Bus	Private
1975	Pretoria-Witwatersrand-Vereeniging (PWV) transportation survey	7%	20%	3%	22%	49%
1999/ 2003	1998/1999 Tshwane Survey and 2002/2003 Gauteng Transport Survey for the GTS 2000 survey	9%	6%	31%	6%	48%
2003	National Household Travel Survey	11%	9%	31%	6%	42%
2009	GCRO's QoL Survey (Gauteng results only)	10%	4%	41%	4%	41%
2011	GCRO's QoL survey	6%	5%	42%	3%	43%
2013	National Household Travel Survey	13%	7%	30%	5%	44%

In present day, the commuter rail service, Metrorail, is run by the Passenger Rail Agency of South Africa (PRASA). The service operates along the east-west and the south and south-west of the city, ill-matched with the present day decentralised economic nodes of the CoJ (CoJ, 2013). The service has 58 stations, 2 depots and operates 20 routes within the CoJ municipal boundary (Noble & Bickford, 2013). Due to three decades with no investment in the service, the rolling stock is dilapidated, the service is unsafe, unreliable and it offers uncompetitive travel times, therefore passenger numbers continue to decline (CoJ, 2011). The 2013 National Household Travel Survey (NHTS) revealed that there was a decrease in the percentage of public transport users who were likely to make at least one transfer on a trip from 26.5% in 2013 to 17.1% in 2013, however, train users were the most likely public transport users to transfer from one mode to another (StatsSA, 2014). In light of this, another pertinent shortfall of the Metrorail, in the context of its mismatch with current economic nodes of the city, is its lack of integration with other modes (CoJ, 2013).

The Gautrain, introduced to Gauteng in 2010, is more suited to the present day land use patterns of the CoJ, serving the decentralised economic nodes such as Sandton, Rosebank, as well as the O.R. Tambo International Airport (CoJ, 2013). However, the service has been criticised for: a) its high costs, which do not cater for the urban poor, and b) for potentially perpetuating the use of private vehicles by building train stations with high levels of parking (Todes, 2014). Figure 2-10 displays both the Gautrain and Metrorail routes in the city.

Figure 2-11 displays the relatively widespread Metrobus network in the CoJ, which has an average route length of 27.2km (CoJ, 2013). The Metrobus serves 90,000 passengers daily but, like the Metrorail, grapples with the challenge of an old fleet (CoJ, 2011). There are 1200 subsidised commuter buses in the city, some of which are subsidised by the city's Metrobus company and others through contracts with the Gauteng Department of Roads and Transport. The latter includes the Putco Soweto contract, Eldorado Park contracts and the South Western Areas contracts (CoJ, 2013). In August 2009, an additional bus service, the Bus Rapid Transit (BRT) dubbed Rea Vaya, was introduced to the CoJ, making it the first African city to operate a full BRT service (Venter & Vaz, 2014). The design of this system was largely based on South American models, such as the TransMilenio in Bogotá, Colombia, which includes dedicated lanes, enclosed station and a high quality of service (Venter & Vaz, 2014). Phase 1A of Rea Vaya (see Figure 2-12), which consists of a 26km trunk line and five feeder routes within Soweto became fully operational in February 2011 (CoJ, 2013).

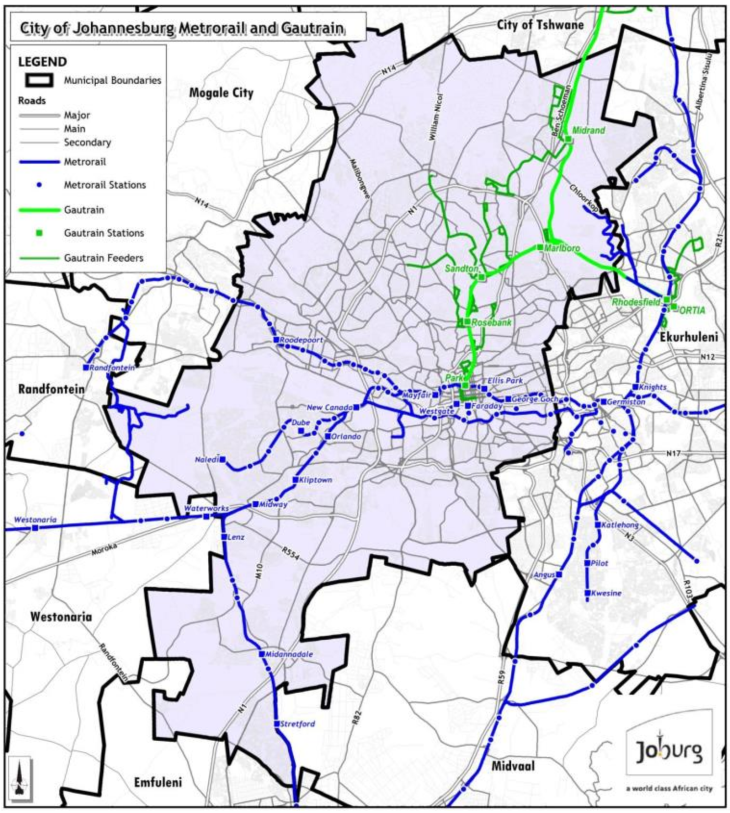

Figure 2-10: CoJ Metrorail and Gautrain networks (CoJ, 2013)

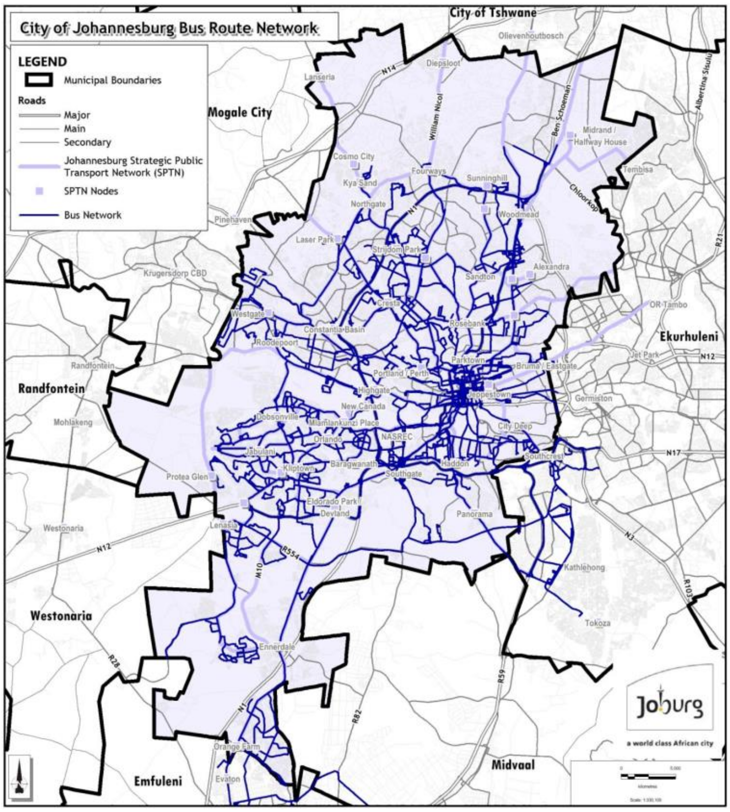

Figure 2-11: CoJ Metrobus network (CoJ, 2013)

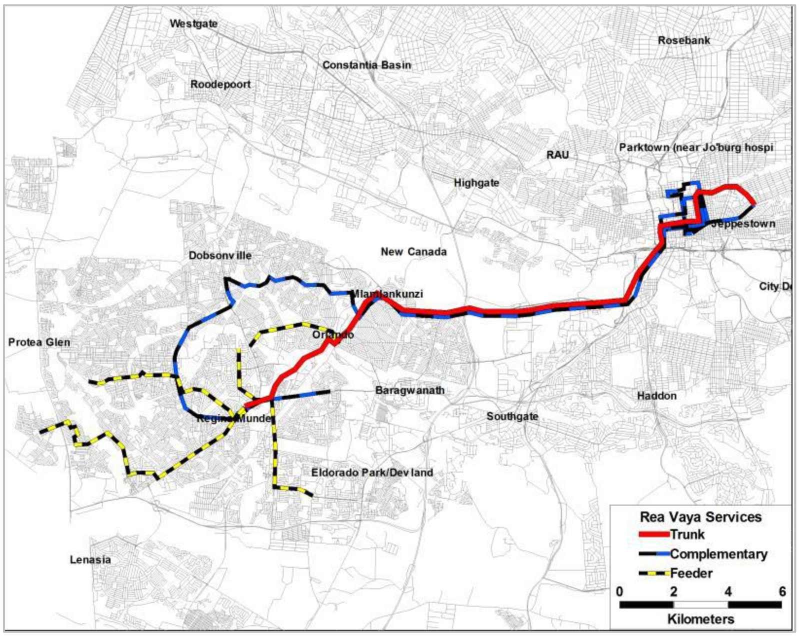

Figure 2-12: The CoJ Rea Vaya Phase 1A network (CoJ, 2013)

The minibus taxi network in the CoJ is reflected in Figure 2-13. As aforementioned, this is the most widely used mode in the CoJ. There are approximately 32 minibus taxi associations which operate on more than 1000 routes in the city from 450 different starting points (CoJ, 2013). The government has made attempts to re-organise or formalise the service with little long term success (CoJ, 2013).

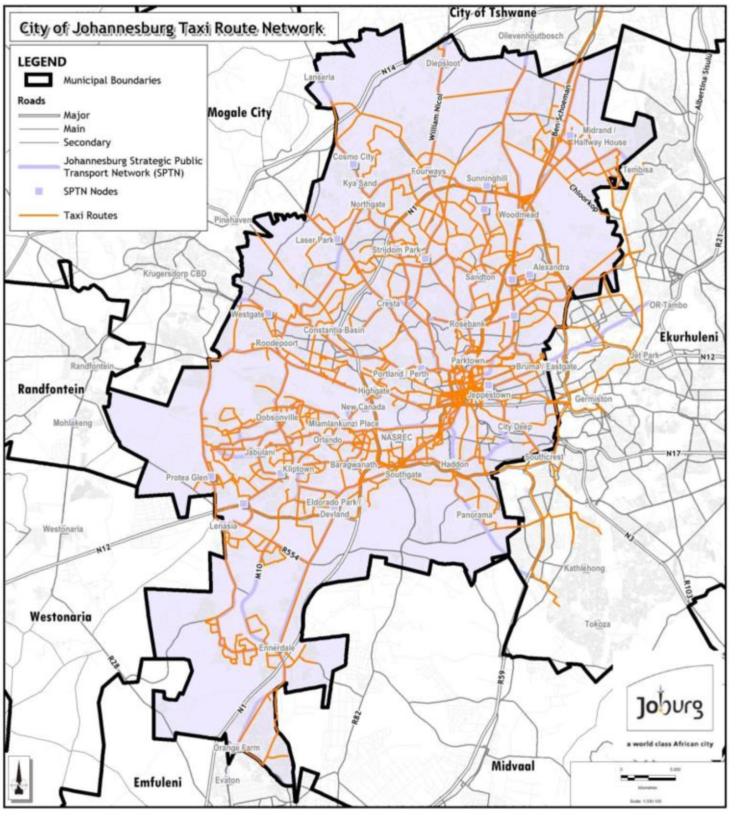

Figure 2-13: CoJ Minibus taxi network (CoJ, 2013)

2.3.3 Transport challenges in the CoJ

"The daily lives of Gauteng's residents are influenced by the efficiency of the transport they use. Reducing the cost and increasing accessibility of transport are critical for improving people's access to opportunities and services" (Gotz et al., 2015). In the G2055, a document that discusses the long-term development plan of the GCR, South Africa is commended for making significant leaps in transport infrastructure since 1994, however, transport affordability remains a pressing issue. In this regard, according to the OECD (2011), Gauteng is considered the least affordable region relative to other African cities, with residents typically spending approximately 21% of their monthly income on transport; this was prior to the introduction of e-tolling on the highways (GPG, 2012, Gotz Wray Venter et al., 2014). For higher income households, transport costs constitute of those incurred to maintain a private vehicle, and for lower-income residents, these costs constitute of public transport fares (Mokonyama & Mubiwa, 2014). This high transport expenditure impacts severely on the poor because in addition to challenges of transport affordability, there is poor access to public transport in the peripheries of cities where the poor are typically located, in tandem with poorly defined routes and little to no modal integration (Gotz et al., 2014).

Transport planning in the GCR is confronted by the challenges of a growing population, together with severe spatial, social and environmental challenges (Gotz et al., 2014). The GCR mobility report by the GCRO (Gotz et al., 2014) lists a number of transportation challenges facing the GCR. Some of these challenges are supported by various other pieces of literature and those challenges that have been mentioned previously will now be discussed in greater depth. The challenges are as follows:

- *Transport sustainability:*
  Table 2-1 reflects the modal shifts that have taken place in Gauteng from 1975 to 2013; it is evident that the most widely used mode is consistently the private vehicle (Gotz et al., 2014). In the 1960s and 1970s, transportation planning in South Africa was vehicle-centric and it revolved around road-based modes of transport; however, this is no longer sustainable (Bickford, 2013, Gotz et al., 2014). The most dramatic modal shift, seen in Table 2-1, is that from government owned rail and bus services to the privately owned minibus taxi. The reason identified for this dramatic shift is the deteriorating operational reliability and performance of these rail and bus services, making the minibus taxi the best alternative option for transit captive residents (Gotz et al., 2014). Travel Demand Management (TDM) is considered one of the most effective methods of improving transport sustainability, however, although all municipalities are required to include a TDM strategy in their ITPs, very little progress has been made in implementing successful TDM strategies in South Africa (Bickford, 2013).
- *Sprawl and low density development:*
  In 2003, 11.3% of commuters travelling from home to work had to walk for fifteen minutes to the nearest public transport stop. The 2013 StatsSA National Household Travel Survey revealed that this number increased to 17% ten years later. It was concluded that public transport services may be improving but the accessibility to these services continues to decline. The placement of Reconstruction and Development Programmes (RDP) housing on the peripheries of the city region with poor provision of public transport results in townships with poor accessibility (Gotz et al., 2014, Venter & Cross, 2014). On the other hand, the advent of gated communities over the last decade has resulted in low density development that does not allow for the efficient operation of a public transport system and thus generates private vehicle trips that exacerbated congestion on the road network (Gotz et al., 2014).
- *Affordability of transport*:
  StatsSA (2014) revealed that transport costs had increased from the OECD (2011) value of 21% to a value in excess of 26% of monthly household income (Gotz et al.,

2014). The 2013 National Household Travel Survey report gave a breakdown of the cost of transport per mode per month, and it was as follows: a) private vehicle drivers spend R1,727 per month, b) minibus taxi commuters spend R625 per month, c) bus commuters spend R580 per month, and d) train commuters spend R466 per month (Gotz et al., 2014). It is clear that the two most expensive modes in the country are the most widely used, as reflected in Table 2-1.

- *Inadequate resources for transport infrastructure:*
  Inadequate funding is a key challenge identified by the GPG (2012) and it was also stated in the 25-year Integrated Transport Master Plan (ITMP25) (Gotz et al., 2014). The project manager of the ITMP process believes that ideally, transport budgets need to be increased to four times what they are now over the next 25 years in order to have sufficient funds for the infrastructure (Gotz et al., 2014). Bickford (2013) questions the financial sustainability of the public transport investment in the country. His argument is that, as it stands, large operational subsidies are required to operate public transport services. With more and more public transport services being implemented in the country, he states that it is unclear whether national government will be able to continue to provide these large subsidies and whether costs will be recovered through fares (Bickford, 2013). The danger now becomes that public transport operators will target areas with people who can afford higher fares so as to generate the greatest amount of revenue, once again, at the expense of the poor (Bickford, 2013).

The following sections present the interventions implemented and those to be implemented within the GCR to address the some of the above stated challenges.

2.3.4 Road based transport interventions

One of the major road-based public transport investments in the GCR is the ongoing implementation of the Bus Rapid Transit (BRT) systems in the three metropolitan municipalities of the GCR with joint funding from the local and national government (Gotz et al., 2014). BRT had become a favoured public transport investment choice in both developed and developing countries due to its ability to induce modal shifts (if it is operated efficiently, it provides an attractive alternative for choice users), relieve traffic congestion, reduce carbon emissions and provide additional mobility options for the poor (Cervero & Kang, 2009, Naudé, 2015). The main advantages that this mode has over rail is its operational flexibility; the ability to operate in mixed traffic as a feeder service and also operate on exclusive right-of-way lanes as a trunk service (Cervero & Kang, 2009).

The implementation of BRT systems in the GCR started in the CoJ with a system called *Rea Vaya*. Construction of phase 1A (see Figure 2-12), completed in 2009, connects Soweto and the Johannesburg inner city (Gotz et al., 2014). Phase 1B (see Figure 2-14), completed in early 2014, also connects Soweto to the Johannesburg inner city, however, it runs to the north past Wits and UJ. The construction of phase 1C (see Figure 2-15), which links Alexandra and Sandton to the existing network began in April 2014 (Gotz et al., 2014).

Construction of the Tshwane BRT system, named *A Re Yeng*, began in April 2013 and the first seven kilometre leg was completed in 2014 (Gotz et al., 2014). Brickford (2013) expresses concern regarding the lack of research reflecting the benefits of BRT systems in the South African context and whether or not they are operating to meet broader policy objectives. Venter and Vaz (2014) reveal that indeed the BRT in Johannesburg does have mobility benefits, however, these benefits are enjoyed more by middle-income commuters than poor commuters. In addition, the BRT's ability to invoke a shift from private vehicles to the BRT is a benefit that will take longer to manifest (Venter & Vaz, 2014).

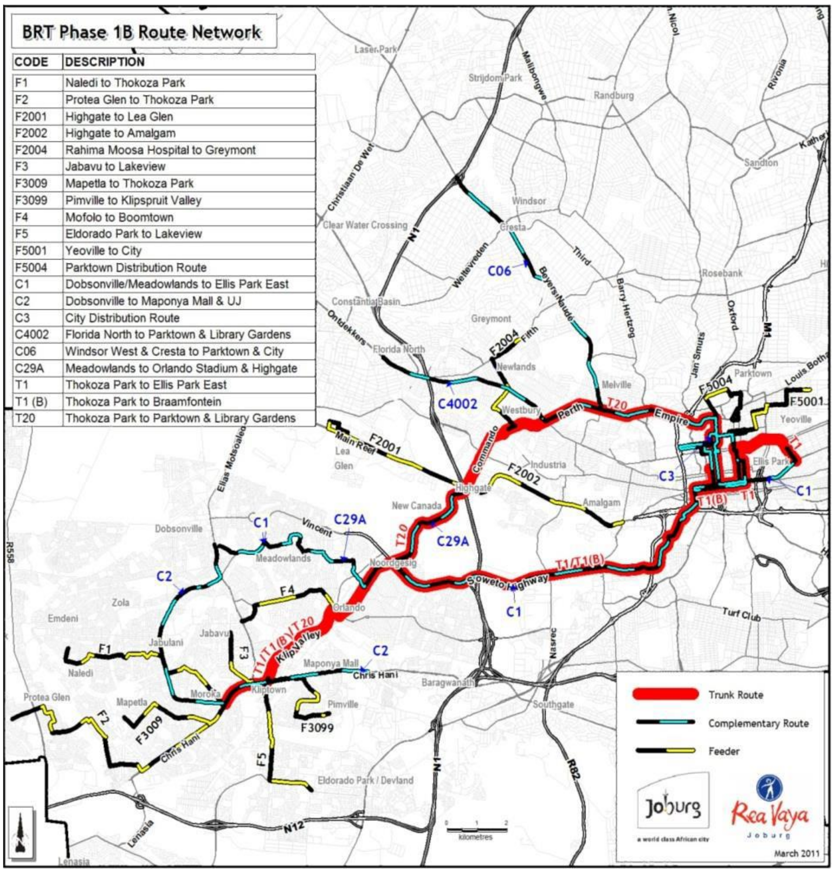

Figure 2-14: Rea Vaya Phase 1A and Phase 1B network (CoJ, 2013)

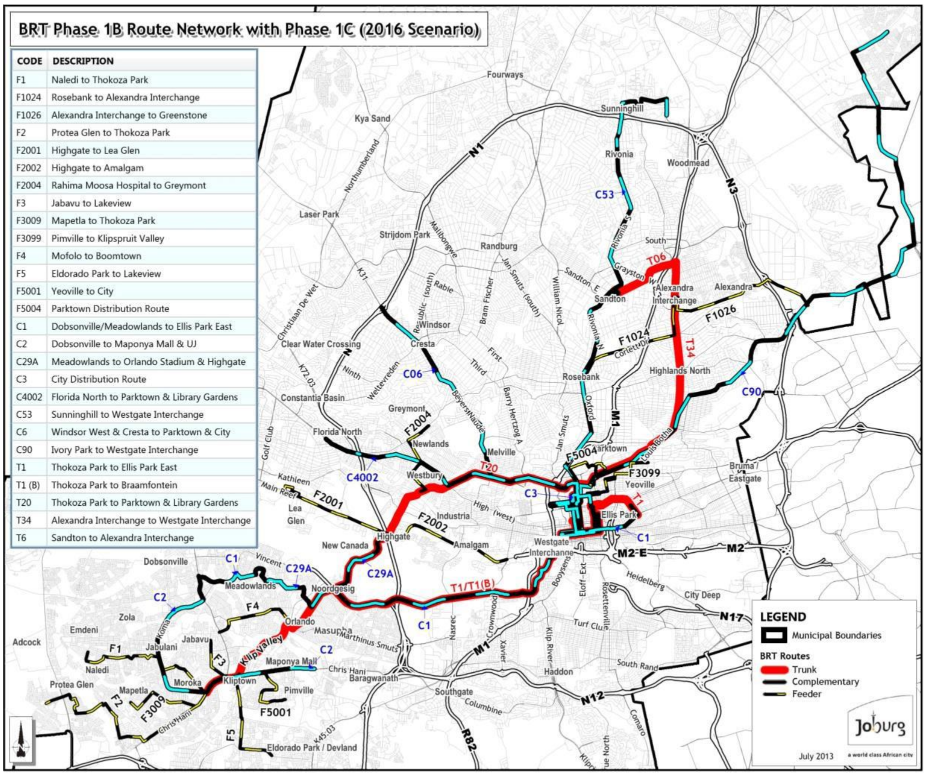

Figure 2-15: Rea Vaya Phase 1A, Phase 1B and Phase 1C network (CoJ, 2013)

One of the most controversial of road-based transport interventions is the South African Roads Agency (SANRAL) led Gauteng freeway improvement project particularly due to the introduction of electronic tolling (e-tolls) on South African freeways. The multi-billion rand project was initiated in 2007 and involves the widening of highways and the redevelopment of notoriously congested interchanges. The e-tolls were introduced in attempt to recover the costs of the new infrastructure, however, GCR residents have shown their disapproval of this tolling system through protest action and continued payment avoidance. A critique of this project is that it is inherently contradictory as it improves highways and thus encourages private vehicle use but in the same breath it encourages public transport use by taxing private vehicle users (Gotz et al., 2014).

2.3.5 Rail and Rapid Rail interventions

The Gautrain Rapid Rail Link is a Gauteng Provincial Government (GPG) project and is currently the largest infrastructure investment in South Africa with a capital cost of R25 billion (Gotz et al., 2014). The rapid rail link connects the urban nodes of the city-region between Pretoria and Johannesburg. The O.R Tambo International Airport to Sandton link was introduced in 2010, just before the start of the 2010 FIFA World Cup. Currently, the Gautrain operates along eighty kilometres of track; fifteen of these kilometres are underground, see Figure 2-16 (Gotz et al., 2014). Although the GPG has prospects of extending the Gautrain network by introducing links in the eastern parts of Pretoria, the West Rand and Soweto (Gotz et al., 2014), it has come under immense scrutiny regarding the basis for its implementation (Bickford, 2013). It is believed by some that this investment has just further entrenched the inequalities of the past as the Gautrain only serves the privileged portion of the population who are already well-located, while those living in the peripheries who are in dire need of improved public transport systems continue to be socially and economically excluded (Bickford, 2013).

The Passenger Rail Agency of South Africa (PRASA) is undergoing a rail modernisation project which involves procuring new rolling stock, upgrading the track and signalling system, redeveloping the stations, communication and marketing and renewing the Metrorail brand (Gotz et al., 2014, PRASA, 2015b). The last time PRASA purchased new trains was in the mid-1980s and in 2014, 98% of the rolling stock was older than that, therefore this investment was necessary after decades of underinvestment (Gotz et al., 2014). The acquisition of new rolling stock is to achieve key government objectives such as ensuring the delivery of quality service to citizens, employment creation and skills development (PRASA, 2015a). PRASA will invest R123.5 billion into acquiring approximately 7224 new rolling stock over the next two decades, with the first set of roughly 1200 trains expected to arrive in 2015 (Gotz et al., 2014, PRASA, 2015b, PRASA, 2015a). In Gauteng, the project will primarily focus on the essential Mabopane-Pretoria-Germiston-Johannesburg-Soweto corridor and the first phase of the upgrading of the signalling system is expected to be completed in 2016 (Gotz et al., 2014).

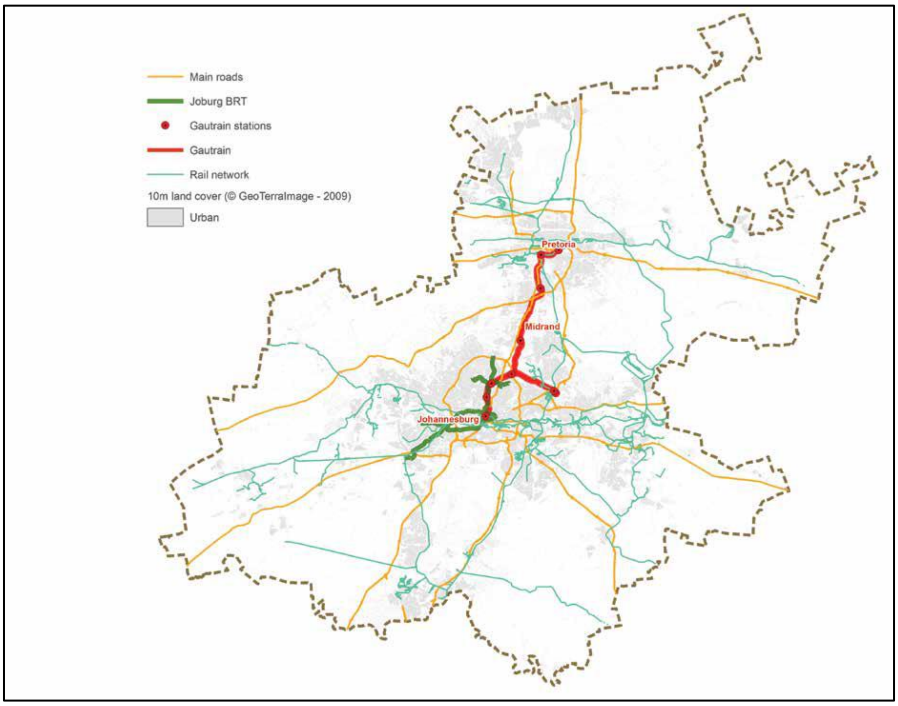

Figure 2-16: Gautrain rapid rail link (Gotz, Wray., 2014)

2.3.6 Transport according to the QoL surveys

The Gauteng City-Region Observatory, a publicly funded entity formed in response to the challenges faced in the GCR. It is a partnership formed between the Gauteng Provincial Government (GPG), the local government in Gauteng, the University of Johannesburg (UJ), the University of Witwatersrand (Wits) and the Gauteng branch of the South African Local Government Association (SALGA) (GCRO, 2014). This entity conducts Quality of Life (QoL) surveys in the GCR biennially since 2009 with the aim of benchmarking the city-region and its various constituents, identifying the causes of improvements or decline in QoL over time and developing an understanding of the perception of the GCR by its residents (Everatt et al., 2011, Gotz et al., 2015)

The GCRO's 2013 QoL survey revealed that the most common trip purposes amongst QoL residents are trips to work and trips to shops (Gotz et al., 2015). The most commonly utilised modes of transport for work trips were private vehicles (44%) and minibus taxis (37%), followed by trains (5%) and buses (4%) (Gotz et al., 2015). Less than 10% of the respondents in the metropolitan municipalities used NMT modes (walking and cycling) for work trips despite the known benefits of reduced congestion and improved affordability (Gotz et al., 2015).

Work trips usually occur during peak periods, therefore, long travel times are expected particularly due to the inevitable congestion caused by the extensive private vehicle ownership and use in the region (Gotz et al., 2015). Travel times are further exacerbated by the GCR's urban form which is characterised by urban sprawl and subsequently results in long distances between home and work (GPG, 2012, Gotz et al., 2015). The travel times for work trips in 2013 in the GCR are reflected in Figure 2-14 for the various municipalities; these long travel times have adverse effects on the economy, quality of life and the environment (Gotz et al., 2014, Gotz et al., 2015). Travel times to work also varied across modes, those who walked to work travelled for 35 minutes, those who used trains travelled for 1 hour and 23 minutes, private vehicle users travelled for 47 minutes and lastly, those using minibus taxis travelled for 59 minutes (Gotz et al., 2015). The GCRO believes that investment in public transport should particularly aim at reducing these work trip travel times by attracting the private vehicle dependent residents (Gotz et al., 2015). Comparing the 2011 and 2013 work travel times in the three metropolitan municipalities, there has been an increase in travel time over this two year period, see Figure 2-17.

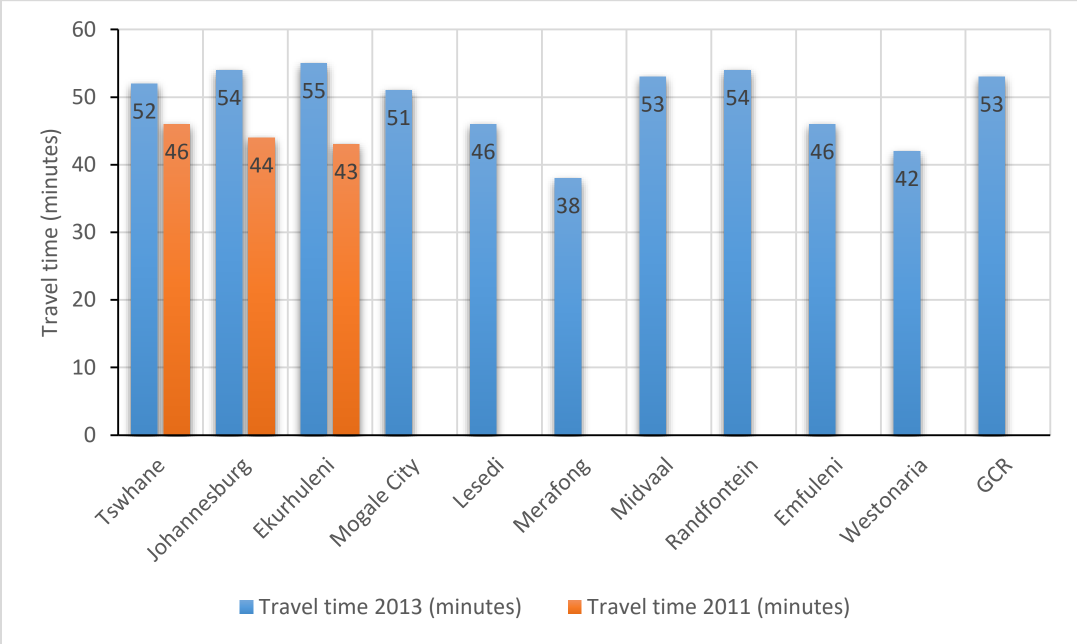

Figure 2-17: Average travel times to work as per QoL surveys (Gotz, Abrahams et al., 2015)

The access envelope technique (refer to chapter 2.1.4) makes use of the travel time budget concept which suggests that people tend to allocate a maximum amount of time a day to travel. This concept differs from and is not as directly measurable as travel time expenditure (see Figure 2-17), which, unlike the travel time budget, refers to the actual time spent travelling and not the time one is willing to spend on travel (Ahmed & Stopher, 2014; Venter & Cross, 2014).

Literature suggests that those who are somehow able to save on this travel time, allocate the remainder of their travel time budget to other trips or they travel to further destinations so as to keep the allocated daily travel time constant (Venter & Cross, 2014). The travel time budget has been reported to be between 1 to 1.3 hours per person per day in various contexts across the world (Ahmed &Stopher, 2014).

2.4 SOCIAL WELFARE

2.4.1 Measures of social welfare/well-being

Gross Domestic Product (GDP) provides an indication of a country's economic status and it also permits comparison of economic performance between countries (van den Bergh & Antal, 2014). In the 1950s, GDP, commonly substituted with the phrase "standard of living", was considered an adequate proxy of social welfare. (van den Bergh & Antal, 2014, Sumner, 2004). According to van den Bergh and Antal (2014), this proxy is not substantiated by any macroeconomic theory but rather became a convention of social welfare measures over time. However, Greyling (2013), argues that this notion that economic growth would improve well-being is based on the utility theory. The utility theory assumes that increases in income result in increases in consumption, which leads to increased utility and well-being (Greyling, 2013). Various academics have criticised the use of GDP as a proxy of social welfare and van den Bergh (2009) organised the critiques into categories, some of which are presented below:

- *Principles of proper accounting:* GDP only estimates the costs and not necessarily the benefits of market-related economic activity. GDP also omits certain costs incurred by society.
- *Empirical studies of happiness:* This is based on two major concepts, the 'Threshold hypothesis' and the adaptation hypothesis. The 'threshold hypothesis' states that beyond a certain threshold income level, the cost of growth will exceed the benefits. Thus, it can be found that although GDP per capita continues to grow steadily, social welfare stagnates or regresses. The adaptation phenomenon, which is not captured by GDP, is one in which individuals adapt to changed circumstances, therefore social welfare will change temporarily with an increase in income but will soon return to its original baseline after the individuals adapt accordingly.
- *Formal versus informal economy:* GDP only covers formal market-related economic activates and does not capture informal economic activity which can be found in both the developed and the developing world. Therefore GDP will tend to overestimate changes in social welfare as one transitions from the informal sector to the formal sector and it is always assumed that this is a positive change however it could have a significantly negative effect on the poorer citizens of a country.
- *Environmental externalities and depletion of natural resources:* The monetary cost of environmental externalities and depletion of natural resources is not easily determined and thus not captured by GDP; ergo, it is excluded from the social costs. In addition to this, the damage caused by pollution is not captured by GDP but the cost incurred in rectifying this damage increases GDP.

In 2011, van den Bergh and Antal took cognisance of these above stated shortcomings and put forth four alternative measures of social welfare: Index of Sustainable Economic Welfare (ISEW) and Genuine Progress Indicator (GPI), Sustainable or green(ed) GDP, Genuine savings or investments and composite indices. Although these alternative measures present their own shortcomings, van den Bergh and Antal (2011) believe that they are significantly superior to GDP and that policy and decision-makers should not wait for a perfect measure to be developed before giving less importance to GDP as a measure of social welfare.

In Sumner's study (2004) of the evolution of the meaning and measurements of well-being, it is evident that as more data became available, the measurements of well-being developed and started to stray away from pure economic measures (in the 1950s) to multi-dimensional, multidisciplinary measures (post 1960s). In the 1960s, more social data became available, however, GDP still remained the main measure of well-being although it was now GDP per capita as opposed to overall GDP growth (Sumner, 2004). In the late 1960s, the concept of basic needs (which encompasses food, shelter, public goods and employment) was introduced and generally accepted as a measure of well-being in the 1970s (Sumner, 2004). The first composite measure of well-being was developed by Morris in 1979 and it was termed the Physical Quality of Life Index (PQLI). This index was the first of its kind to explicitly focus on the non-economic aspects of well-being, it constituted of the following three components: life expectancy at birth, infant mortality and adult literacy (Sumner, 2004).

In the 1980s, Amartya Sen, an economist at the United Nations Development Programme (UNDP), pioneered the annual Human Development Report (HDR) which gave a new perspective on human development and well-being by shifting the focus from means (having income to buy food) to ends (being well nourished) (Sumner, 2004). The HDR also introduced a new set of composite indicators (combining the economic and non-economic measures of well-being) including the UNDP’s Human Development Index (HDI) (Sumner, 2004). In the 1990s, the measures of well-being returned to the individual: the body, mortality and knowledge (Sumner, 2004).

In the year 2000, in the World Development Report, where various tables with well-being measures are presented, social indicators of well-being became more prominent. One of the composite measures of well-being included in the report was Quality of Life (QoL), developed by the World Health Organisation (WHO) (Sumner, 2004). This composite measure considers six domains or dimensions of quality of life, namely: physical well-being, psychological well-being, independence, social relations, environmental well-being and spiritual well-being (Sumner, 2004).

2.4.2 Quality of Life: definitions, dimensions or domains, and indicators

Literature does not provide a standard definition of QoL (Bowling, 1999, Doi et al., 2008, Greyling, 2013), in fact several research papers, including Felce (1997) and Andelman, Board et al (1998), have been dedicated to solely studying, clarifying and developing definitions of this concept. As a result, the term has been used in various contexts and disciplines, including but not limited to: healthcare, planning, geography, social science, political science and international development (Bowling, 1999, Greyling, 2013, Everatt, 2015).

Massam (2002) describes QoL as a “ubiquitous concept that has different philosophical, political and health related definitions”. Some of the earlier broad definitions include that of Abrams (1973) who defines QoL as the extent to which people are dis(satisfied) with various aspects of their lives. Rodgers and Converse (1975), state that quality of life, partly defined, encompasses "the way in which individuals perceive and evaluate their own lives". Moberg and Brusek (1978) state Gerson's (1976) distinction between two approaches to QoL; these approaches are consistent with the work of Cutter (1985). The first approach is the individualist approach which defines QoL as the degree of an individual's achievements, triumphs over adverse circumstances and overall satisfaction with life and the environment. The second approach is the transcendentalist approach which shifts the focus of QoL from the individual to the community; the degree of solidarity amongst members of a community, economic activity and equity. Massam (2002) also distinguishes between two aspects of QoL with regards to town and regional planning, he states that QoL can be based on a cause of attraction to a place and on "the outcome of conditions that are perceived to exist and the degree to which they meet the desires and expectations of individuals". More recently, David Everatt (2015) defines quality of life (QoL) as a tool or measure that is used to evaluate or describe the well-being of individuals and societies. The corpus of literature on QoL reveals that, although it is a concept often used by planners and policy-makers, QoL is a vague concept which is extremely complex and not easily delineated as it should theoretically incorporate all aspects of a person's life (Massam, 2002, Bowling, 1999, Everatt, 2015). Boddy and Parkinson (2004) express the danger of this term, QoL, as they perceive it as a tool used in cities and city-regions as merely an impetus to attract prospective investors, with little regard for the value it has to the very citizens being studied. In concurrence with the work of Boddy and Parkinson (2004), Everatt (2015) adds that QoL can be easily misused as a marketing tool to influence investment decisions as it is absorbed by this "global fad" of ranking world cities, a ranking system that is arguably already heavily based on the bias of the developed world.

There are two linked dimensions that social indicators can be classified as: objective indicators which focus on the provision of basic services, connectivity and jobs, and subjective indicators which focus on the psycho-social aspects of social welfare, such as social capital, social exclusion, racism, xenophobia. (Everatt, 2015, Everatt et al., 2011, Massam, 2002, Doi et al., 2008). According to Massam (2002), it is often contended in literature that for one to provide a holistic QoL measurement for a person or a place, both these dimensions must be considered simultaneously.

Measuring QoL subjectively, an approach that was developed in the behavioural sciences, became more widely accepted in the late 1990s (Greyling, 2013). More recently, the concept of sustainability, which is broadly defined as "the effort of meeting the needs of the present generation without compromising those of future generations", is making its way into the theoretical approaches of QoL (Greyling, 2013) and it implies that the environment should be afforded the same treatment as humans. This altered approach is substantiated by a statement made by Sirgy (2011) that, “one cannot have a good human condition in a bad environment”.

QoL indicators are used in various studies and by policy-makers to evaluate the impacts of changes in society and the environment on QoL and to measure and monitor the QoL of individuals and communities over time (Doi et al., 2008). Each QoL domain or dimension is described by various QoL indicators which can either be subjective or objective. Doi, Kii et al. (2008) made a selection of indicators based on four criteria: a) action focused, b) measurable, c) important, and d) simple.

2.4.3 Accessibility, QoL and transport related social exclusion

The contemporary definition of QoL is not restricted to satisfaction and availability of resources, but it is also inclusive of the ability of a person to access and make use of various opportunities (Craglia et al., 2004). In concurrence, Doi, Kii et al. (2008), developed a QoL-based accessibility measure as they were of the view that, “While conventional accessibility measures are plain, and easy to understand and apply, they have received considerable criticism as a highly simplified representation of opportunities without appropriate consideration of people’s values or behavioural criteria and abilities”. They argued that the simplistic nature of accessibility measures does not assist planners in evaluating increasingly pertinent issues such as quality of life and social exclusion (Doi et al., 2008). When evaluating QoL, physical accessibility is not the only important dimension, but also the freedom of choice of opportunities afforded to individuals through improved access (Doi et al., 2008). Massam (2002) states that an individual’s definition of QoL is heavily dependent on his or her family, community, place of birth and values, hence, Doi, Koi et al. (2008) found it appropriate to include a weighting method when evaluating the QoL-based accessibility measure, as this would help focus on what values contribute the most to the overall life satisfaction of individuals.

Social exclusion, an increasingly pertinent issue, has sometimes been used interchangeably with poverty (Church et al., 2000); however, these are two distinct concepts in which social exclusion is the concept that provides a broader understanding of human disadvantage (Church et al., 2000, Kenyon, 2003, Lucas, 2012). Poverty is a cause of social exclusion, however, a person does not have to be poor to be socially excluded; feelings of social exclusion could arise from living in an area with high crime rates, low skills, or poor accessibility to essential services and opportunities (Kenyon, 2003). Therefore, like QoL, social exclusion is multi-dimensional and can be defined as “the enforced, not chosen, inability to participate in the normal activities of the community in which one lives, for one or more of many reasons” (Kenyon, 2003). In the transport context, social exclusion does not refer to the lack of opportunities and/or services but rather the lack of access to opportunities and/or services (Preston & Rajé, 2007).

Delbosc and Currie (2011a, 2011b, 2011c) also speak of transport disadvantage which, in concurrence with Venter and Cross (2014) and Lucas (2011), limits access to opportunities which decreases QoL by denying individuals their basic human rights, simultaneously aggravating social exclusion. Transport disadvantage is another multi-dimensional construct typically tied to "location, access to mobility and limitations on personal access associated with the physical, social and psychological characteristics of individuals" (Delbosc & Currie, 2011c). In a study of perceived social exclusion and transport disadvantage and how these constructs interactively and individually affect perceived well-being in Australia, Delbosc and Currie (2011a) reveal that respondents who were both socially excluded and suffered from transport disadvantage reported the lowest scores of well-being. However, individually, the results revealed that social exclusion had more of an adverse effect on well-being than transport disadvantage; therefore transport interventions which address mobility issues related to transport disadvantage may be futile in improving perceived well-being.

The United Kingdom (UK) is one of the countries that promoted the study of social exclusion after the 1997 newly elected Labour government created the Social Exclusion Unit which went on to publish a report titled *Making the Connections* in 2003 (Preston & Rajé, 2007, Kenyon, 2003). In the UK, the issue of social exclusion arose due to the sprawling land use patterns of the UK, in which activity areas (home, work, education, shopping and leisure etc.) continued to grow increasingly further apart, increasing journey lengths, number of journeys and the complexity of journeys (Kenyon, 2003). Explosive car ownership is both a cause and a consequence of these problematic land use patterns and has resulted in a society that is highly dependent on mobility (Kenyon, 2003). Therefore, mobility is necessary to allow members to participate in the UK society; those who are not highly mobile are inevitably socially excluded (Kenyon, 2003).

Making the Connection puts forth transport policies to combat transport related social exclusion. The report focuses on improved accessibility as a key component in combating social exclusion (SEU, 2003, Kenyon, 2003). The following are initiatives, as stated in the report, to reduce mobility-related social exclusion (SEU, 2003):

- *Accessibility*: Improving physical accessibility and availability of transport
- *Affordability:* Making travel more affordable
- *Land use*: Reducing the need to travel, largely through changes in land-use policy
- *Safety:* Making streets and stations safer

In the South African context, the 2003 NHTS revealed that poorer households experience poor access to private vehicles and public transport, and ultimately poor access to key social activities (Lucas, 2011; Lucas, 2012). According to the 2003 NHTS, on average, in the lower income households, only 26% had access to a car, more than 75% did not have access to a train station and roughly 40% did not have access to a bus service. 83% of the white population had a driving license while only 10% of the black population had a driving license. Subsequently, the black population of South Africa was socially excluded as they experienced difficulties accessing work, education, healthcare, and even visiting extended family members (Lucas, 2012).

Church, Frost et al. (2000) categorises, from existing research, the interrelated factors that are contributing to or caused by transport related social exclusion as follows:

- *Physical exclusion:* This is caused by the presence of physical barriers that prevent the access to transport services. This includes, but is not limited to, vehicle design, the lack of facilities for people with disabilities and the lack of timetable information
- *Geographical exclusion:* This is as a result of spatial isolation, residing in the peripheries of cities and poor provision of transport.
- *Exclusion from facilities:* Those who reside in socially excluded areas often experience a lack of access to most social activities, such as shopping, leisure, financial activity and education due to reduced affordability of transport services and the fact that these facilities are not common in these types of areas.
- *Economic exclusion:* This is as a result of a lack of income or transport services that limit the distance over which one can search for jobs and potentially access the labour market.
- *Time-based exclusion:* The inability to allocate sufficient time to travel due to organisation of commitments and transport network constraints.
- *Fear-based exclusion:* This is caused by the fear of being in public spaces due to issues such as crime.

A qualitative study of low-income households conducted by Lucas (2011) in the City of Tshwane, South Africa, revealed that the overarching concerns of these populations with regards to the transport system were pertaining to the following factors: i) *Exclusion from facilities* due to unaffordability of minibus taxi fares as a result of the lack of subsidies, the poor provision of formal public transport systems in their residential areas and the lack of regulation of minibus taxi fares, ii) *Fear-based exclusion* due to safety concerns at stations and stops, and

iii) *Geographical exclusion* due to provision of housing in the peripheries instead of on well-located land in close proximity to opportunities.

Only a select few of the transport related social exclusion factors can be solved by altering the operations, affordability and availability of transport services; the others require transport policy interventions, particularly with regards to understanding the role that transport plays in achieving other policy objectives, such as reduced social exclusion, poverty and improvements in well-being (Church et al., 2000; Delbosc & Currie, 2011a; Lucas, 2011). In concurrence, Garrett and Taylor (1999) stress the importance of considering social outcomes and not merely ridership when evaluating potential transit projects. Social outcomes are critical as transit captive residents suffer social and economic isolation when transit services do not provide sufficient access to destinations (Garrett & Taylor, 1999).

2.4.4 History of QoL in South Africa

Møller (2007) classifies South Africa as a transition country, more specifically as one that was "catapulted from a closed economy into liberal democracy overnight". During the times of apartheid, black South Africans, who then made up 78% of the population, suffered the worst QoL in the country, the white minority enjoyed the highest QoL and everybody else fell somewhere in-between (Møller, 2007). In 1994, the QoL of black South Africans soared but subsequently regressed to depict the same trends observed pre-1994 (Møller, 2007). These QoL trends were revealed by the General Household Surveys conducted by Statistics South Africa (StatsSA). Møller (2001) hypothesised that the decreased QoL of black South Africans post-1994 was because democracy had met their political needs but not their material needs. Everett (2015) states that this allowed academics in this field to take a closer look at other QoL indicators that should be considered in a democratic society such as; service delivery, employment and crime, and how they are experienced across all racial groups in the country.

In 1998, eThekweni Metropolitan Municipality conducted its first annual survey that was used to monitor the QoL of Durban residents. This study did not attempt to provide an overall QoL index, it merely presented data for the various indicators (Everatt, 2015). Higgs (2007), however, developed a composite index termed the Everyday Quality of Life index (EQLi) that measured the QoL of South African residents across many domains, such as; socio-economic status, urbanisation, health, stress or pressure, quality of the environment, satisfaction of human needs, connectivity, optimism and subjective well-being. The overall measure of well-being was the EQLi itself which allowed one to track changes in QoL and to make comparisons across all facets of South Africa's population (Higgs, 2007).

The 2055 vision of the GCR is one in which all residents have an improved QoL which implies equal access for all, reduction of poverty and inequality and equal opportunities for all (GPG, 2012). The GPG (2012) states that the concept of QoL is reflected in a number of areas such as: access to employment opportunities, access to education, access to housing, access to healthcare, access to infrastructure, services and amenities, safety and security, food, water and energy security, sense of well-being, family cohesiveness, sense of community, extent of civic participation and, opportunities for self-realisation.

The current QoL survey conducted by the GCRO builds on a multivariate index constructed in 1991 in a project known as the 'marginalised youth project' (Everatt, 2015). The index was constructed in an attempt to understand the impact of apartheid and its repercussions on the youth of the country (Everatt, 2015). A survey was conducted that collected data on both objective and subjective indicators, the subjective indicators utilised in that study are still pertinent indicators in the current QoL survey (Everatt, 2015).

2.4.5 GCRO QoL Survey and Indices

As aforementioned, biennially, since 2009, the GCRO conducts a QoL survey in the GCR. The survey data is gathered and a multivariate analysis, using both subjective and objective indicators (see table 2-2), is conducted to determine a QoL index for each respondent (Gotz et al., 2015).

The multivariate analysis is carried out using 56 indicators, classified under the dimensions reflected in Table 2-2 (Gotz et al., 2015).

Table 2-2: GCRO QoL survey dimensions and indicators (Everatt, Gotz et al., 2011)

Dimensions	Subjective indicators	Objective indicators
Work	• Amount of money available • Household status • Standard of living • Working conditions	• Employment status • Household income • No debt

Socio-political	• Politics is a waste of time • General election free and fair • Judiciary is free • Trust between races • Foreigners taking benefits • Government performance • Government officials and batho pele	• Public participation • Voted in 2009 • Asked for bribe
Security	• Safety in area during day • Safety in area during night • Safety at home • Crime situation improved	• Victim of crime
Life satisfaction	• Life satisfaction • Alienation • Anomie • Country going in right direction	
Education/connectivity	• Press is free	• Level of education • Telephone/cell phone • Radio/television • Internet connection
Community	• Trust community • Friends • Important to look after environment	• Membership in clubs, organisations, societies
Family	• Marriage/relationship • Family life • Time available • Leisure time	• Ability to feed children/self
Housing	• Rating of dwelling • Rating of area/place	• Dwelling structure • Dwelling ownership • Overcrowding
Infrastructure	• Improvement in community • Water cleanliness	• Sanitation access • Water access • Electricity • Refuse removal • Cut offs/evictions

Health	• Rating of health • Health affects work • Health affects social activities	• Access to health care

The first QoL survey was conducted in 2009 with a sample size of 6,636 respondents, of which 5,821 were located in the Gauteng Province and 815 from the wider GCR (Everatt et al., 2011, Gotz et al., 2015). Overall, the survey data displayed positive results as 46% of GCR residents were satisfied with their lives. 34% of respondents were dissatisfied and for 41% of them, it was due to unemployment or a lack of job opportunities (Everatt et al., 2011). The main dimensions pulling down the QoL score were work (unemployment and poor quality jobs), psycho-social issues (racism, xenophobia, gender equality etc.) and crime-related issues (Everatt et al., 2011). Conversely, dimensions such as health, housing and infrastructure followed by family and community assisted in pulling up the QoL scores (Everatt et al., 2011). The average QoL score of the region was 6.32 with no respondents scoring below 2 (Everatt et al., 2011).

In 2011, the second QoL survey was administered to a sample of 16,729 respondents, all of which resided in the Gauteng province (Gotz et al., 2015). The average QoL index across the GCR in 2011 was 6.25. Given the average QoL index of 6.32 presented by the GCRO for the 2009 QoL survey in their *2011 City-Region Review* (Everatt et al., 2011), there was a decline in the QoL score from 2009 to 2011. However, according to the GCRO's online *State of the Gauteng City-Region Review 2013* document, the average QoL in 2009 was 6.24, in that case, the QoL of GCR residents increased from 2009 to 2011. The GCRO attributes this marginal increase in the QoL score to government's basic services delivery as well as perceptions of reduced crime by the residents (GCRO, 2016b).

The third quality of life survey was conducted in 2013 and was administered to 27,490 respondents, all of which resided in the Gauteng province (Gotz et al., 2015, GCRO, 2016a). This large expansion of the sample size was made possible by the generous contributions of all three metropolitan municipalities in the GCR over and above the funds provided by the GPG (Gotz et al., 2015). The average QoL index in 2013 was 6.28, an increase from 2011, which is primarily due to infrastructure and government's service delivery, health, dwelling and connectivity, followed by improved security, especially in the metropolitan areas (Gotz et al., 2015)

Of all the respondents, 6,588 were located in the Tshwane Metropolitan Municipality and they had the highest QoL index recorded across all three metros: 6.45 (Gotz et al., 2015). Tshwane was followed by Johannesburg which had a QoL index of 6.3 and finally Ekurhuleni with a

QoL index of 6.21, which fell below the city-region average, see Figure 2-18 (Gotz et al., 2015). The municipalities that fall to the right of the red line are those that have a QoL index below the GCR average of 6.28 and the reverse applies to those that fall to the left of the red line.

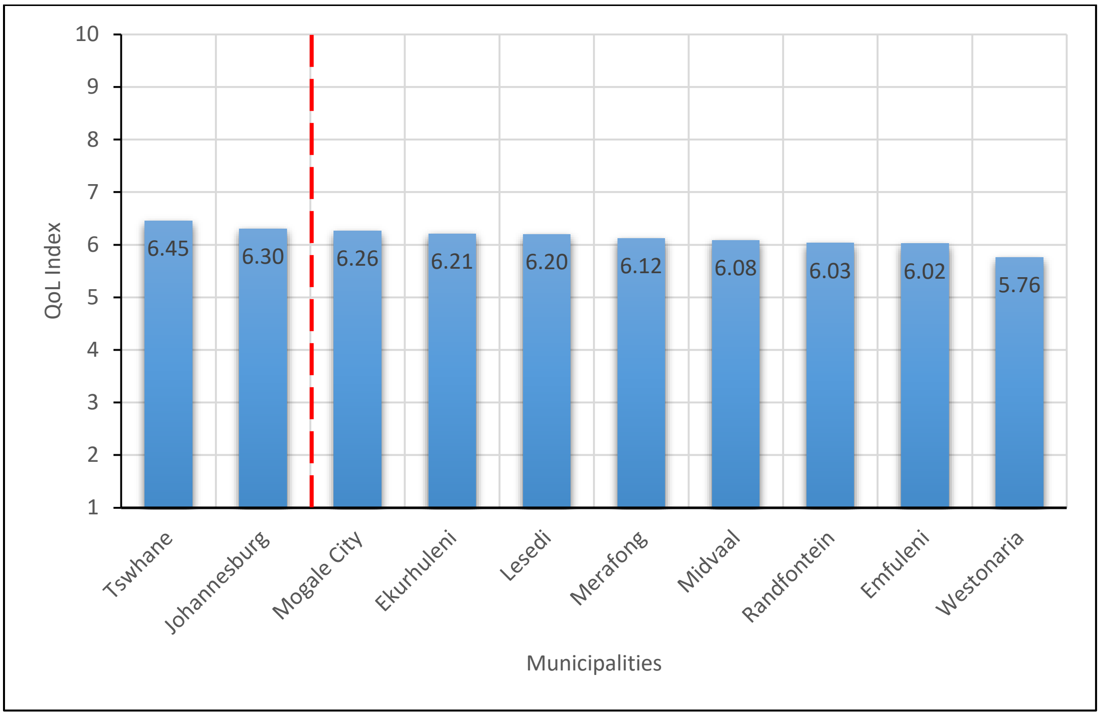

Figure 2-18: QoL index of various municipalities in 2013 (Gotz, Abrahams et al., 2015)

The dimensions that have pushed the 2013 QoL index up are government infrastructure (access to service, improvements in the community and water cleanliness etc.), health, dwelling, family and connectivity, followed by small improvements in security in the metropolitan areas, Mogale City, Merafong and Midvaal (Gotz et al., 2015). There was a significant decline in the community, socio-political and work dimensions in 2013 as more people in the GCR felt alienated and that the country was generally not heading in the right direction (Gotz et al., 2015). Previously (2009 and 2011 QoL surveys), the employment dimension was the weakest but in 2013 it was surpassed by socio-political issues (Gotz et al., 2015).

The GCRO applies a rigorous population sampling technique, ensuring the sample is representative at the electoral ward level. The wards are further broken down into small area layers to allow for a balanced sample distribution across each ward (Mushongera et al., 2015). In 2011, the distribution of the population in each small area layer was determined and from there each fifth stand was selected to conduct the survey. In the event that there were multiple households on a single stand, then simple random sampling was used to select a single household to conduct the survey (Mushongera et al., 2015). The extensive and informative nature of these QoL surveys and the thorough sampling technique makes them a reliable source upon which subsequent informative indices can be constructed.

2.5 SUMMARY

The study of accessibility has taken on many forms over the years and thus various accessibility measures have been developed, each with their pros and cons. What remains is that improving accessibility is essential to improving people's QoL thus it is an essential transport planning policy objective. According to Foth, Manaugh et al. (2013) very few studies have considered both accessibility over time and accessibility across socio-economic groups simultaneously. In South Africa, a country that is believed to be amongst the most unequal in the world, this will be a particularly useful study. This study aims to add to the knowledge of understanding the wider social benefits of transport projects, particularly in the advent of BRT services in Gauteng and determine whether these investments are contributing to key policy objectives stated by the GPG (2012), such as equal access to opportunities and reduction in poverty and inequality. Over and above this, the time-series analysis of accessibility gives a good indication of the performance of the land-use and transportation planning policies in the study area (El-Geneidy & Levinson, 2006).

3 METHODOLOGY

3.1 OVERVIEW

The methodology comprises of three parts: a) the accessibility measurement technique and its summary measures, b) time-series analysis of accessibility using the various summary measures and, c) modelling the effect of BRT implementation in Soweto on the social welfare of Soweto residents. An elaboration of the procedure followed for each part is provided in the subsequent subchapters.

3.2 MEASURING ACCESSIBILITY

3.2.1 Access Envelope Technique

The access envelope technique was used to determine the accessibility to jobs from randomly selected origin zones in selected townships of the CoJ (refer to chapter 2.1.4 for background on this technique). Figure 3-3 displays the study surface which was divided into 19,113 hexagonal zones, and from each of these zones the NWAC to every other zone on the study surface can be determined.

The NWAC, which describes the location specific accessibility to spatially distributed job opportunities, was determined as follows:

$$NWAC_{ij}^{m} = I_j - 2.Fare_{ij}^{m} - 2.\delta.v_3 \tag{3-1}$$

$$\delta = \begin{cases} 1 \; if \; t_{ij}^{m} > T \\ 0 \; otherwise \end{cases}$$

$$v_3 = \frac{t_{ij}^{m} - T}{H}.I_j \tag{3-2}$$

Where:

$NWAC_{ij}^{m}$ – Net Wage After Commute from zone *i* to *j* using mode *m* expressed in Rands/day

I_j – Average potential daily wage earnable for all jobs in zone j expressed in Rands/day

$Fare_{ij}^{m}$ – Fare from zone *i* to zone *j* using mode *m* expressed in Rands

$\delta.v_3$ – Travel time penalty expressed in Rands and it is only incurred if $t_{ij}^{m} > T$

t_{ij}^{m} – Travel time from zone *i* to *j* using mode *m* expressed in minutes

T – Travel time budget which was taken as approximately 60 minutes per person per direction

H – Typical daily working time expressed in minutes

The travel time budget concept was introduced in chapter 2.3.6, where it was stated that it is reported to be between 1 to 1.3 hours per person per day in various contexts across the developed world (Merven, Stone et al., 2012; Ahmed &Stopher, 2014). However, due to apartheid spatial legacy, South African cities are notably less dense than developed cities, with the poor residing far from opportunities, therefore the South African travel time budget may not necessarily conform to the reported standard figures (Merven, Stone et al., 2012). Subsequently, a travel time budget was estimated for this study using the actual travel time values reported by respondents of the 2013 QoL surveys for their most frequent trips. Figure 3-1 displays the travel time distribution for private vehicle trips in the city, with an average travel time of 44 minutes per person per direction and 76% of these trips were completed in 60 minutes or less. Figure 3-2 displays the travel time distribution for public and non-motorised transport trips in the city, with an average travel time of 49 minutes per person per direction and 73% of these trips were completed in 60 minutes or less.

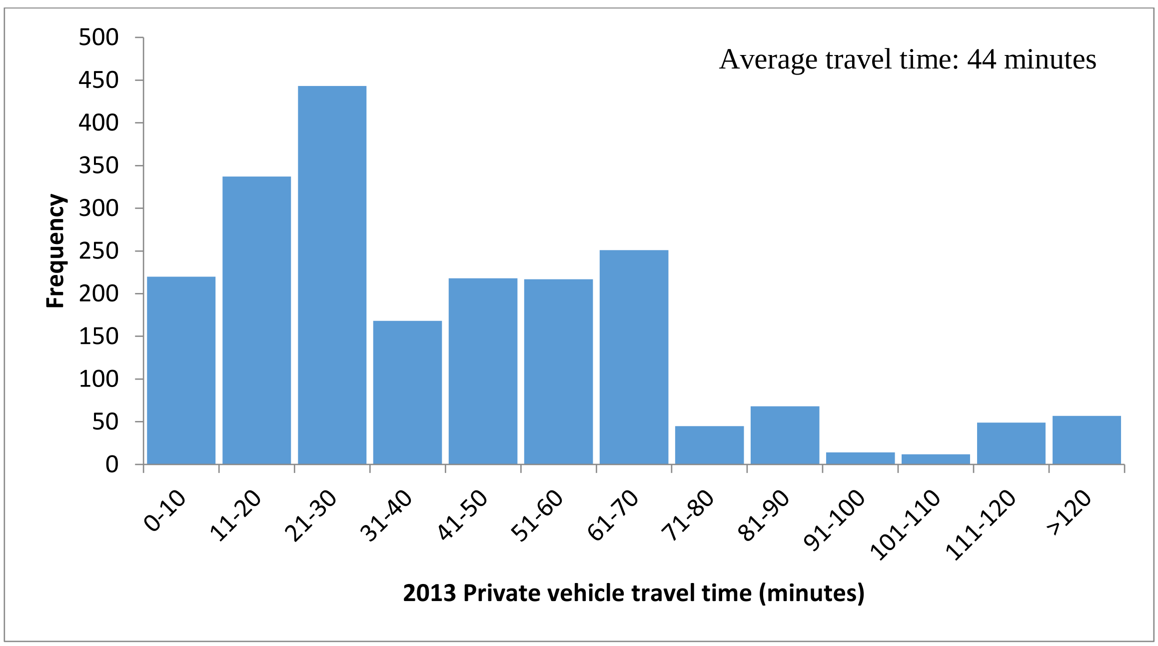

Figure 3-1: Private vehicle travel time distribution in the CoJ

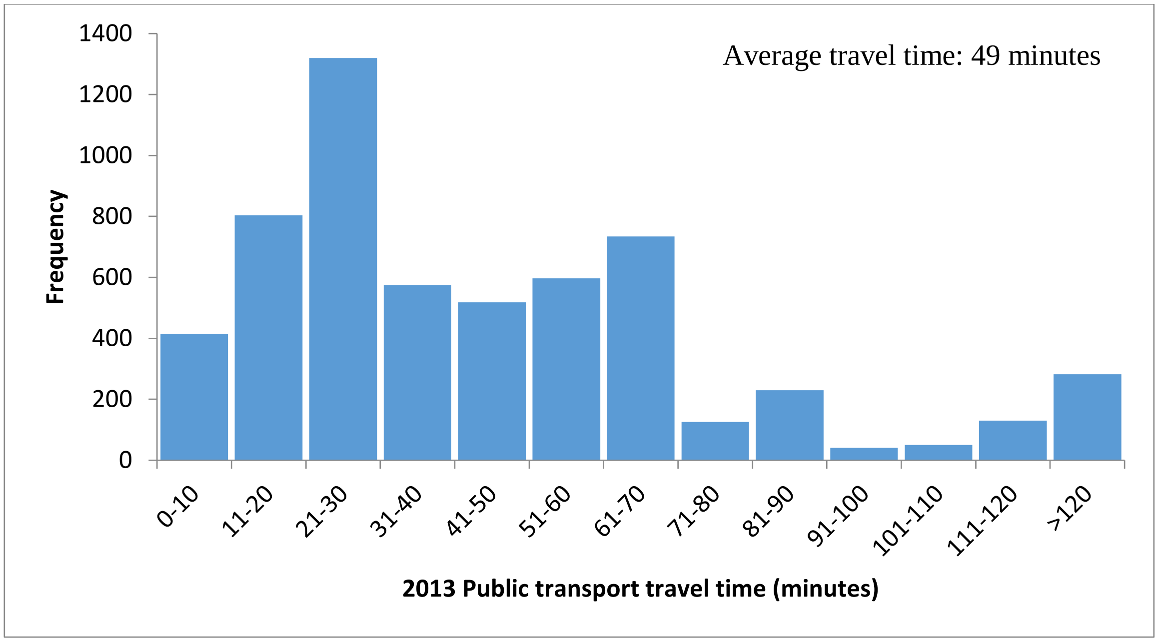

Figure 3-2: Public transport travel time distribution in the CoJ

This travel time expenditure per person per direction reported by the 2013 QoL survey respondents is almost equivalent to the travel time budget per person per day reported in literature for developed countries, suggesting that the travel time budget per person per day in Johannesburg could be double that estimated in developed cities, consistent with findings of Venter & Cross (2014). Therefore, we assumed the travel time budget in the CoJ to be 60 minutes per person per direction (2 hours per person per day) for purposes of this study.

Table 3-1 reflects some advantages and disadvantages of the two most commonly used traditional measures of accessibility in comparison to the NWAC. The choice of the NWAC for this study was based on its ability to account for both the transport and land-use component while weighing opportunities and ultimately remaining intuitive and easily communicable to both technical and non-technical groups. Various applications of the measure, including this one, have been presented to both technical and non-technical groups since its development and gauging from the feedback received, it has been well-received and understood by these audiences.

The NWAC explicitly accounts for travel cost as a measure of impedance, over and above travel time, thus acknowledging the challenge of public transport affordability experienced by low-income residents who are typically far removed from centres of economic activity in the context of the study. Further studies using this relatively new measure will also allow for the refinement of the measure and ultimately its calibration for use as a transport and land-use planning tool.

Table 3-1: Comparing the NWAC to traditional accessibility measures (Geurs & Wee, 2004; Venter & Cross, 2014)

	Gravity-type measures	**Threshold type measures**	**NWAC**
Pros	• Distance-decay or impedance function weighs opportunities based on distance, time and/or cost from the origin. • Can be used as input to evaluate wider economic or social implications of transport projects.	• Ease of interpretation and use of the measure - it is not a data intensive measure. • No assumptions made with regards to a person's perception of transport, opportunities and their interaction.	• Explicitly accounts for time and cost as measures of travel impedance. • An intuitive measure that is easily communicated to and understood by non-technical groups. • Weighs opportunities beyond a specified travel time budget.
Cons	• Not easily understood or communicated to non-technical groups. • Does not account for competition effects.	• Arbitrary selection of the cut-off point • Assumes all opportunities are desirable regardless of travel time or distance and type of opportunity.	• Fairly new accessibility measure which has not, as of yet, been tested outside of the South African context. • Does not, as of yet, account for competition effects.

A typical outcome of the access envelop technique is an NWAC surface such as that displayed in Figure 3-4, in which the NWAC to every zone on the study surface is displayed from a selected origin in Soweto. For ease of comparison between various origin zones and over time, three summary measures were developed:

- **Number of jobs accessible with NWAC > R85/day:** This gives an indication of the number of jobs a commuter can access while retaining a reasonable NWAC (assumed to be R85/day). This amount of R85 is based on the assumption of a single breadwinner and a household size of four (the average household size in the GCR based on the 2009, 2011 and 2013 QoL surveys). A sole breadwinner in such a household will have to take home R85 a day to ensure that each individual in the household lives above the lower bound poverty line (ignoring equivalence scales). The lower bound poverty line of R416 per month, as defined by StatsSA (2014), is the line below which food items are sacrificed to afford other non-food items such as transport. This summary measure is also referred to as the NWAC accessibility in subsequent chapters.

- **Number of jobs accessible within 60 minutes of travel time:** This gives an indication of the spatial distribution of jobs within one hour of travel time from the origin. Origins that score high on this measure are typically within close proximity to economic nodes and/or are served by faster modes of public transport. This summary measure is also referred to as the travel time (TT) accessibility in subsequent chapters.
- **Average NWAC of the closest 200,000 jobs:** This gives an indication of the distribution of the NWAC in the immediate surroundings of the origin zone while controlling for the number of jobs. Origins that score high on this measure are typically surrounded by high paying jobs and/or low transport costs in conjunction with shorter travel times to economic nodes.

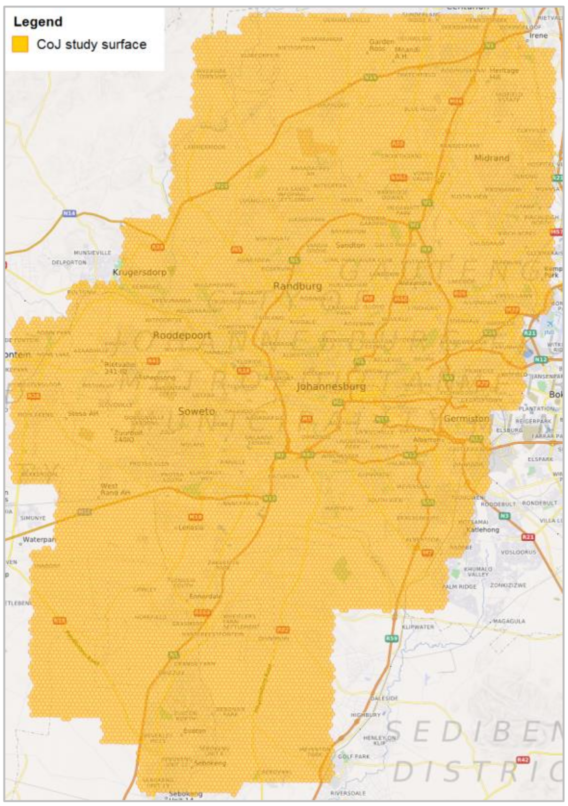

Figure 3-3: CoJ study surface

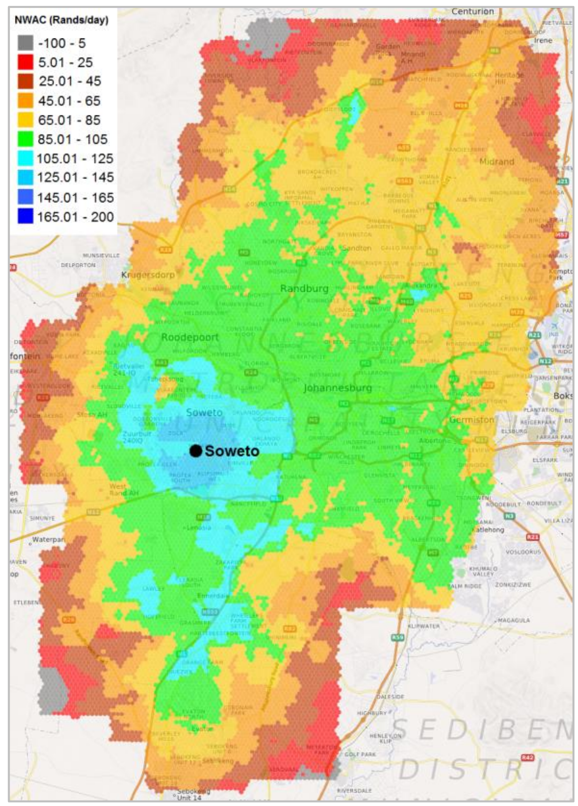

Figure 3-4: Typical NWAC surface

3.2.2 Input data

The subsequent subchapters describe the input data, and its sources, that was required to map the NWAC and to compute the abovementioned summary measures. This includes the assumptions made with regards to the temporal variation of the relevant input data to allow for a reasonable time-series analysis of accessibility.

3.2.2.1 The spatial distribution of jobs

This is the distribution of jobs in the CoJ assumed to be suitable to the typical skill set and educational profile of a lower-income resident in the city. This data was obtained from the 2011 Gauteng Transport Model job location data across the following sectors: Retail, Office, Industrial, Commercial, Local, Agriculture, Construction, Domestic, Informal at work, Informal at home, and Security.

There was a total of 3,326,390 jobs on the study surface and Figure 3-5 displays the spatial distribution of these jobs in the CoJ. It is evident that the highest densities of job opportunities are observed in the region of the CBD, its immediate surroundings and towards the north of the city where the major decentralised economic nodes are found, namely: Rosebank, Sandton, and Midrand. The distribution of jobs in the city was kept constant from one analysis year to the next in order to observe the effect of the temporal variation of the input variables specific to computing the NWAC; the distribution of jobs in the city were required only to compute the summary measures.

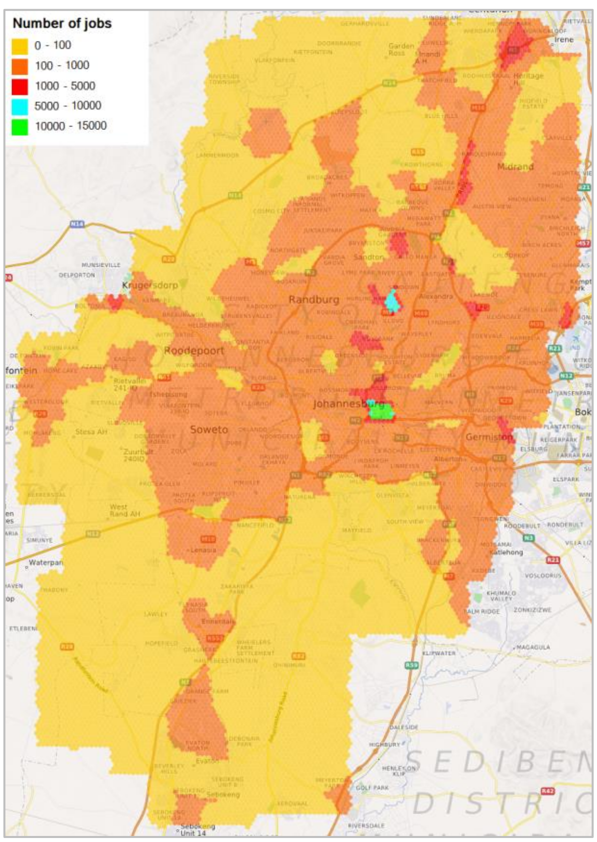

Figure 3-5: Spatial distribution of jobs in the CoJ

3.2.2.2 Average potential daily wage earnable at each zone

This is the average potential daily wage of all jobs in each zone. Figure 3-6 displays the spatial distribution of these wages for 2011; the wages were increased with inflation (+/- 5.75%) from one analysis year to the next as a means of accounting for increasing wages across the various employment sectors.

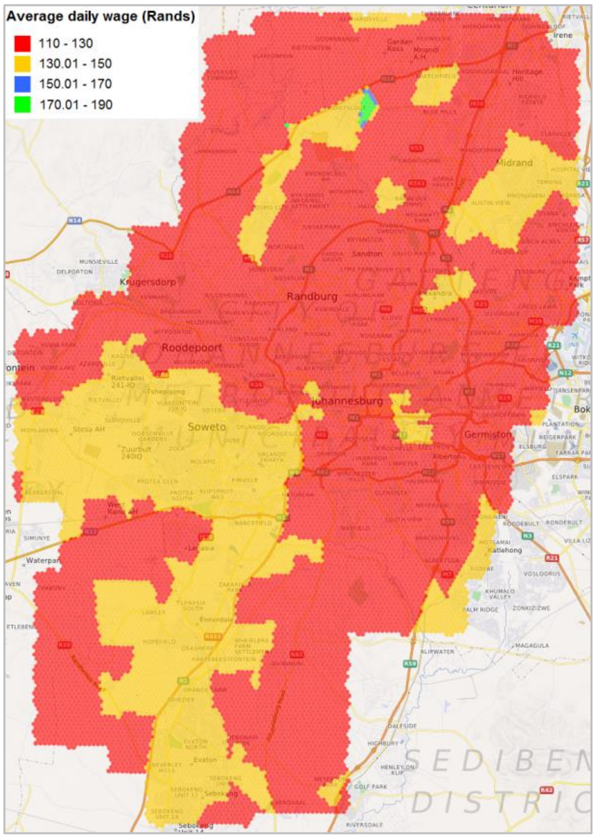

Figure 3-6: Average potential daily wage earnable at each zone (2011)

The wages across the employment sectors for low-income populations were obtained from surveys conducted in Gauteng in 2011 among low-income populations which were classified as households earning less than R3500 per month (Venter & Cross, 2014). The average daily wage reported for each employment sector was as follows:

- Retail – R130
- Office – R130
- Industrial – R130
- Commercial – R130
- Local – R130
- Agriculture – R120

- Construction – R120
- Domestic – R105
- Informal – R87
- Informal at work – R87
- Security – R95

These average daily wage values per sector are only applicable to low-income workers who are likely to share the education and vocational characteristics of the target population group of this study.

3.2.2.3 Public transport routes and associated fares

Critical components of computing the accessibility measure are the actual public transport networks and routes and their associated public transport fares. Table 3-2 reflects the operational public transport modes considered over the three analysis years.

Table 3-2: Operational public transport modes in the analysis years

Year	2009	2011	2013	Route
Public transport modes	Minibus taxi	Minibus taxi	Minibus taxi	Figure 3-7
	Metrorail	Metrorail	Metrorail	Figure 3-8
	Metrobus	Metrobus	Metrobus	Figure 3-9
		Rea Vaya BRT (Phase 1A)	Rea Vaya BRT (Phase 1A)	Figure 3-10

The 2011/12 fares[1] for the minibus taxi, Metrorail and Metrobus were obtained from the *City of Johannesburg Public Transport Record* (Noble & Bickford, 2013). These fares were used as the 2011 fares for the analysis. To determine the fares for 2009 and 2013, the 2012 average inflation rate in South Africa of 5.75% was applied to the 2011/12 fares to determine fares for 2009/10 (used as 2009 fares) and 2013/14 (used as the 2013 fares).

The Rea Vaya fares were obtained from the Rea Vaya website. In 2011, Rea Vaya utilised a flat fare structure such that the cost of commuting along a feeder route was R4.50, commuting along the trunk route was R8.50 and commuting along both a feeder and the trunk route amounted to R12.00. The introduction of the Rea Vaya smartcard in 2012 came in tandem with a distance-based fare structure which resulted in the BRT becoming the second cheapest mode in the city after rail

[1] All the fares utilised for the accessibility calculation are single trip fares which are typically higher than fares associated with monthly or weekly passes.

in 2013. Figure 3-11, Figure 3-12 and Figure 3-14 reflect the linear approximations of the distance-based fare structures across all the modes in 2009, 2011 and 2013, respectively. For each commuter trip on any mode, the y-axis intercept of the linear function was the base fare and the gradient of the function was the rate by which the fare was increased per kilometre of travel. According to Figure 3-14, in 2013 the most expensive mode in the city was the Metrobus, followed by the minibus taxi, the Rea Vaya BRT and finally the Metrorail.

To compare the 2011 flat fare structure of the BRT to the distance-based fare structures of the other operational modes at the time, Figure 3-13 displays a scenario of the fare that would be incurred using the BRT from the Naledi terminal in Soweto to the Johannesburg Art Gallery in the CBD. In this arbitrary scenario, the transfer from the feeder route to the trunk route occurred at the Thokoza Park station, where the fare increased from R4.50 to R12.00 for the remainder of the trip. It is evident from Figure 3-13 that using both a feeder and trunk line was more expensive than the Metrorail (across a relatively long distance), the minibus taxi (for distances less than roughly 25km), and the Metrobus (for distances less than roughly 12km).

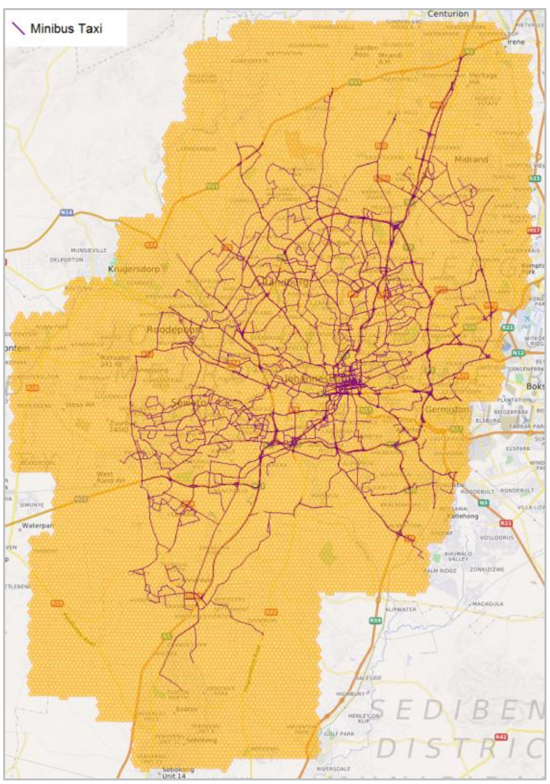

Figure 3-7: Minibus taxi network

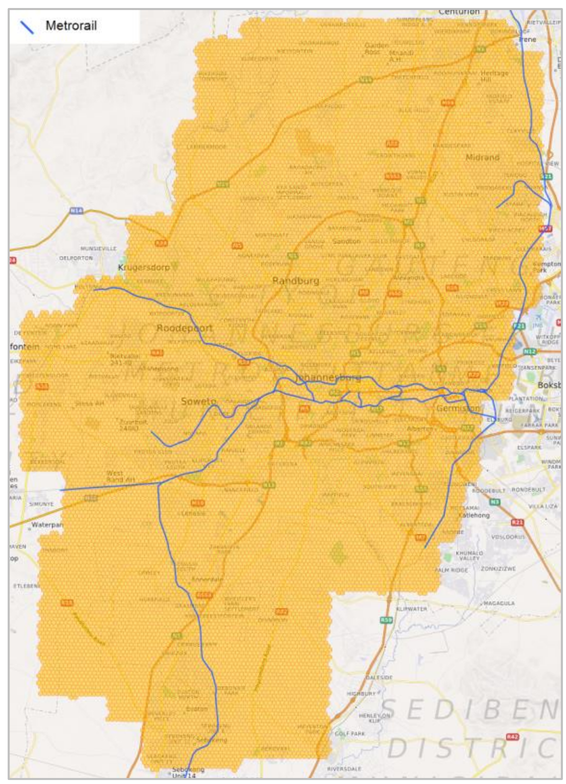

Figure 3-8: Metrorail network

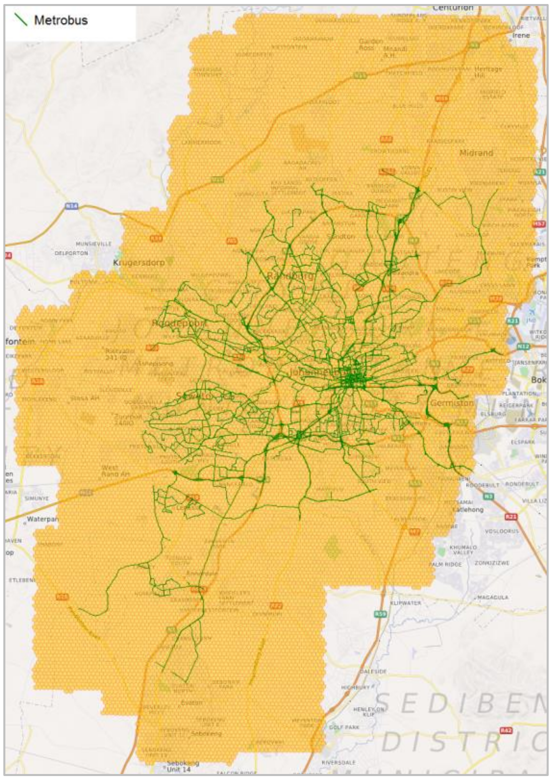

Figure 3-9: Metrobus network

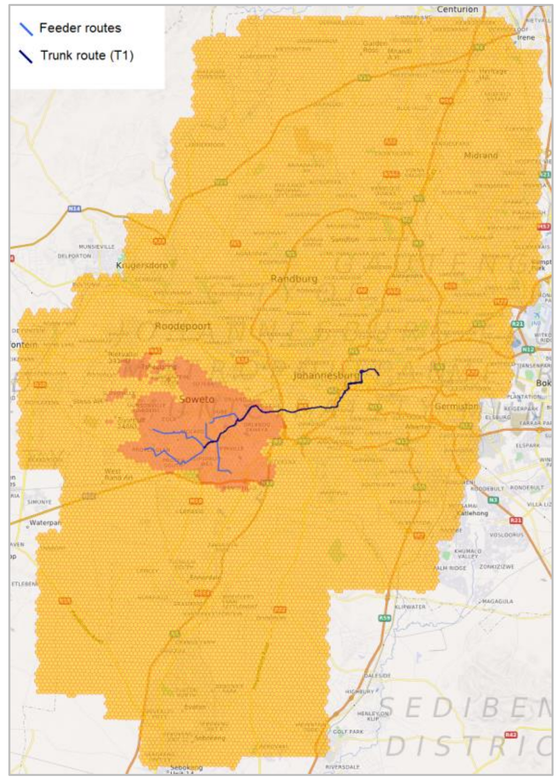

Figure 3-10: BRT network (excluding complimentary route)

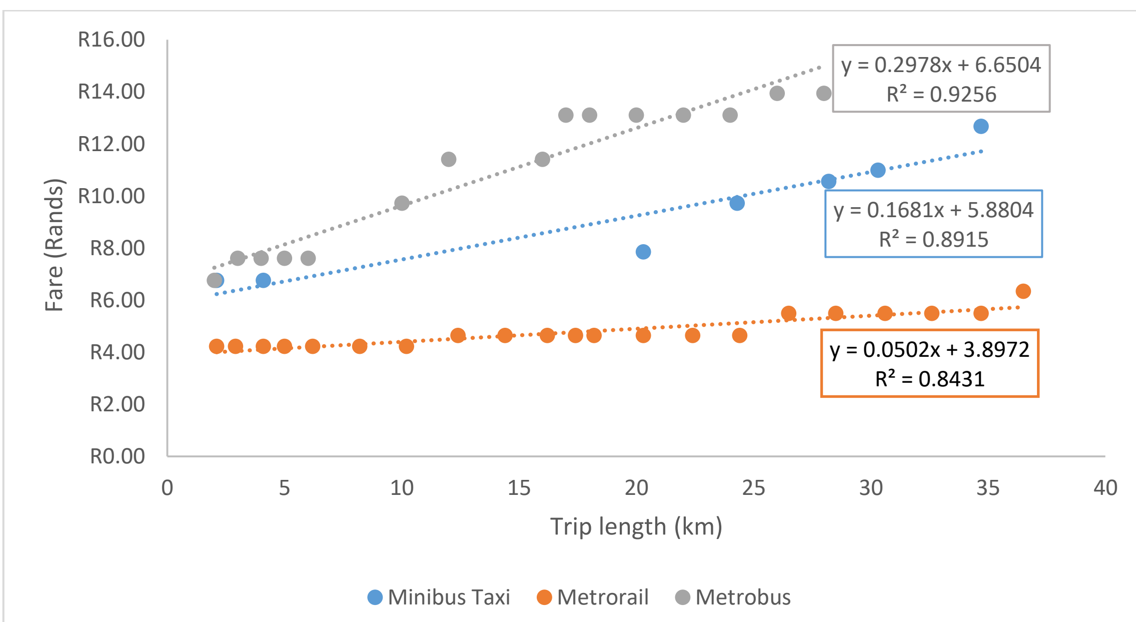

Figure 3-11: 2009 single trip fares

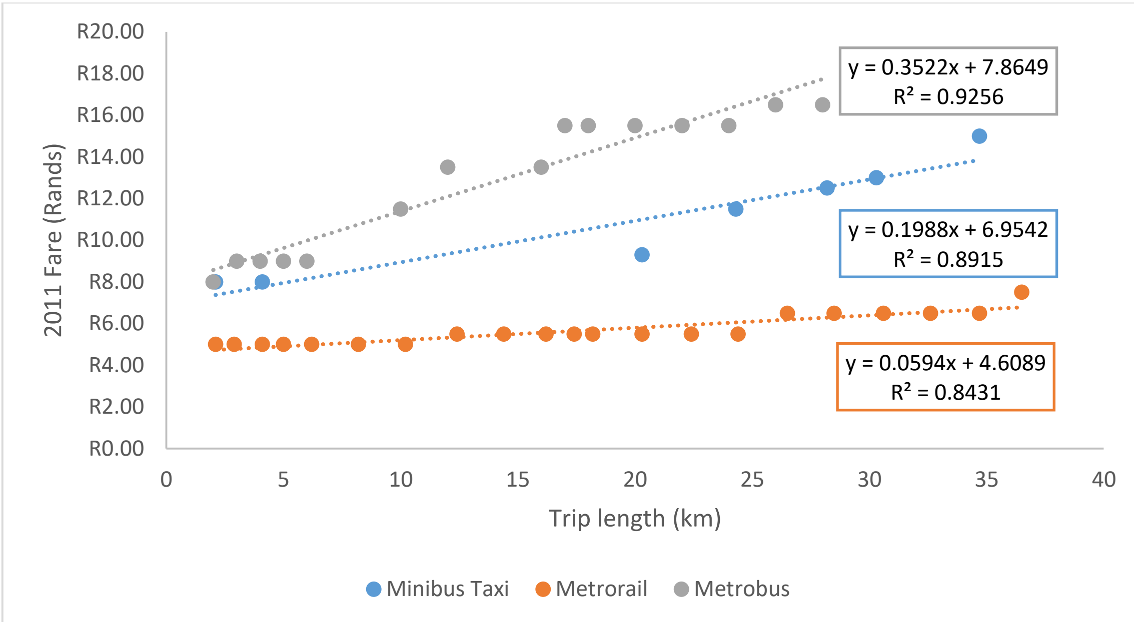

Figure 3-12: 2011 single trip fares

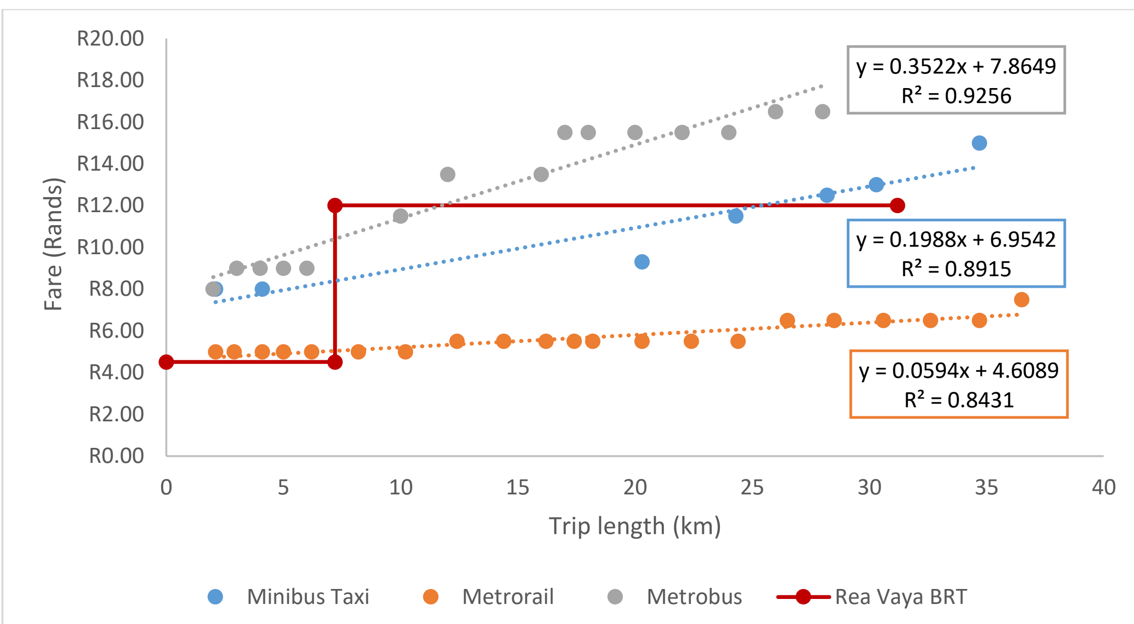

Figure 3-13: 2011 single trip fares including single BRT fare scenario

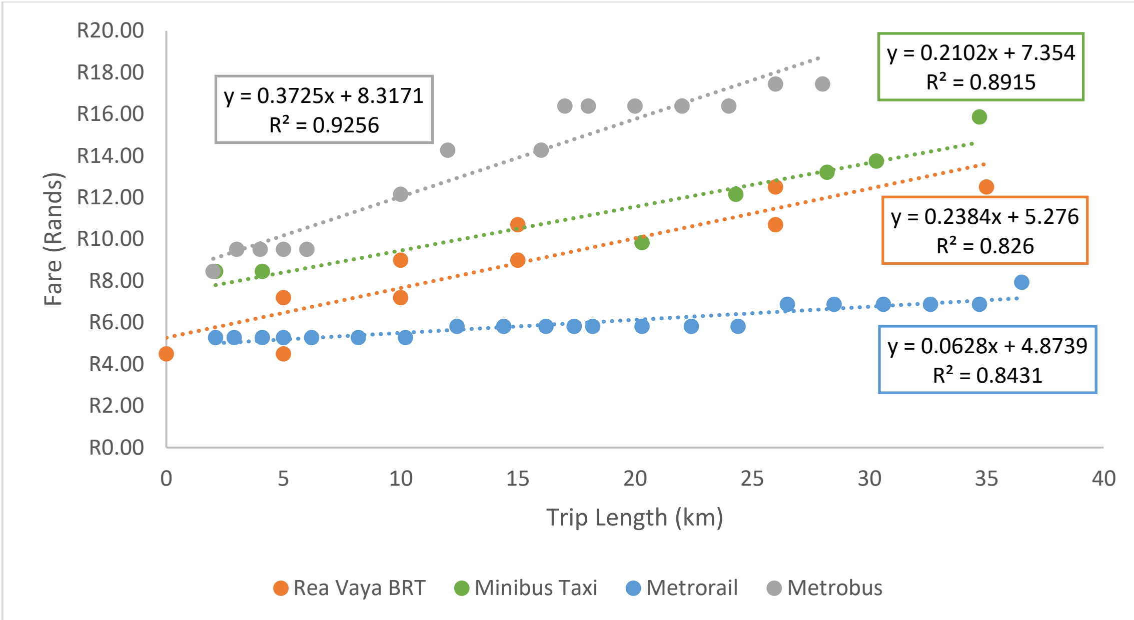

Figure 3-14: 2013 single trip fares

According to the 1998/99 Tshwane Survey, the 2002/03 Gauteng Transport Survey, the GCRO's QoL surveys (2009 and 2011) and the National Household Travel Survey (2009 and 2013); outside of the private vehicle, the minibus taxi is the most widely used mode in Gauteng and its metropolitan cities; therefore it was imperative to ensure that the minibus taxi fares used to compute the accessibility measures were within an acceptable margin of error of the actual fares. The informality of the service posed a challenge with regards to obtaining a record of the current fares. The 2011/12 minibus taxi fares reported in the Johannesburg Public Transport Record (Noble & Bickford, 2013) were obtained through interviews with passengers at various stations. Upon inflating these 2011/12 minibus taxi fares to 2016/17 fares, a validation exercise was conducted through informal interviews with taxi operators at the Noord Taxi Rank and the Bree Taxi Rank located in the Johannesburg CBD regarding fares along various routes in September 2016. The fares obtained from the interviews are reflected in Figure 3-15. The raw field data can be found in Table A-1 and Table A-2 for the Noord and Bree taxi rank respectively in Appendix A.

The linear function in Figure 3-15 was compared to the linear functions of the 2015/16 and 2016/17 fares in Figure 3-16. It is evident that the 2015/16 fares line up almost exactly with an average discrepancy of R0.30 for the trip distances considered. It is also evident that the 2016/17 inflated fares are consistently approximately R1 higher than the collected 2016 fares. This discrepancy between the inflated and collected 2016 fares was expected given that the increase in public transport fares is not adequately reflected by the general consumer price index inflation figure, but other specific factors including transit operating costs, transit ridership and fuel prices (TCRP, 2004). The discrepancies between the inflated and collected minibus taxi fares were deemed acceptable, particularly for the sake of maintaining consistency regarding the treatment of fares across all modes and analysis years and these inflated fares provided slightly more conservative accessibility results.

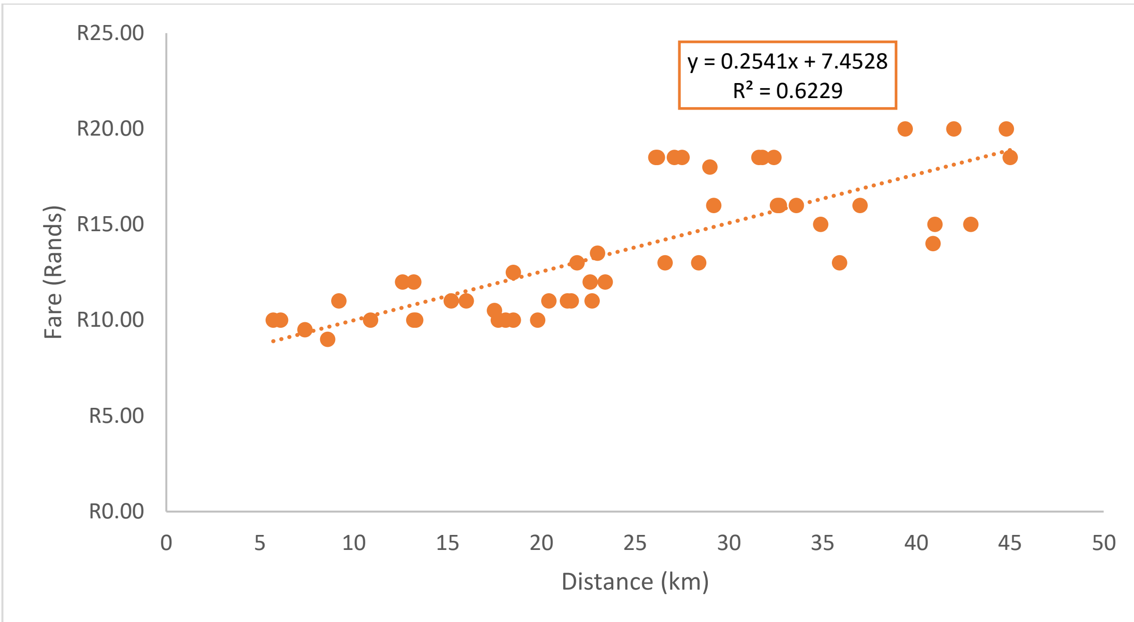

Figure 3-15: Minibus Taxi 2016 fares collected in September 2016

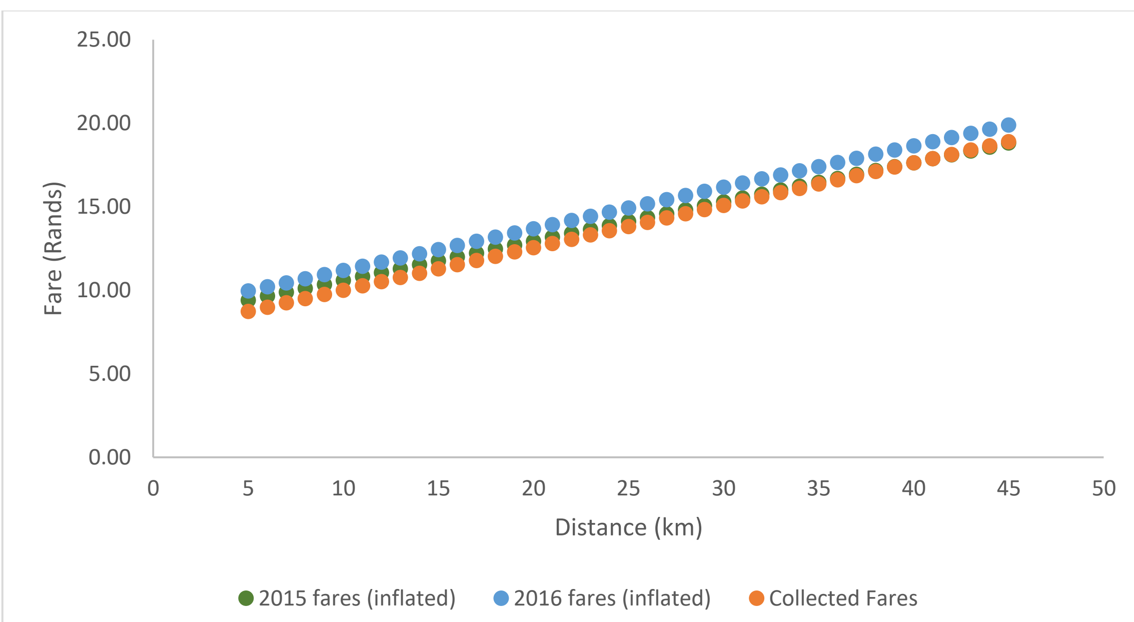

Figure 3-16: Comparison of collected Minibus Taxi fares to inflated Minibus Taxi fares

3.2.2.4 Walking and waiting times

Walking was the only NMT mode considered for public transport access and egress, therefore walking routes were a necessary input. The assumed walking speed of 5km/h was used along the walking routes to estimate public transport access and egress times. Walking was also the only NMT mode that could be used to complete a commuter trip from origin to destination, however, there was no fare associated with walking, ergo, the "cost" of a walking trip was only incurred once the travel time budget was exceeded and the travel time penalty sustained.

The waiting times for the various public transport modes were included in the calculation of the trip travel time. The waiting time for each mode was accepted as half of the estimated peak-time headway of that mode. The estimated average waiting time per mode, based on the peak-period timetable of the corresponding mode (with the exception of the minibus taxi) are reflected in Table 3-3.

Table 3-3: Estimated average waiting time per mode

Mode	Average waiting time (minutes)
Metrorail	15
Metrobus	15
Minibus taxi	5
Rea Vaya BRT feeder	5
Rea Vaya BRT trunk	2.5

3.2.2.5 Speed of the public transport modes

The average peak-period speed of the each mode was required to estimate the travel time along the corresponding routes. The Metrorail speed was taken as 30km/h. The operating speed of the Metrorail, particularly in the CoJ was not readily available in academic literature or the Metrorail website. The speed of 30km/h is based on the Metrorail speeds observed in eThekwini (Onderwater, 2012) and was corroborated through an informal interview regarding average Metrorail travel times with a Metrorail employee.

The speed of each road-based mode was estimated to be a percentage of the speed limit of the roads along which the mode operates. This percentage is expressed as a speed factor in Table 3-4, which is then multiplied by the speed limit of the road section to determine the operating speed of the mode on that specific road section. For modes that travel in mixed traffic, the speed factor estimate was 0.8 and for those that travel in dedicated lanes, such as the Rea Vaya BRT trunk, the speed factor estimate was 0.9.

Table 3-4: Speed factor estimates for road based public transport modes

Mode	Speed factor	Speed on a 60km/h road (km/h)
Minibus taxi	0.8	48
Metrobus	0.8	48
Rea Vaya BRT feeder	0.8	48
Rea Vaya BRT trunk	0.9	54

The speed of the Metrorail and the speed factors of the road based modes provide the operational speed of each of the modes on a specific rail or road section, excluding stops at station or bus stops with the corresponding dwell times for alighting and boarding. Therefore, following consideration of the dwell times as well as the average waiting time for each mode, the travel time of any particular trip increases, and this is the travel time used to determine the average speed of the mode over a said trip distance. Table 3-5 displays the average speed of each of the modes for a trip from a zone in Soweto to a zone in the Johannesburg CBD (see Figure 3-17) with an average distance of 24km. The minibus taxi was assigned a lower speed factor than the BRT trunk, however, the minibus taxi reports a higher average speed in Table 3-5; this is due to the following:

- The use of both the BRT feeder and trunk results in a transfer, increasing the average travel time.
- The BRT feeder operates in mixed traffic, thus increasing the overall travel time of the system when both the feeder and trunk are used.
- The high frequency of minibus taxis result in shorter headways, which result in shorter waiting times and thus an overall shorter travel time.

Although the average speeds in Table 3-5 may be slightly conservative, the calculated average speeds were considered acceptable, particularly for the road based modes as they approached peak period average speeds.

Table 3-5: Calculated average speed of modes for a trip from Soweto to the CoJ CBD

Mode	Average speed (km/hr)	Travel time (minutes)
Metrorail	24	60
Metrobus	25	58
Rea Vaya BRT (feeder and trunk)	26	55
Minibus taxi	27	53

Figure 3-17: Origin and destination of example trip

3.2.3 NWAC decay

Unlike traditional accessibility measures, the NWAC measure does not include the typical exponential deterrence or distance decay function observed in gravity-type measures, for example. This was done with the purpose of aiding interpretation of the measure such that it is easily comprehensible, even for non-technical groups. Figure 3-18 displays how the NWAC decreases with distance for a commuter trip using the various modes from a zone in Soweto to a zone in the CBD (excluding intermodal transfers).

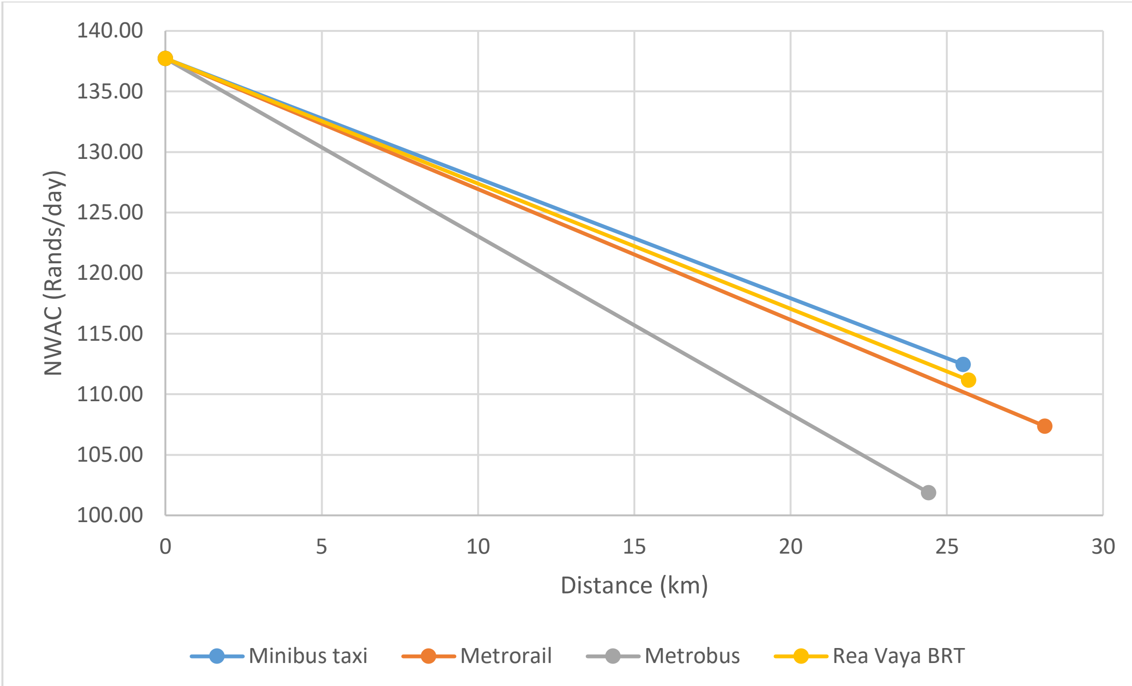

Figure 3-18: Distance decay of the NWAC per mode

For each commuter trip, the methodology selected the mode or combination of modes (including walking) that maximised the NWAC. This required a worker or a work-seeker to trade off travel time and travel cost in such a way as to maximise his/her take-home pay at any given location. Maximising the NWAC will typically occur through the use of the lowest-cost mode, however, once the travel time budget is exceeded, higher cost but faster modes may be used to avoid excessive encroachment on the daily working time, which would reduce the take-home pay. Therefore, according to Figure 3-18, the mode that the methodology would utilise for this commuter trip is the minibus taxi as it yields the highest take-home pay.

Due to the lack of integration of the public transport modes in the city, a transfer from one motorised mode to another would be accompanied by the payment of an additional fare and non-optimal transfer delays. Therefore, the analysis revealed that trips in which intermodal transfers occurred amongst the motorised modes seldom resulted in the highest take-home pay.

3.3 STUDY REGIONS

The NWAC was designed as a poverty relevant metric, therefore, it was imperative to apply this measure in the appropriate context. Eight townships in the CoJ (see Figure 3-19) were selected as the main study regions, namely: Alexandra, Soweto, Diepsloot, Orange Farm, Lawley, Lenasia, Lenasia South (abbreviated to Lenasia S. in Figure 3-19) and Ennerdale. Due to the apartheid spatial legacy, most of these townships are located in the peripheries of the city and historically accommodated lower-income non-white households which was the main premise for their selection. The boundary of each township was estimated using the household locations of the 2011 QoL survey respondents reported as residents of that township.

A number of sample origin zones were randomly selected from each township and used to compute average summary measures for that township. As samples were collected from populations with unknown probability distributions, large sample sizes ($n \geq 30$) were collected to allow for application of the central limit theorem. This theorem states that although sampling occurs from a population that has an unknown distribution, the sampling distribution of the sample mean will still be approximately normal if the sample size is large (Montgomery & Runger, 2011). Therefore, for each township, the 95% confidence interval on each summary measure average could be determined using the following equation without the assumption of normality of the underlying population distribution:

$$\bar{x} - z_{0.025}.\frac{s}{\sqrt{n}} \leq \mu \leq \bar{x} + z_{0.025}.\frac{s}{\sqrt{n}} \quad (3\text{-}3)$$

Where:

$\bar{x}$ – Sample mean

$z_{0.025}$ – Z-score for a double-sided 95% confidence interval (1.96)

s – Sample standard deviation

n – Sample size

μ – Population mean

The number of sample zones selected for each township, the average summary measures and the corresponding double-sided 95% confidence intervals for each analysis year can be found in Appendix B.

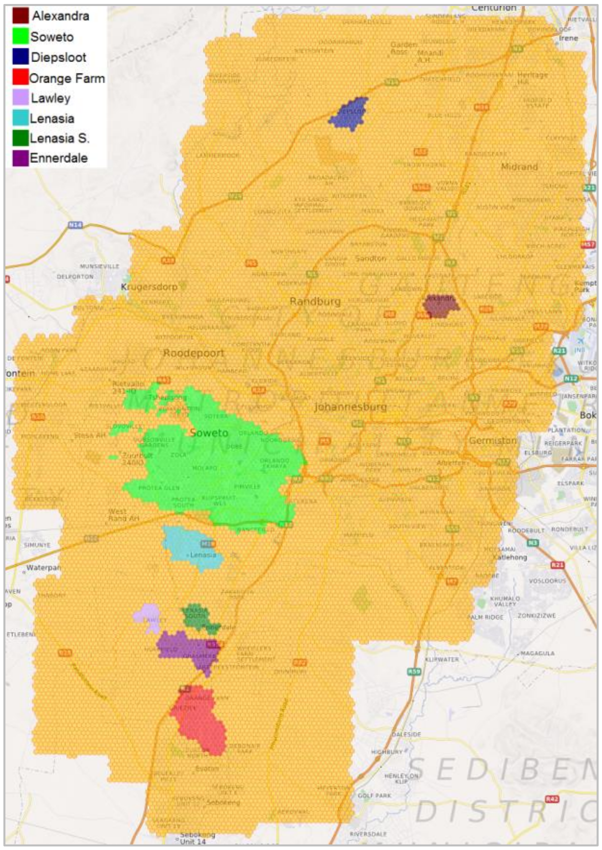

Figure 3-19: Study regions in the CoJ

3.4 TIME-SERIES ANALYSIS OF ACCESSIBILITY

A time-series analysis of accessibility, defined by the computed summary measures (refer to chapter 3.2.1), was conducted to assess the temporal change of accessibility observed for the various townships. Furthermore, the study explored the effect of geographical location on the accessibility distribution within each township and how it altered over time.

3.4.1 Accessibility quadrant plot

A quadrant plot of accessibility was used to explore the interaction between two of the accessibility summary measures as well as the changes of that interaction over time. Figure 3-20 displays a schematic of this quadrant plot, in which the x-axis was defined by the number of jobs accessible with NWAC > R85 (NWAC index) and the y-axis was defined by the number of jobs accessible within 60 minutes of travel time (TT index). Each summary measure was standardized about the overall average which was taken across all regions over all three analysis years. The overall mean of the NWAC accessibility was 1,882,455 jobs and the overall mean of the TT accessibility was

849,952 jobs. Therefore, a value of 0 on any axis of the quadrant plot indicates that the average accessibility measure for that township is equal to the corresponding overall average, and a value of 1 indicates that the average accessibility measure for that township is 100% greater than the corresponding overall average. The schematic of the four quadrant plot also details the accessibility attributes of each quadrant.

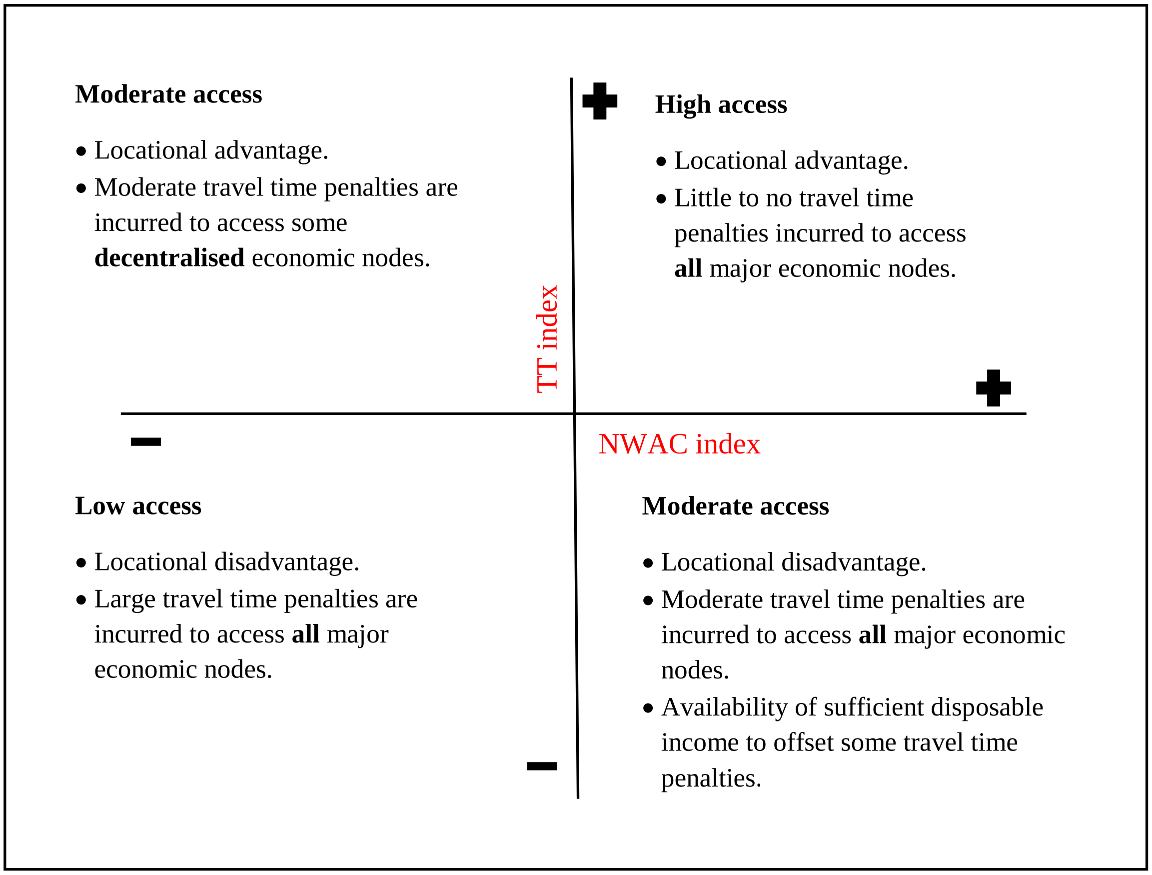

Figure 3-20: Schematic of accessibility quadrant plot

3.4.2 Accessibility distribution

The accessibility distribution within each township is depicted through a cumulative distribution plot where the x-axis recorded the percentage of jobs (relative to the total number of jobs on the study surface: 3,326,390) accessible with NWAC > R85/day, and the y-axis recorded the cumulative percentage of zones in each township.

The uniformity of each cumulative distribution was estimated as follows:

$$U = \frac{\bar{x}_{0.25}}{\bar{x}} \qquad (3\text{-}4)$$

Where:

U – Uniformity.

$\bar{x}_{0.25}$ – The mean of the lowest 25% of accessibility measures from the sample.

$\bar{x}$ – The sample mean accessibility.

The higher the value of uniformity (U), the more uniform the distribution of accessibility in a township was deemed to be.

3.5 DIFFERENCE-IN-DIFFERENCES

A difference-in-differences research design was adopted to unpack the effect of the implementation of the BRT in Soweto on the social welfare of Soweto residents. Typically, this statistical technique estimates the outcome of a particular treatment for two different groups at two different time periods. One group, referred to as the treatment group, is exposed to a treatment in the second time period but not the first. The other group, referred to as the control group, is not exposed to the treatment in both time periods (Wooldridge, 2007). The key assumption in this technique is that the outcome for the control and treatment groups would follow the same trend in the absence of the treatment.

When dealing with panel data, the difference-in-differences estimator is determined by subtracting the average gain of the control group over the time period from the average gain of the treatment group in the same time period (Wooldridge, 2007). The difference-in-differences methodology is graphically explained in Figure 3-21, in which the intervention effect is the treatment effect estimated by the difference-in-differences technique.

Using repeated cross-sectional data, such as the QoL survey data that was used in this study, the basic difference-in-differences model would look as follows:

$$y = \beta_o + \beta_1.G + \beta_2.T + \beta_3(G.T) + \beta_4(Covariates) + \varepsilon \qquad (3\text{-}5)$$

Where:

y – Dependent variable

G – A dummy variable whose coefficient β_1 captures the differences between the treatment group and the control group

T – A dummy variable whose coefficient β_2 captures the effect of time on the outcome

β_3 – The difference-in-differences estimator which captures the causal effect of the treatment on the outcome

ε – Error term

Applications of this technique in transportation studies can be seen in the work of Bocarejo et al. (2013) and Combs (2017). The former applies this methodology to determine the effect of the TransMilenio in Bogotá, Colombia on densification of the city's development, and the latter applies the methodology to examine the effect of the TransMilenio on the mobility of lower-income households.

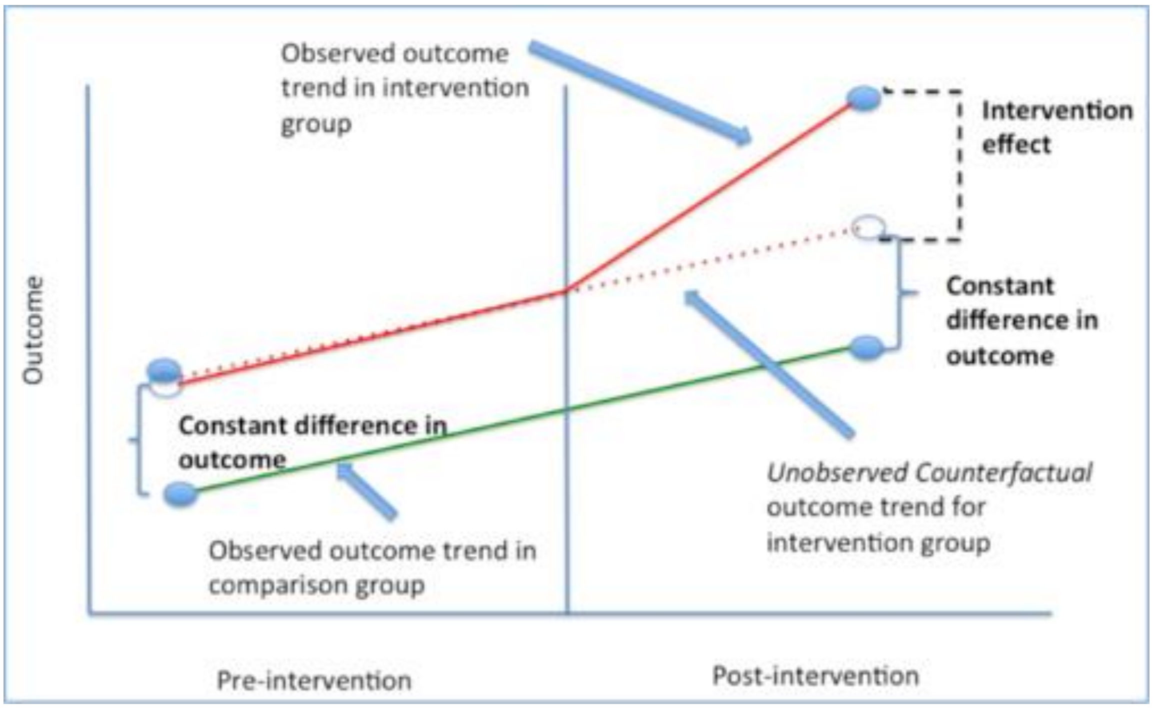

Figure 3-21: Difference-in-differences graphical explanation (Source: https://www.mailman.columbia.edu/research/population-health-methods/difference-difference-estimation)

3.5.1 Analysis of the dependent variable

In the difference-in-differences model, the time considered before and after BRT implementation was 2009 and 2013, respectively. The treatment group comprised of Soweto QoL survey respondents residing within 800m of feeder and/or trunk route stations while the control group comprised of Soweto QoL survey respondents further than 800m from the stated stops and/or stations. Appendix B reveals that 60 zones were randomly selected to conduct the time-series analysis of accessibility for Soweto; this was increased to 90 zones with a total of 423 respondents to conduct the difference-in-differences analysis.

Each QoL survey has a personal well-being section which asks a number of questions across various areas of the respondent's life, for which responses were provided on an ordinal scale from 1 ("Very satisfied") to 5 ("Very dissatisfied"); see Table 3-6. The dependent variable was the number of questions in the abovementioned section of the survey for which respondents were either "Dissatisfied" or "Very dissatisfied".

Table 3-6: QoL survey questions used to construct the dependent variable

	Question	Possible response
1.	The amount of money you have available to you personally	1 = Very satisfied 2 = Satisfied 3 = Neutral 4 = Dissatisfied 5 = Very dissatisfied
2.	The amount of time you have to do the things you want to do	1 = Very satisfied 2 = Satisfied 3 = Neutral 4 = Dissatisfied 5 = Very dissatisfied
3.	Your marriage or relationship with your partner	0 = Not in a relationship 1 = Very satisfied 2 = Satisfied 3 = Neutral 4 = Dissatisfied 5 = Very dissatisfied
4.	Family life – the time you spend and the things you do with them	1 = Very satisfied 2 = Satisfied 3 = Neutral 4 = Dissatisfied 5 = Very dissatisfied
5.	Friends	1 = Very satisfied 2 = Satisfied 3 = Neutral 4 = Dissatisfied 5 = Very dissatisfied
6.	Your standard of living	1 = Very satisfied 2 = Satisfied 3 = Neutral 4= Dissatisfied 5 = Very dissatisfied
7.	The way you spend your leisure time – recreation, relaxation, etc.	1 = Very satisfied 2 = Satisfied 3 = Neutral 4 = Dissatisfied 5 = Very dissatisfied

8.	The place where you live now	1 = Very satisfied 2 = Satisfied 3 = Neutral 4= Dissatisfied 5 = Very dissatisfied
9.	Life as a whole these days	1 = Very satisfied 2 = Satisfied 3 = Neutral 4 = Dissatisfied 5 = Very dissatisfied

Table 3-7 and Figure 3-22 depict how the count variable dissatisfaction (abbreviated to "Dis." in Table 3-7) changed with respect to time for both the treatment and control group from 2009 to 2013. The values in square brackets in Table 3-7 indicate the number of respondents in the corresponding year for the respective groups. A clear decrease in dissatisfaction was observed for both the control and treatment groups over time; the larger decrease being observed for the treatment group.

Table 3-7: Temporal change in dissatisfaction

	Treatment group					**Control group**				
	2009 [62]		**2013 [182]**		**% change**	**2009 [46]**		**2013 [133]**		**% change**
	Mean	**SD**	**Mean**	**SD**		**Mean**	**SD**	**Mean**	**SD**	
Dis.	2.79	1.94	1.66	1.41	- 40.5	2.63	2.25	1.75	1.59	- 33.5

Figures 3-23 and 3-24 display the distribution of dissatisfaction for both the treatment and control groups in 2009 and 2013, respectively. An unpaired t-test is typically used to test the difference between two independent means, however, it assumes the population distribution of the dependent variable is normal and that the dependent variable is continuous, thus it was not applicable to the dissatisfaction count data. A non-parametric alternative to the unpaired t-test known as the Mann-Whitney U-test was then used to test if there was a significant difference in dissatisfaction between the control group and treatment group in both the pre- and post-treatment years. This statistical procedure was more applicable as it makes no assumptions about the underlying population distribution and it is applicable to data measured on an ordinal scale. The dependent variable of dissatisfaction can be interpreted as ordinal data such that:

- "0" = neither dissatisfied or very dissatisfied in the stated areas of well-being, and
- "9" = dissatisfied or very dissatisfied in all stated areas of well-being.

The null hypothesis of the Mann-Whitney U-test, for both the 2009 and 2013 data, is that the treatment group respondents have the same distribution of dissatisfaction as the control group respondents. To reject the null hypothesis would be to say the population distributions of dissatisfaction of the control and treatment group are different in some way, either in the measure of central tendency, spread and/or shape. The results of the Mann-Whitney U-tests are reflected in Table 3-8 for the pre-treatment and post-treatment samples. The results reveal that in both the pre- and post-treatment case there is failure to reject the null hypothesis, as the asymptotic significance or p-value of the 2-tailed test is greater than 0.05. This suggests that the two groups are from the same population with respect to dissatisfaction both in 2009 and 2013.

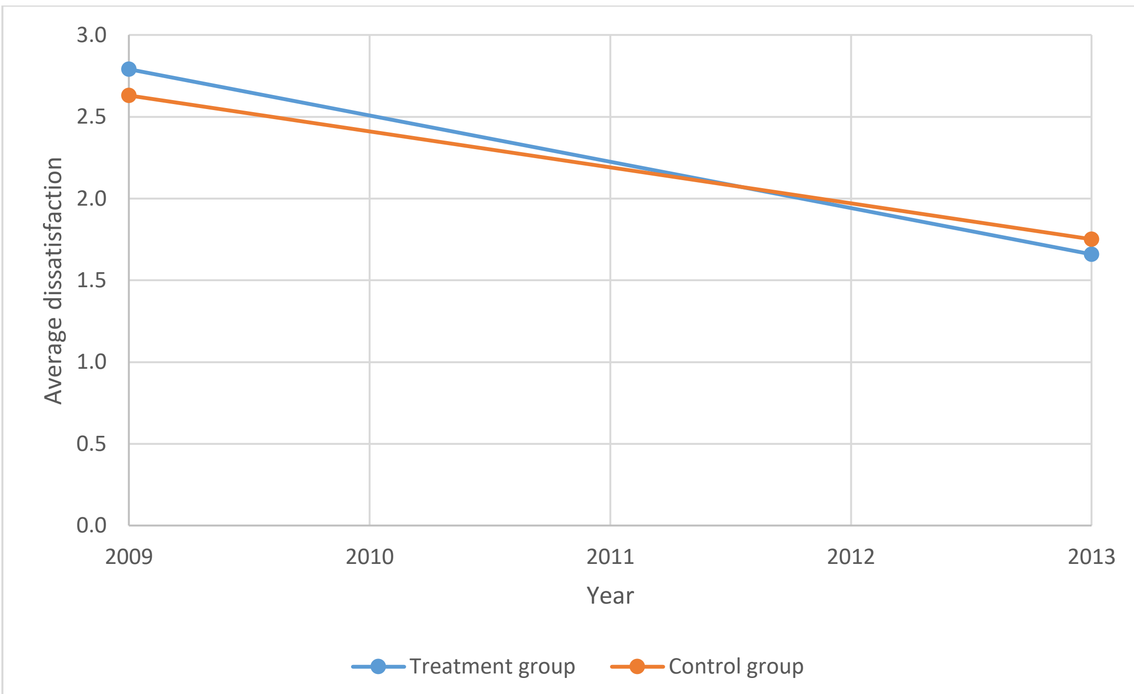

Figure 3-22: Change in average dissatisfaction with time

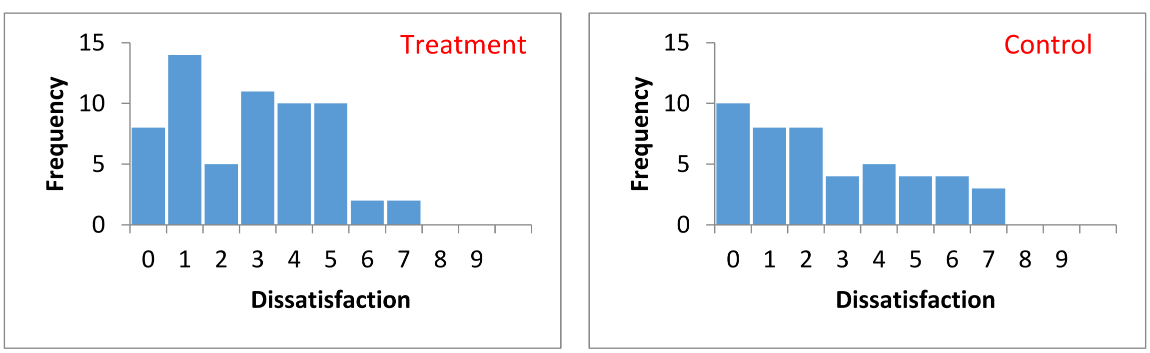

*Figure 3-23: Distribution of dissatisfaction for the **2009** treatment and control groups*

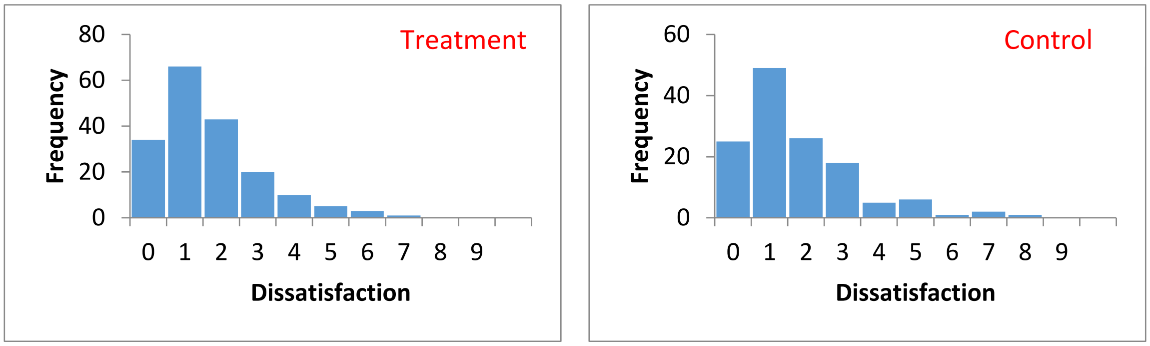

*Figure 3-24: Distribution of dissatisfaction for the **2013** treatment and control groups*

Table 3-8: Pre-treatment (2009) Mann-Whitney U-test results

	Dissatisfaction 2009	Dissatisfaction 2013
Mann-Whitney U	1332.0	11967.5
Wilcoxon W	2413.0	28620.5
Z	-0.591	-0.176
Asymp. Sig. (2-tailed)	**0.555**	**0.860**

The pre-treatment result is intuitive as the treatment had not been administered at that stage, therefore one does not expect to observe a significant difference in the dissatisfaction distributions of the treatment and control group populations. This could also imply that in the absence of the treatment, the control and treatment group dissatisfaction levels are likely to follow the same trend, thus satisfying an assumption of the difference-in-differences technique.

The post-treatment result reveals that even after implementation of the BRT, dissatisfaction distributions of the treatment and control group populations are not significantly different from each other in any way. This is consistent with findings in a study by Venter & Vaz (2014) which revealed that although the Rea Vaya BRT came in tandem with the improvement of some amenities along the trunk route, such as upgrades to streets and public spaces around stations, and this was well received by residents residing in close proximity to the line, this did not translate to an overall increase in satisfaction with life in the neighbourhood. The study found that satisfaction was predominantly driven by other factors such as household type.

The difference-in-differences design tests the hypothesis that households with access to the BRT (within 800m of both feeder and trunk line stops and/or stations) are less dissatisfied than those without access to the BRT, however, the design will control for psycho-social factors (in as far as possible) through a Social Exclusion Index, vehicle ownership, accessibility to jobs and account for pre-treatment dissatisfaction levels. The approach aims to further unpack the findings of the Mann-Whitney U-tests, and possibly identify if other factors in conjunction with proximity to the BRT affect dissatisfaction.

It should be noted that any measurement of subjective well-being is imperfect due to the inability to capture all person-specific factors, and there is a possibility of large error terms due to day-to-day variations in latent phenomena.

3.5.2 Regression model

As aforementioned, the dependent variable was the number of questions in the well-being section of the QoL surveys for which respondents were either "Dissatisfied" or "Very dissatisfied", therefore, a count regression model was used. Selecting "very dissatisfied" as the only count variable criteria resulted in an under-dispersed count variable which is not as readily modelled as an equi-dispersed or over-dispersed count variables. The descriptive statistics of the data set gave a mean of 1.96 and variance of 2.93, suggesting an over-dispersed sample, therefore the data was initially modelled using a negative binomial regression model. This model gave an over-dispersion factor of 0.1366 with an associated p-value of 0.0052 meaning the over-dispersion factor was statistically different from zero at the 0.05 significance level, suggesting that the negative binomial regression model was more suitable to model the data than a Poisson regression model. This was further corroborated by a comparison of the model fit parameters in Table 3-9. Maximum likelihood is typically used to fit statistical models by maximising the likelihood function $L(\beta)$ of a model parameter β to estimate its value. Alternatively, one can estimate a parameter β by minimizing the natural logarithm of the likelihood function, which is $-LogL(\beta)$ also referred to as $-LogLikelihood$. Smaller values of $-Loglikelihood$ or $-2Loglikelihood$ (such as that shown in Table 3-9) indicate better model fits.

Other model fit criteria include the Akaike's Information Criterion (AIC), the corrected Akaike's Information Criterion (AICc) and the Bayesian Information Criterion (BIC), each of which are a function of the $-2Loglikelihood$ value, the number of estimated parameters in the model and/or the number of observations in the data set. The model with the smaller AIC, AICc or BIC values is considered better. Therefore, according to the values reflected in the Table 3-9, the negative binomial regression model is unanimously better than the Poisson regression model to model this data set.

Table 3-9: Comparison of model fit

Model	-2LogLikelihood	AIC	AICc	BIC
Poisson regression model	1460.7	1478.7	1479.1	1515.1
Negative binomial regression model	1448.8	1468.8	1469.4	1509.3

In a negative binomial regression model, the dependent variable is a count of the number of times an event occurs. This regression model is typically used to model over-dispersed count data and one of its distinguishing factors from the Poisson regression is its additional parameter to model over-dispersion.

The probability that an observation y_i takes on a value y under the negative binomial distribution is given by the following:

$$Pr\{y_i = y|\mu_i, \alpha\} = \frac{\Gamma\left(y+\frac{1}{\alpha}\right)}{\Gamma(y+1)\cdot\Gamma\left(\frac{1}{\alpha}\right)} \cdot \left(\frac{1}{1+\alpha\cdot\mu_i}\right)^{\frac{1}{\alpha}} \cdot \left(\frac{\alpha\cdot\mu_i}{1+\alpha\cdot\mu_i}\right)^{y} \quad (3\text{-}6)$$

Where:

α – Over-dispersion parameter.

Γ – Gamma function which is a generalisation of the factorial function such that: $\Gamma(n) = (n-1)! = (n-1) \times (n-2) \times \ldots \times 1$

μ_i – The mean of the negative binomial distribution and the expected value of y_i given a combination of explanatory variables x_p such that:

$$\mu_i = E\left(y_i \middle| x_p\right) \geq 0$$

The logarithm of the dependent variable's expected value can be modelled by a linear combination of independent variables $(x_1, x_2, \ldots, x_p)$ such that:

$$\ln(\mu_i) = \beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + \cdots + \beta_p \cdot x_p \quad (3\text{-}7)$$

The 9 questions depicted in Table 3-6 were those that were common to both the 2009 and 2013 QoL surveys, therefore the negative binomial regression model used for this study was slightly adapted from that in equation 3-6 by being right truncated at 9 as shown in equation 3-8:

$$Pr\{y_i = y|\mu_i, \alpha, 0 \leq y \leq 9\} = \left[\frac{\Gamma\left(y+\frac{1}{\alpha}\right)}{\Gamma(y+1)\cdot\Gamma\left(\frac{1}{\alpha}\right)} \cdot \left(\frac{1}{1+\alpha\cdot\mu_i}\right)^{\frac{1}{\alpha}} \cdot \left(\frac{\alpha\cdot\mu_i}{1+\alpha\cdot\mu_i}\right)^{y}\right] / \left[Pr\{y=0\} + \cdots + Pr\{y=9\}\right] \quad (3\text{-}8)$$

$$\ln(\mu_i) = \beta_0 + \beta_1 \cdot year + \beta_2 \cdot BRT + \beta_3 \cdot PT\ user + \beta_4 \cdot SEI + \beta_5 \cdot Acc + \beta_6(year.BRT) + \beta_7(year \cdot BRT \cdot PT\ user) + \beta_8(BRT \cdot AccBRT) + \varepsilon \quad (3\text{-}9)$$

Where $\mu_i = E(y_i|x_p)$

The count variable y_i was described by individual variables as well as interactions between them. Three of the independent variables in equation 3-9 are dummy variables, namely; *year*, *BRT* and *PT user*. *year* took on the value of “0” for pre-treatment respondents (2009) and a value of “1” for post-treatment respondents (2013). *BRT* took on the value of “0” for Soweto respondents located more than 800m away from BRT route stations and/or stops, and a value of “1” for respondents within 800m of the BRT route stations and/or stops. *PT user* took on the value of “1” if the respondent is a frequent public transport (PT) user and a value of “0” if the respondent is not a frequent PT user. *SEI* is a social exclusion index (SEI) computed for each respondent based on selected indicators from the 2009 and 2013 QoL surveys; its purpose was to capture a range of other psycho-social factors that could influence a respondent’s perception of subjective welfare. The construction of the SEI is elaborated upon in chapter 3.5.3. *Acc* is the TT accessibility summary measure computed for each household.

A preliminary analysis of correlations, using a correlation matrix, between the independent variables in equation 3-9 is displayed in Table 3-10. The correlations observed between interaction variables and the individual variables they are a product of are relatively high in comparison to the correlations observed between the individual variables. For example, independent variable x_6 $(year.BRT)$ is relatively highly correlated to the main effect independent variables x_1 $(year)$ and x_2 (BRT); this is to be expected for all the interaction variables in the model and can be ignored. However, of concern is the high linear correlation (greater than 0.7) observed between two interaction variables, namely x_6 $(year.BRT)$ and x_7 $(year \cdot BRT \cdot PT\ user)$ which could result in the provision of redundant information in the model and it may make the estimated coefficients for these variables unstable.

Table 3-10: Correlation matrix of independent variables in equation 3-9

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
x_1	1							
x_2	0.00327	1						
x_3	0.03472	0.08606	1					
x_4	0.11352	-0.09649	-0.14562	1				
x_5	-0.13120	-0.13875	-0.04265	0.00309	1			
x_6	0.50884	0.74432	0.09338	-0.00632	-0.15410	1		
x_7	0.41184	0.60242	0.43748	-0.09785	-0.09474	**0.80936**	1	
x_8	0.33251	0.48638	0.07818	0.00311	0.06691	0.65346	0.54524	1

Bearing this in mind, the negative binomial regression model reflected by equation 3-9 was adapted to give the model reflected by equation 3-10 where x_7 was changed from $year \cdot BRT \cdot PT\ user$ to $BRT \cdot PT\ user$. This was done with the aim of observing if there was a significant difference in dissatisfaction between frequent and non-frequent PT users with access to the BRT in 2013. This then produced the correlation matrix displayed in Table 3-9 in which we observe an acceptable correlation of 0.59 between x_6 and x_7 . The descriptive statistics of the final independent variables of the model are reflected in Table 3-12.

$$\ln(\mu_i) = \beta_0 + \beta_1 \cdot year + \beta_2 \cdot BRT + \beta_3 \cdot PT\ user + \beta_4 \cdot SEI + \beta_5 \cdot Acc + \beta_6(year.BRT) + \beta_7(BRT \cdot PT\ user) + \beta_8(BRT \cdot AccBRT) + \varepsilon \qquad (3\text{-}10)$$

Table 3-11: Correlation matrix of independent variables in equation 3-10

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
x_1	1							
x_2	0.00327	1						
x_3	0.03472	0.08606	1					
x_4	0.11352	-0.09649	-0.14562	1				
x_5	-0.13120	-0.13875	-0.04265	0.00309	1			
x_6	0.50884	0.74432	0.09338	-0.00632	-0.15410	1		
x_7	0.03258	0.75152	0.54576	-0.15218	-0.09937	0.58590	1	
x_8	0.33251	0.48638	0.07818	0.00311	0.06691	0.65346	0.39839	1

Table 3-12: Descriptive statistics of the independent variables

Independent variable	Data type	Min	Max	Mean	Median	Mode
x_1 $year$	Categorical	0	1	-	1	1
x_2 BRT	Categorical	0	1	-	1	1
x_3 $PT\ user$	Categorical	0	1	-	1	1
x_4 SEI	Continuous	0	7.78	3.17	3.21	3.57
x_5 $Acc\ (\times 100{,}000)$	Continuous	0.27	21.32	11.94	12.76	14.45
x_6 $year \cdot BRT$	Categorical	0	1	-	0	0
x_7 $BRT \cdot PT\ user$	Categorical	0	1	-	0	0
x_8 $BRT \cdot AccBRT$	Continuous	0	7.38	-	0	0

Below is a list of the coefficients in equation 3-10 and a description of the effect on the count variable, dissatisfaction, which each coefficient describes while holding constant for all other independent variables in the regression model:

β_0 – Constant

β_1 – The general time trend from 2009 to 2013

β_2 – The effect of residing within 800m of the BRT line stops and/or stations relative to residing further than 800m from the BRT line stops and/or stations

β_3 – The effect of being a frequent public transport user relative to not being a frequent public transport user

β_4 – The effect of a unit increase in the social exclusion index

β_5 – The effect of a unit increase in accessibility

β_6 - The effect of the implementation of the BRT on the treatment group respondents relative to the control group respondents in 2013 (taking into account pre-existing differences between the treatment and control group and the general time trend)

β_7 - The effect of being a frequent PT user (thus more likely to use Rea Vaya BRT) relative to being a non-frequent PT user in the treatment group (taking into account pre-existing differences between frequent and non-frequent PT users and pre-existing differences between the control and treatment groups).

β_8 - The effect of a unit increase in the accessibility offered by the BRT on the 2013 treatment group respondents, relative to the effect of the unit increase on control group respondents.

Equations 3-10 was modelled using Statistical Analysis Software (SAS); the raw data and the script are provided in Appendix C.

3.5.3 Construction of the SEI

Based on the available data, the SEI is best described by seven dimensions, namely: employment, education, infrastructure, food security, transport, connectivity, and health limitations. The selection of dimensions and indicators was predominantly informed by Wright's report (2008) which was part of the *Indicators of Social Exclusion and Poverty Project* listing indicators of poverty based on socially perceived necessities. The construction of the index was informed by the work done by Mushongera et al. (2015) in which the authors constructed a Multidimensional Poverty Index (MPI) for the Gauteng province as well as the index construction guidelines outlined in the *OECD Handbook on Constructing Composite Indicators: Methodology and User Guide* (2008). The initial list of questions in the QoL surveys selected to construct the SEI are reflected in Table 3-13.

The missing data summary for the selected questions is reflected in Table 3-14. The OECD outlines three types of missing data: a) missing completely at random (MCAR), b) missing at random (MAR) and c) not missing at random (NMAR), each of which are briefly explained below (OECD, 2008):

- *MCAR* – The missing data is not dependent on the question itself or any other preceding question.
- *MAR* – The missing data is not dependent on the question itself; however, it depends on preceding questions in the survey.
- *NMAR* – The missing data depends on the question itself, for example, in events where certain groups are reluctant to disclose specific information.

Missing data or respondents with missing data were not deleted from the data set as this could potentially significantly decrease the data set and thus lead to standard errors caused by a smaller sample (OECD, 2008). Due to the difficulty of proving that missing data follows a NMAR pattern, it was assumed that all missing data was either MCAR or MAR and thus missing data was replaced by a single imputation of the mean of the existing data set. It is acknowledged that this method allows the existing data to influence the missing data, however, it could potentially minimise the bias that would be caused by case deletion (OECD, 2008) and was thus the preferred option. The most robust method of data imputation is that of multiple imputations, which provide several possible values for the missing data, and thus more effectively reflects the uncertainty due to imputation (OECD, 2008). The selection of the single imputation was based on its simplicity and the fact that no data imputation method is free of assumptions and possible bias. It is imperative to note that responses such as “Unspecified”, “Other”, “Don’t know” were also considered as missing data and were replaced accordingly. In Table 3-14, the detail below the missing data percentage is the existing data mean that was used to replace the missing data entries.

Table 3-15 reflects how the indicators were recoded to ensure that the responses were reduced to a common scale to facilitate the index construction. In this case, “favourable responses” were assigned a value of 0 and “unfavourable responses” were assigned a value of 1. This recoding technique is such that the higher the SEI, the more socially excluded an individual is considered to be. The recoding of indicator 9 (closest public transport stop) was informed by the *Guidelines for Human Settlement Planning and Design* (2000) which states that, in low density areas, such as residential suburbs, bus stops should be around 800m apart. Having assumed that the average human walks 5km/h, 800m should take the average human 9.6 minutes to walk; therefore an answer of 10 minutes or longer was considered “unfavourable”. The recoding of indicator 10 (travel time) was based on the assumed South African travel time budget of 60 minutes per direction (Venter & Cross, 2014); therefore, a travel time longer than 60 minutes was considered “unfavourable”. The PCA revealed that indicator 7 (Adult skips meal) and indicator 8 (Child skips meal), were highly correlated (correlation greater than 0.7), as well as indicator 12 (Health prevents daily work) and 13 (Health prevents social activities); subsequently, both indicator 8 and 13 were arbitrarily selected to be excluded from the construction of the SEI to avoid double counting.

The dimensions, and their final corresponding indicators and weights are reflected in Table 3-16. The SEI was constructed as a multi-dimensional index, and equal weights were applied to each dimension. The weights per dimension were determined as followed:

$$w_d = \frac{1}{D} \tag{3-11}$$

Where:

w_d = the weight applied to each dimension d

D = the total number of dimensions

Each dimension comprised of one or more indicators (see Table 3-16); equal weights, based on the dimension weights, were applied to each indicator of a dimension. The indicator weights, per dimension, were determined as follows:

$$w_n^{d_i} = w_d \cdot \frac{1}{N_{d_i}} \quad (3\text{-}12)$$

Where:

$w_n^{d_i}$ = the weight applied to each indicator n of dimension d_i where i = (1,2,3,…,D)

N_{d_i} = the total number of indicators that describe the dimension d_i where i = (1,2,3,…,D)

This approach was applied as opposed to applying equal weights to each indicator of the index as the latter would result in bias of the index towards the dimensions that constituted of the most indicators (OECD, 2008). Each weight was applied to the corresponding recoded value of the indicator and the algebraic sum of the weighted indicators gave the preliminary index, $I_{p,k}$. The $I_{p,k}$ was then rescaled to give the final SEI out of ten for each respondent using the following formula:

$$I_k = \left(\frac{I_{p,k} - I_{p,min}}{I_{p,max} - I_{p,min}}\right) . 10 \quad (3\text{-}13)$$

Where:

I_k = the final index of respondent k

$I_{p,k}$ = the preliminary index of respondent k

$I_{p,min}$ = minimum preliminary index

$I_{p,max}$ = maximum preliminary index

Table 3-13: QoL survey questions used to construct the SEI

	Question	Possible response
1.	What is your employment status?	1 = Employed full time, formal sector 2 = Employed part time, formal sector 3 = Employed full time, informal sector 4= Employed part time, informal sector 5 = Self-employed, own business, NOT working from home 6 = Self-employed, own business, working from home 7 = Unemployed and looking for work 8 = Unemployed, not looking for work, but would accept work 9 = Not wishing to work 10 = Disabled 11 = Housewife/ home-maker 12 = School pupil/ Full-time student 13 = Retired person/ pensioner

	Question	Possible response
2.	What is the highest level of school education you have completed?	0 = None/ Grade 0 1 = Grade 1/ Sub A 2 = Grade 2/Sub B 3 = Grade 3/ Std 1/ L1 4= Grade 4/ Std 2/ L2 5= Grade 5/ Std 3/ L3 6 = Grade 6/ Std 4/ L4 7 = Grade 7/ Std5/ L5 8 = Grade 8/ Std 6/ L6 9 = Grade 9/ Std 7/ L7 10 = Grade 10/ Std 8/ L8/ Form 11 11 = Grade 11/ Std 9/ L9 12 = Grade 12/ Std 10/ Matric 13 = College/ technikon/ university/ certificate 14 = College/ technikon/ university diploma 15 = Technikon/ university degree 16 = Post-graduate degree 17 = Unspecified
3.	What type of toilet facility is available in this house?	1 = Full waterborne (flush toilet) 2 = Septic tank 3 = Ventilated Improved Pit Latrine 4 = Basic Pit Latrine 5 = Chemical toilet 6 = Communal toilet 7 = Neighbours 8 = Bush 9 = Bucket 10 = No toilet 11 = Other
4.	How is the refuse or rubbish of this household disposed of?	1 = Refuse removed from the house by local authority at least once a week 2 = Refuse removed from the house by local authority, less often 3 = Removal by local authority from community refuse container 4 = Place on communal refuse dump but not collected by local authority 5 = Place on own refuse dump but not collected by local authority 6 = Burnt in pit 7 = Buried 8 = None 9 = Other

	Question	Possible response
5.	What is the main water source for this household?	1 = Piped – in dwelling with no meter 2 = Piped – in dwelling with pre-paid meter 3 = Piped – in dwelling with meter 4 = Piped – yard tap with no meter 5 = Piped – yard tap with prepaid meter 6 = Piped – yard tap with meter 7 = Street taps (standpipes) free water 8 = Street taps (standpipes) paid for 9 = Borehole/well 10 = Rainwater tank 11 = Flowing river/ stream 12 = Dam 13 = Water truck 14 = Other
6.	What type of electricity supply, if any, does this house have?	1 = Electricity with conventional meters 2 = Electricity with prepaid card 3 = Other electricity supply: Solar, Wind generators 4 = Other electricity supply: Petrol/diesel generators etc. 5 = Connection to neighbour's electrified house 6 = Dwelling does NOT have electricity
7.	In the last year, has there ever been a time when you or any adult in this household had to skip a meal because there was not enough money to buy food?	1 = Yes 2 = No
8.	In the last year, has there ever been a time when you did not have enough money to feed the children in the household?	1 = Yes 2 = No
9.	How far is the closest access point to public transport from your house? (i.e. taxi stop, bus stop, train station)	1 = Less than 5 minute walk 2 = From 5 minutes to less than 10 minute walk 3 = From 10 minutes to less than 20 minute walk 4 = From 20 minutes to less than 30 minute walk 5 = More than 30 minute walk
10.	How long after leaving home, does it take you to reach your place of work or study or the place where you look for work?	1 = Do not work, study or look for work 2 = Up to 15 minutes 3 = From 16 minutes to 30 minutes 4 = From 31 minutes to 45 minutes 5 = From 46 minutes to 60 minutes 6 = From 61 minutes to 90 minutes 7 = From 91 minutes to 120 minutes 8 = More than 120 minutes (more than 2 hours)
11.	Does this household have a cell phone which is connected/ being used/ in good working order?	1 = Yes 2 = No

	Question	Possible response
12.	How often, if ever, does your health status prevent you from doing your daily work?	1 = Always 2 = Some of the time 3 = Hardly ever 4 = Never
13.	How often, if ever, does your health status prevent you from taking part in your usual social activities? (Physical and emotional problems?)	1 = Always 2 = Some of the time 3 = Hardly ever 4 = Never

Table 3-14: SEI missing data summary

Question	Indicator	Percentage of missing responses		
		2009	2011	2013
1.	Employment status	0.12% Self-employed, own business, working from home	0.84% Unemployed and looking for work	No missing data
2.	Highest level of education	0.47% Grade 10	3.28% Grade 10	1.21% Grade 10
3.	Sanitation	0.03% Septic tank	4.77% Flush toilet with septic tank	0.22% Flush toilet with septic tank
4.	Refuse removal	1.60% Refuse removed from the house by local authority, less often	2.21% Refuse removes from the house less often	0.42% Refuse removed from the house less often
5.	Water source	0.12% Piped - in dwelling with meter	4.56% Piped - in dwelling with standard meter	No missing data
6.	Electricity supply	0.62% Electricity with prepaid card	1.34% Electricity with prepaid card	1.76% Electricity with conventional meter
7.	Adult skips meal	0.02% No	0.47% No	No missing data
8.	Child skips meal	0.23% No	0.91% No	No missing data

9.	Closest public transport stop	32.85% From 5 to less than 10 minute walk	15.39% Up to 10 minute walk	51.72% From 11 to 12 minute walk
10.	Travel time	0.37% From 16 to 30 minutes	39.08% 45 minutes	12.05% 42 minutes
11.	Cell phone	No missing data	0.93% Yes	8.48% Yes
12.	Health prevents daily work	0.05% Hardly ever	2.34% Hardly ever	No missing data
13.	Health prevents social activities	0.02% Hardly ever	2.21% Hardly ever	No missing data

Table 3-15: Recoding SEI indicators

	Indicator	**Responses**	**Recoded response**
1.	Employment status	Informal sector employment, unemployed, school pupil/student, disabled **Formal sector employment, Self-employed, pensioner, home-maker, not wishing to work**	1 **0**
2.	Highest level of education	No education to Grade 11 **Grade 12 to Post-graduate studies**	1 **0**
3.	Sanitation	Septic tank, ventilated pit latrine, basic pit latrine, chemical toilet, communal toilet, neighbours, bush, bucket, no toilet **Full waterborne (Flush toilet)**	1 **0**
4.	Refuse removal	Removal by local authority from community refuse container, placed on communal refuse dump but not collected by local authority, placed on own refuse dump but not collected by local authority, burnt in pit, buried, none **Refuse removed from the house by local authority at least once a week or less often**	1 **0**
5.	Water source	Piped – yard taps, street taps (standpipes), borehole/well, rainwater tank, flowing river/stream, dam, water truck **Piped – in dwelling with meter, with no meter or prepaid meter**	1 **0**
6.	Electricity supply	Connection to neighbour's electrified house **Electricity with conventional meter or prepaid card, solar or wind generators, generators, petrol or diesel generators**	1 **0**
7.	Adult skips meal	Yes **No**	1 **0**

8.	Child skips meal	Yes **No**	1 **0**
9.	Closest public transport stop	A 10 minute walk or longer **Less than a 10 minute walk**	1 **0**
10.	Travel time	Greater than 60 minutes **60 minutes or less**	1 **0**
11.	Cell phone	No **Yes**	1 **0**
12.	Health prevents daily work	Always, some of the time **Hardly ever, never**	1 **0**
13.	Health prevents social activities	Always, some of the time **Hardly ever, never**	1 **0**

Table 3-16: SEI dimensions and corresponding weights

Dimensions	Indicators	Weights
1. Employment	Employment status	0.143
2. Education	Highest level of education	0.143
3. Infrastructure	Sanitation	0.036
	Refuse removal	0.036
	Water source	0.036
	Electricity supply	0.036
4. Food security	Adult skips meal	0.143
5. Transport	Closest public transport stop	0.071
	Travel time	0.071
6. Connectivity	Cell phone	0.143
7. Health limitations	Health prevents daily work	0.143

Figure 3-25 contrasts the SEI determined for the GCR with that determined only using the QoL survey respondents residing in Soweto, a subset of which was used in the difference-in-differences analysis. Both the GCR and Soweto social exclusion indices follow the same trend, where the lowest levels of exclusion are observed in 2009 and the highest are observed in 2011, however, the Soweto SEI was higher than the GCR SEI.

The discernible drawback of the construction technique of the index is that due to the recoding mechanism, the index fails to capture the extent of the "favourable" or "unfavourable" circumstances. For example, by recoding to a value of 1 for the highest level of education, it implies that a respondent has completed grade 11 or lower. It can be said that a respondent who has received grade 11 education is "better off" than a respondent who has received no education at all, however, the index does not capture this. For the purpose of this study, where this index is not the primary objective, the method of construction used was deemed to be sufficient.

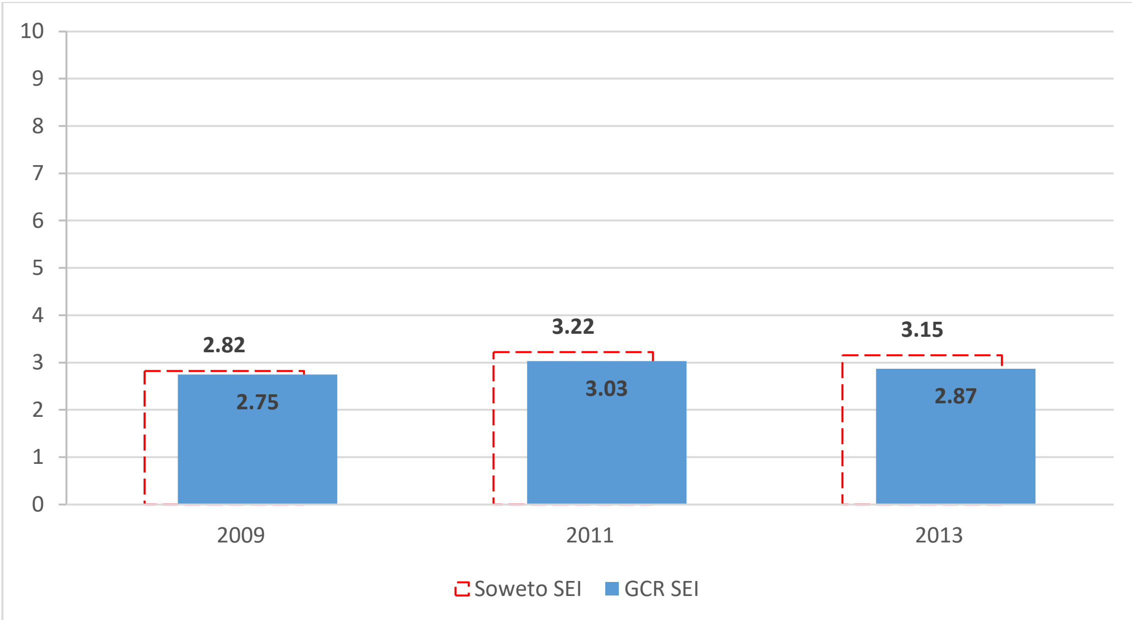

Figure 3-25: SEI: Soweto and the GCR

3.6 SUMMARY

The access envelope technique of accessibility mapping was used to determine the accessibility to jobs from townships in the CoJ. The necessary input data was sourced for all three analysis years, and assumptions were made with regards to the time-related change of some of this data to allow for a reasonable time-series analysis. A difference-in-differences approach was used to estimate the effect of BRT implementation in Soweto on the social welfare of Soweto residents. The measure of social welfare was *dissatisfaction*, which was determined using selected questions from the relevant QoL surveys. The methodology provided a thorough overview of the equations, statistical techniques and methodologies, with their corresponding assumptions and data limitations, used to generate and depict the results that are to follow in Chapter 4.

4 RESULTS

4.1 TIME-SERIES ANALYSIS OF ACCESSIBILITY IN THE CoJ

Figure 4-1 displays the time-series development of transport accessibility in the selected townships of the CoJ. The linear accessibility trend-line arrow for each township indicates the temporal direction of the analysis results from 2009, on the far left, to 2011 and finally 2013, on the far right.

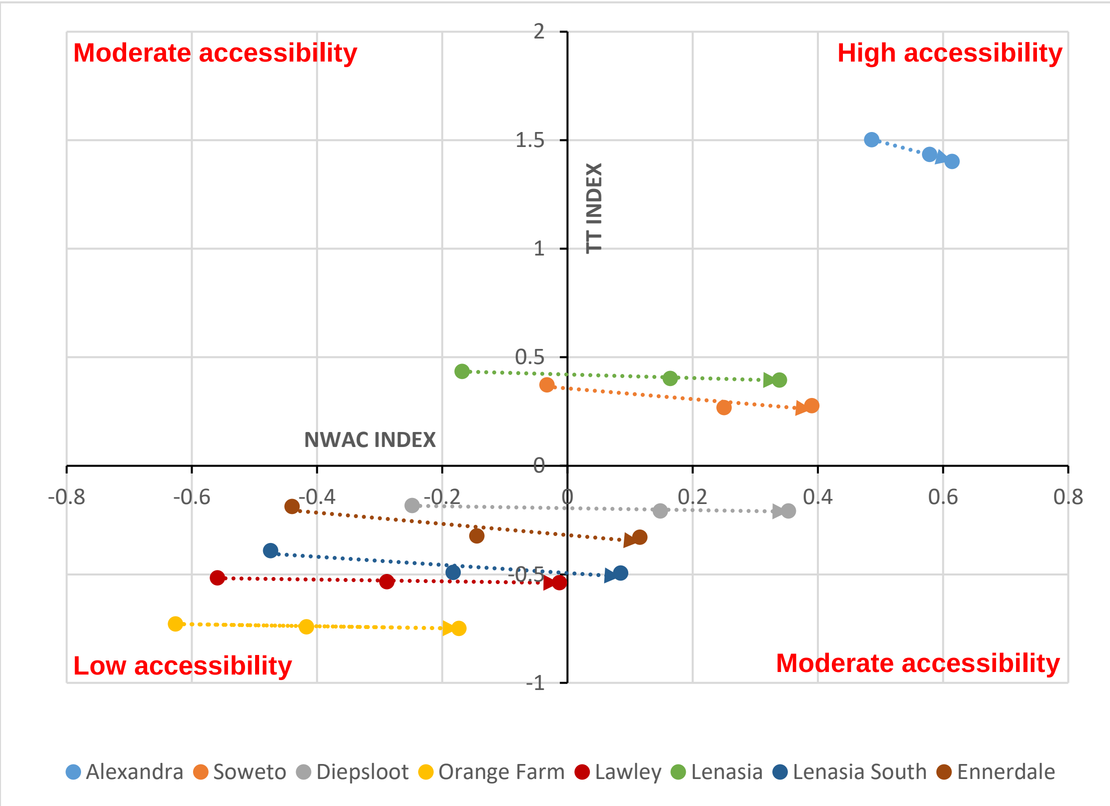

Figure 4-1: Accessibility quadrant plot

The following are the two main trends that emerge from the accessibility quadrant plot for each of the townships and methodological justifications of these observed trends:

- <u>An increase in the NWAC index from one analysis year to the next:</u> In Figure 4-1 all the townships display an increase in the number of jobs accessible while retaining a take-home pay greater than R85 per day from one analysis year to the next. This was partly driven by an increase in the average potential wages earnable from one analysis year to the next. Both the average potential wages earnable and public transport fares were adjusted with inflation from one analysis year to the next, however, the monetary increase in wages was relatively higher than the monetary increase in fares resulting in increased relative affordability of public transport to either a) commute over longer distances using the same mode or b) commute using faster, higher cost public transport modes while retaining a reasonable NWAC in both of these scenarios. Therefore, increased relative affordability of public transport translated to an increase in the number of jobs accessible while retaining a reasonable take-home pay. A series of maps that illustrates this trend is displayed in Figure 4-2 for an origin in Orange Farm, where an expansion in the geographical area for which the take home pay is greater than R85 per day is observed from one analysis year to the next.

- <u>A decrease in the TT index from one analysis year to the next:</u> In Figure 4-1, all the townships (with the exception of Soweto from 2011 to 2013) display a decrease in the number of jobs accessible within one hour of travel time from one analysis year to the next. The decrease in the TT index was partly driven by an increase in fares from one analysis year to the next which resulted in an increase in a) the number of walking commuter trips, and b) the distance over which walking was the mode that maximised the NWAC, thus decreasing the overall number of jobs accessible within one hour. A series of maps that illustrates the second point above is displayed in Figure 4-3 for an origin in Alexandra where an expansion in the geographical area of walking commuter trips is observed from 2009 to 2013 from the same origin.

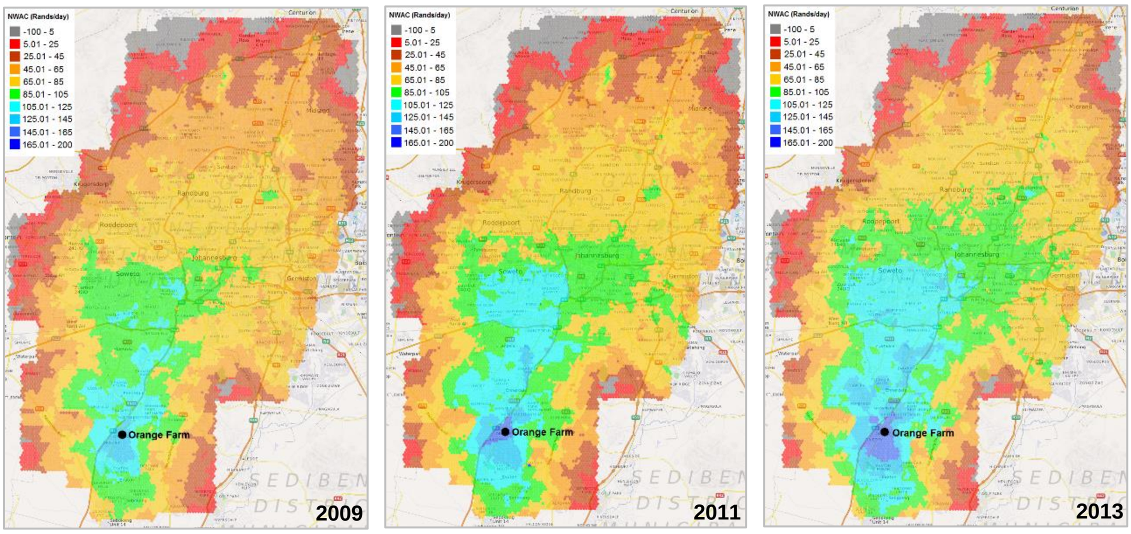

Figure 4-2: Change in NWAC surface from 2009 to 2013: Orange Farm

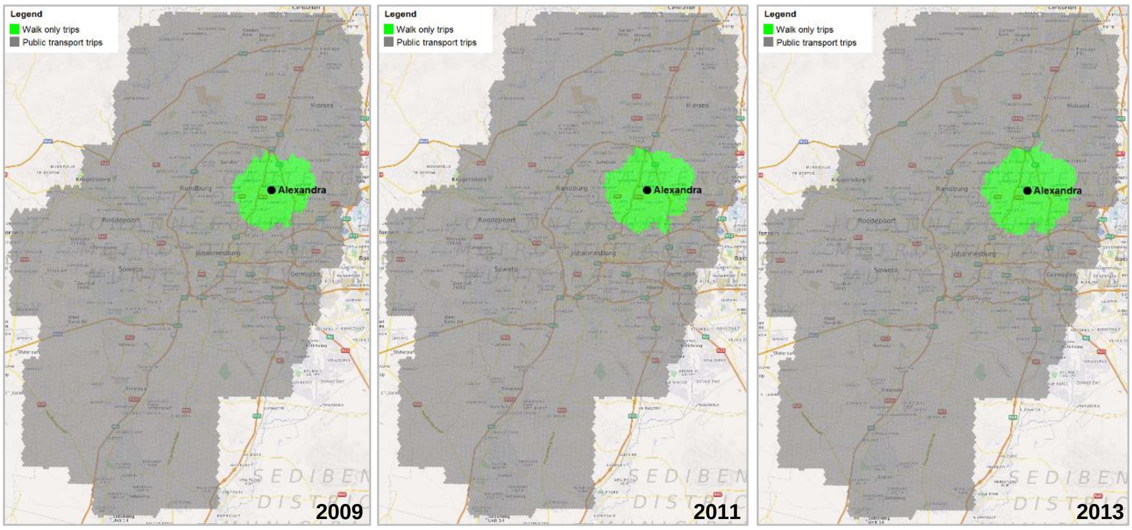

Figure 4-3: Increase in distance of NWAC maximising walking commutes from 2009 to 2013: Alexandra.

The observed trends stated above are further corroborated by Figure 4-4 for a selected origin in Orange Farm and Soweto from 2009 to 2013. The Orange Farm trend in which there was a shift towards NMT trips as fares and wages increased from one analysis year to the next was observed for all other origins on the study surface, the only exception being origins in Soweto from 2011 to 2013 as a result of a shift towards the BRT instead. A trip, in this case, is defined as the movement from one zone to the other, therefore as the number of zones remained constant throughout the analysis period, so did the total number trips possible. Therefore, Orange Farm displayed a 2% increase in walking trips (equivalent to approximately 382 trips) from one analysis year to the next while Soweto displayed no change in walking trips from 2011 to 2013. This shift towards NMT modes as NWAC maximising modes is as a result of the mode selection process of the access envelope technique to maximise the take-home pay at every given location, and the results are somewhat consistent with the findings of the 2011 QoL survey that revealed that most low-income groups resort to NMT modes, not by choice, but because public transport is not affordable and/or it is not easily accessible (Gotz et al., 2014).

Figure 4-4 also displays that the NWAC maximising mode for more than 80% of the trips from the selected origins was the minibus taxi, which literature has shown to be the most widely used public transport mode in the city (CoJ, 2013). However, although the minibus taxi was the NWAC maximising mode for majority of the trips from origins in both Soweto and Orange Farm, these two townships still fall on opposite ends of the accessibility spectrum with Soweto being a high accessibility township and Orange Farm being a low accessibility township (See Figure 4-1). This implies that the distribution of opportunities relative to where the urban poor reside could lead to the perpetuation of disparities in job accessibility even amongst users of the same public transport mode simply because these users reside in different locations relative to the economic nodes of the city, consistent with findings of Guzman et al. (2014). This suggests that transport interventions without the associated Transit-Oriented Development may not lessen accessibility disparities between high and low accessibility areas.

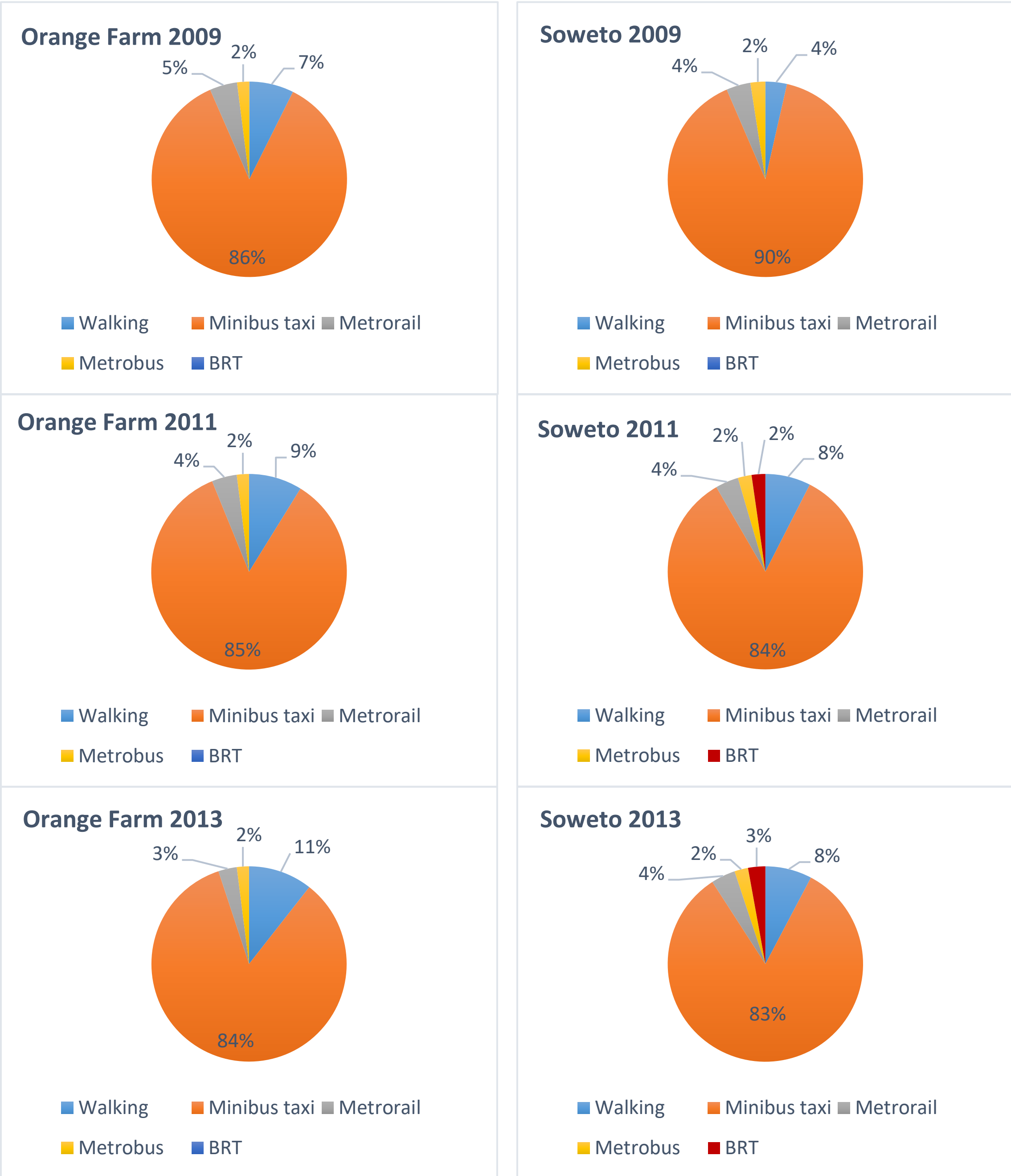

Figure 4-4: NWAC maximising modal split: Orange Farm and Soweto

As stated in the observed trends in Figure 4-1, the increase in the relative affordability of public transport manifests itself in an increase in the average trip distance of the trips that retain a reasonable take-home pay. The percentage increase in this trip distance from 2009 to 2011 and from 2011 to 2013 from a selected origin in each township is reflected in Table 4-1.

Table 4-1: Temporal change in average trip distance for trips that retain NWAC > R85/day

	2009 to 2011			2011 to 2013		
	Average trip length 2009 (km)	Average trip length 2011 (km)	% change	Average trip length 2011 (km)	Average trip length 2013 (km)	% change
Alexandra	25	26	5%	26	27	3%
Soweto	23	26	12%	26	28	8%
Diepsloot	25	29	19%	29	31	7%
Orange Farm	24	29	20%	29	32	11%
Lenasia	24	28	16%	28	30	6%
Lawley	25	29	18%	29	32	11%
Lenasia South	25	29	18%	29	32	11%
Ennerdale	23	26	15%	26	30	12%

The average trip distance for trips that resulted in a reasonable take-home pay was between 23km and 32km from 2009 to 2013, somewhat consistent with the average trip lengths reported by the urban poor residing in the peripheries who travel more than 25km on average to look for work. What is evident in Table 4-1 is the diminishing return of increased relative affordability of public transport from one analysis year to the next in terms of average trip length. The percentage change in average trip length decreased from one time interval to the next albeit the fares and wages increased by the same percentage from 2009 to 2011 and from 2011 to 2013.

4.2 CLASSIFICATION OF TOWNSHIPS

As this was a time-series analysis, the results of some townships traverse two quadrants in Figure 4-1. Therefore, to allow for classification of the townships, the accessibility from a township was defined by a specific quadrant if two or more points, pertaining to the township in question, were plotted in that quadrant. The classification of the townships, based on Figure 4-1, is mapped in Figure 4-5.

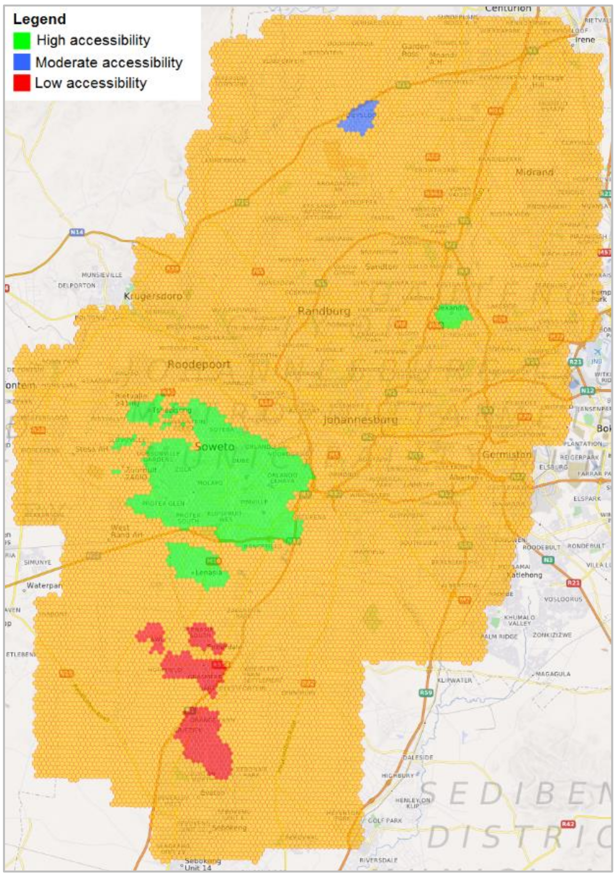

Figure 4-5: Accessibility quadrant classification map

4.2.1 High accessibility townships

The three most centrally located townships in the CoJ (Alexandra, Soweto and Lenasia) plot in the high accessibility quadrant in Figure 4-1, with Alexandra reporting the highest accessibility levels of the three. During the apartheid era, residents of Alexandra successfully resisted relocation to the peripheries of the city (Todes, 2012), subsequently remaining on "well-located" land, which, according to the results, allows them accessibility to all the major economic nodes of the city while retaining a reasonable NWAC. However, Figure 4-1 and Table 4-2 display that the effect of increasing relative affordability of public transport on the NWAC index is not as pronounced for Alexandra as it is for the other townships. In Table 4-2, the selected origin in Alexandra displays relatively low percentages of change in average trip length, in comparison to the other origin zones particularly from 2009 to 2011, with a relatively low associated change in the number of jobs accessible with NWAC greater than R85 per day.

Table 4-2: Temporal change in average trip length and associated accessibility change

	2009 to 2011		**2011 to 2013**	
	% change in average trip length	**Increase in number of jobs accessible with NWAC > R85/day**	**% change in average trip length**	**% change in number of jobs accessible with NWAC > R85/day**
Alexandra	5%	145,691	3%	55,719
Soweto	12%	452,785	8%	261,297
Diepsloot	19%	898,385	7%	261,756
Orange Farm	20%	514,806	11%	558,494
Lenasia	16%	590,450	6%	206,741
Lawley	18%	655,637	11%	489,420
Lenasia South	18%	701,669	11%	460,196
Ennerdale	15%	600,563	12%	501,816

For a high accessibility township like Alexandra, an increase in the relative affordability of public transport generally allowed for longer commutes towards the peripheries of the CoJ while retaining a reasonable take-home pay, see Figure 4-6 which displays the development of the NWAC surface for a selected origin in Alexandra over the analysis period. With fewer job opportunities located in the peripheries, this only had a minimal effect on accessibility, in terms of the NWAC index. This illustrates that improving accessibility to regions with limited economic activity will have an equally limited effect on the accessibility patterns of a region. In addition, this suggests that the marginal benefits of improving the accessibility from regions with already high levels of accessibility are relatively low, the latter being consistent with the findings of López (2007) and Axhausen (2008).

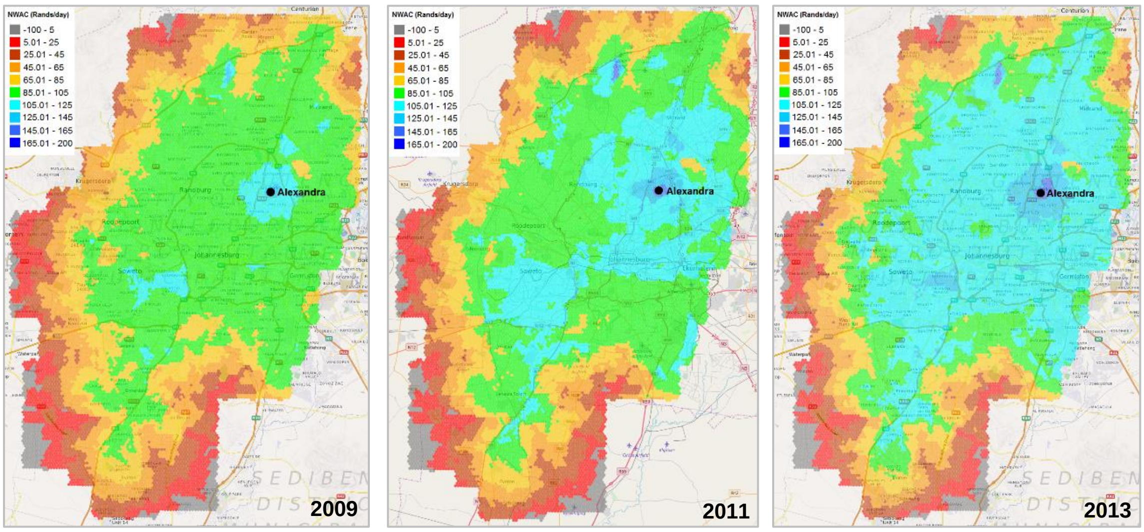

Figure 4-6: Change in NWAC surface from one analysis year to the next: Alexandra

Soweto and Lenasia reported similar accessibility trends, see Figures 4-7 and 4-8. However, Lenasia displayed marginal superiority in the TT index relative to Soweto and Soweto displayed marginal superiority in the NWAC index relative to Lenasia for each analysis year. Soweto's locational advantage is slightly greater than that of Lenasia, as it is closer to the CBD and decentralised economic nodes to the north, therefore reporting higher NWAC values due to shorter travel times and lower fares to reach these economic nodes. Looking within each township, on average, there were 220 job opportunities per zone in Soweto over the analysis period and the mean of the average potential daily wage earnable per zone was within the range of R126 and R150 from 2009 to 2013. In Lenasia, there were 119 job opportunities per zone on average, and the mean of the average potential daily wage earnable per zone was within the range of R114 and R137 from 2009 to 2013. This suggests that Soweto is more economically active that Lenasia on the zonal level. Post-1994, Soweto has experienced increased public investment, which ultimately attracted private investment in developing economic nodes within the township, some of the largest of these nodes being Baralink, Kliptown and Jabulani. The former two are public investments, however, the development of Jabulani towards being Soweto's CBD, with mixed land-use, was driven by a significant private investment in the Jabulani Mall which was opened in 2006 (Harrison & Harrison, 2014). Therefore, this increased investment in the economic development of Soweto could have led to the presence of more and "better" (in terms of average potential wages earnable) economic opportunities within Soweto, relative to Lenasia. This could, in turn, have resulted in more and longer walking commutes within Soweto, to maximise the take-home pay, thus reducing the overall number of jobs accessible within one hour of travel time from Soweto origins relative to Lenasia origins.

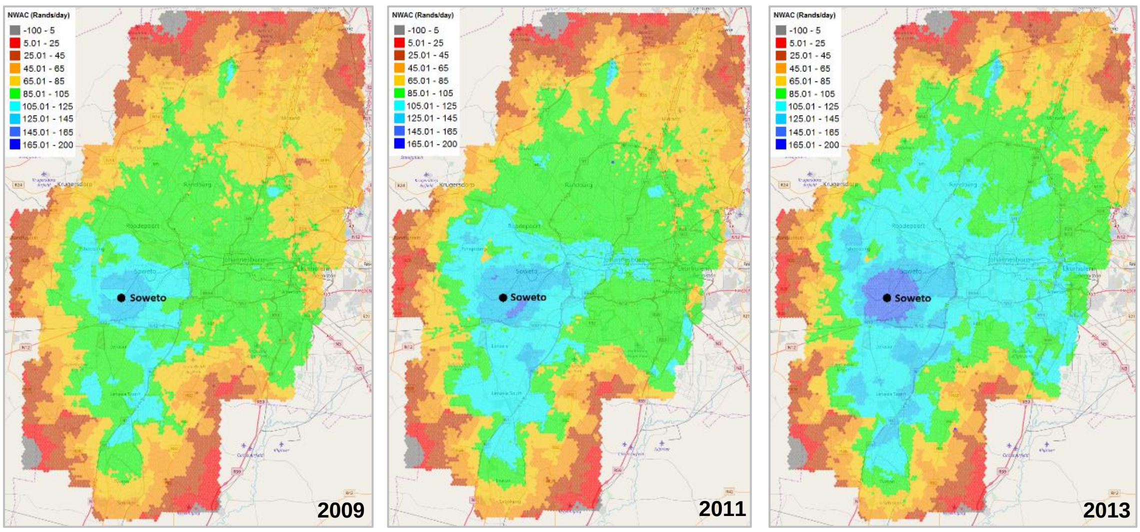

Figure 4-7: Change in NWAC surface from one analysis year to the next: Soweto

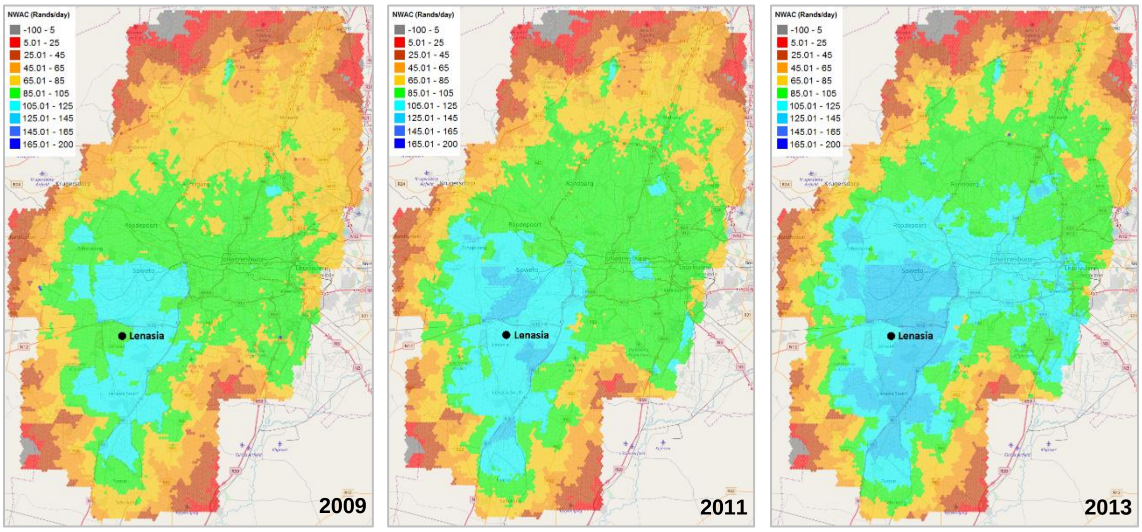

Figure 4-8: Change in NWAC surface from one analysis year to the next: Lenasia

Soweto is the only township that displayed a deviation from the TT index trend from 2011 to 2013; instead of decreasing, this index increased from 0.27 in 2011 to 0.28 in 2013. This is attributed to the speed improvement (over NMT and rail) that was provided by the BRT at a lower cost than both the Metrobus and minibus taxi in 2013. Therefore, the BRT ensured that even as fares increased, TT accessibility did not decrease. Figure 4-9 displays the TT accessibility surface from an origin in Soweto in 2011 versus the TT accessibility surface from the same origin in 2013. The red concentric circles in Figure 4-9 2011 approximate regions for which walking was the mode that maximised the take-home pay from the selected origin. The first concentric circle (smallest radius) indicates regions accessed by walking from the origin within the travel time budget. The annulus of the concentric circles (typically the grey band between the two green regions) indicates regions also accessed by walking in order to maximise the take-home pay, however, the travel time to these regions exceeded 60 minutes from the origin in 2011. However, a notable greening of the grey annulus in Figure 4-9 2013 suggests that the BRT provided a feasible alternative to walking in 2013 particularly for walking trips that exceeded the travel time budget in 2011. This is somewhat consistent with findings of Venter and Vaz (2014) that the BRT is a popular mode of transport for trips within Soweto, particularly work trips. The BRT also provided a feasible alternative for motorised trips towards the Johannesburg inner city from the selected origin, this is indicated by the areas in the blue circles in Figure 4-9. However, an increase of 0.01 in the TT index, which is equivalent to 6,653 jobs, is fairly insignificant.

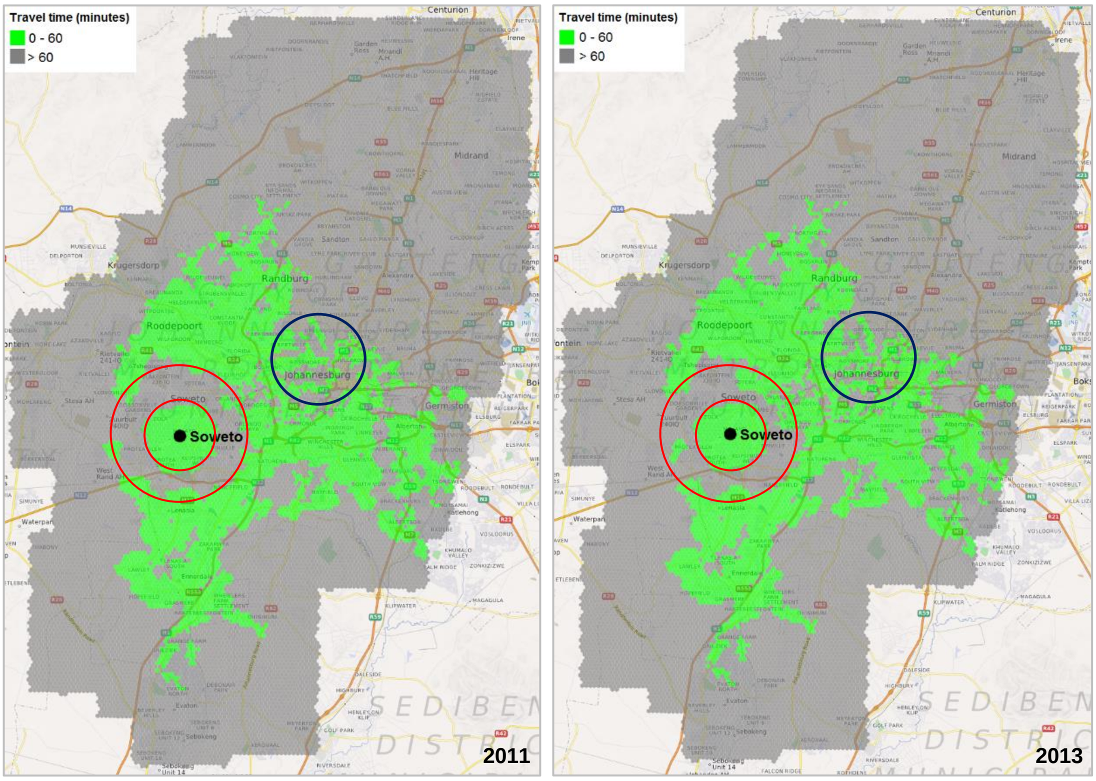

Figure 4-9: TT accessibility surface: Soweto 2011 and 2013

When the BRT was introduced to the CoJ, it was competing with relatively robust public transport systems (the minibus taxi in particular), which had large catchment areas in comparison to the BRT. The BRT also served an already well-served route, which is the Soweto - CBD route, thus duplicating existing services with no real integration between the public transport modes. There were efforts towards milder forms of integration through the process of restructuring the minibus taxi network at the advent of the BRT planning process when 300 former minibus taxi operators surrendered their minibus taxis to the city for scrapping, in exchange for roughly R50,000 to buy a stake in the company that would operate the Rea Vaya Phase 1A. Consequently, former minibus taxi drivers became employed as Rea Vaya drivers (Mokonyama & Mubiwa, 2014). At the advent on the TransMilenio in Bogotá which operates on a feeder trunk approach similar to Rea Vaya, there was major restructuring and reorganising of existing public transport routes and fares to leverage the BRT service. Therefore, the implementation of the BRT in Bogotá, which is now one of the most widely recognised BRT services in the world due to its reported success in combatting congestion, pollution and significantly decreasing travel times, did not only affect the served community, but it extended to the wider community (Combs, 2017). Table 4-3 compares Bogotá to the CoJ as well as their BRTs (Scorcia & Munoz-Raskin, 2017), and the figures clearly depict the difference in urban densities and average BRT trip lengths which, in South Africa, the low densities and long trip lengths are as a result of historic spatial planning, presenting an intrinsic challenge to the efficient operation of the BRT in the CoJ context. If major restructuring efforts were undertaken in Bogotá, a city whose urban form and travel patterns are more favourable to the success and efficiency of BRT operations than the CoJ is, it suggests that perhaps merely removing a few hundred minibus taxis from the network in the CoJ to leverage the BRT service may not have been sufficient to observe a significant effect of BRT implementation on the accessibility patterns in the CoJ.

Table 4-3: CoJ and Rea Vaya compared to Bogotá and TransMilenio

	Bogotá	**Johannesburg**
Urban density (thousand inhabitants per km^2)	13.5	2.7
Average BRT trip length (km)	12	27

Although the BRT was fully operational from February 2011, the Rea Vaya Phase 1A did not have a notable effect on accessibility patterns from 2009 to 2011. This is partly attributed to the flat fare structure employed by the BRT in 2011, in which the use of both the trunk and feeder resulted in the payment of a fare higher than that of the minibus taxi and the Metrobus, over certain distances. Therefore, in 2011, the BRT was a relatively expensive mode and thus rarely the NWAC maximising mode.

In 2011 and 2013, Soweto is the only one of the eight townships served by all four public transport modes in the city, however, the highest accessibility results were not observed from origins in this township. This points towards the inefficacies of public transport investments that duplicate the routes of existing services or serve already well-served corridors, such as the Soweto – CBD corridor in the CoJ, with regards to significantly improving accessibility patterns.

4.2.2 Moderate accessibility townships

Diepsloot is the only township classified as a moderate accessibility township. Although it is as far removed from the Johannesburg CBD as what Orange Farm is (roughly 40km), it boasts of significantly higher accessibility levels than Orange Farm. This is attributed to Diepsloot’s geographical location relative to the major decentralised economic nodes of the city located to the north of the Johannesburg CBD, namely; Sandton, Midrand and Rosebank. This illustrates the value of decentralisation, suggesting that in this context, the accessibility patterns of townships in the peripheries can be significantly improved by merely improving transport affordability without any major investment in transport infrastructure, depending on the overall desired outcome. Figure 4-10 displays the change in the NWAC surface from one analysis year to the next from a selected origin in Diepsloot.

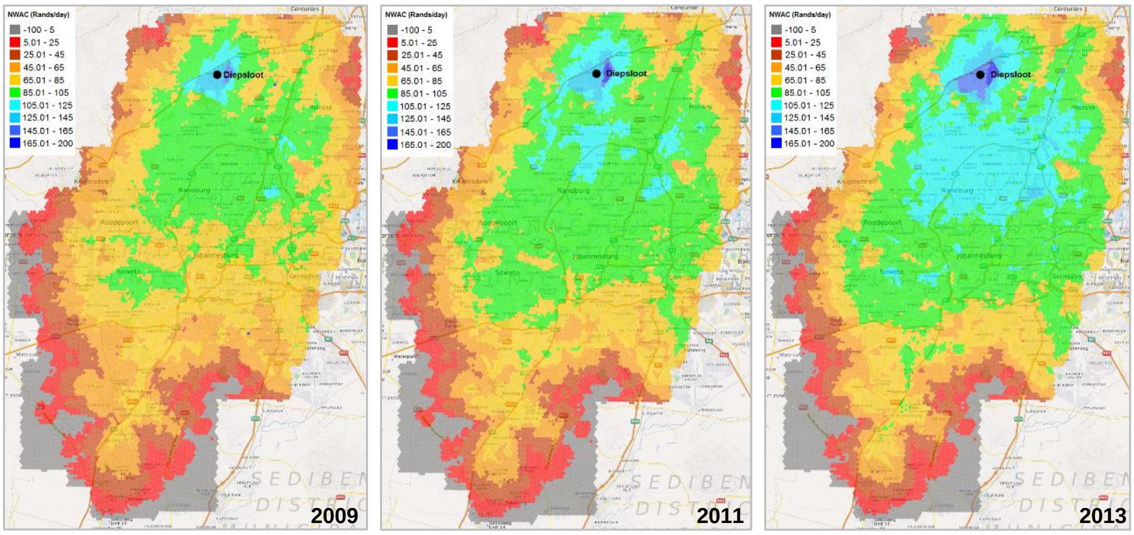

Figure 4-10: Diepsloot NWAC surface (2009, 2011 and 2013)

4.2.3 Low accessibility townships

Four townships were classified as low accessibility townships, namely: Ennerdale, Lenasia South, Lawley and Orange Farm. All of these townships are located to the south of Lenasia in the CoJ, a region where economic opportunities are not as abundant as they are in the north of the city. Residents of these townships travel 35km to 45km to access the CBD, and even greater distances to access the major decentralised economic nodes to the north of the CBD. Although all four of these townships are served by the low-fare Metrorail (unlike Alexandra and Diepsloot), the uncompetitive travel times offered by the train service as well as its limited connectivity to decentralised economic nodes resulted in large travel time penalties for trips originating from the South to the CBD and beyond using this mode, therefore the Metrorail was rarely the NWAC maximising mode from these origins.

The increase in the relative affordability of public transport resulted in longer commutes, allowing access to a larger geographical area while retaining a reasonable take-home pay, particularly towards the North, which significantly increased the NWAC index for these townships. Figure 4-11, Figure 4-12 and Figure 4-13 display the NWAC surface from one analysis year to the next from selected origins in Ennerdale, Lenasia South and Lawley, respectively. The NWAC surface temporal change for Orange Farm is reflected in Figure 4-2.

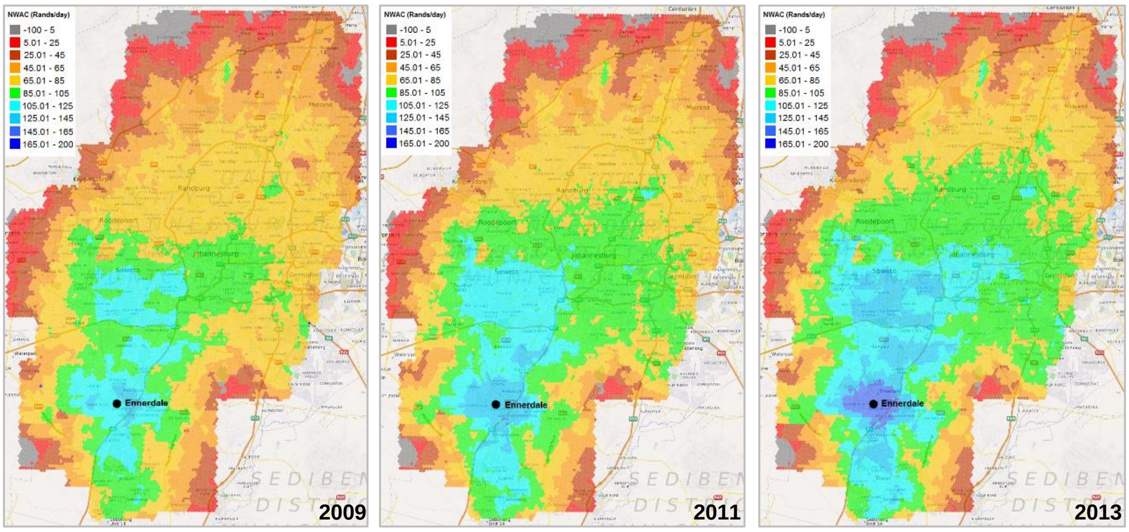

Figure 4-11: Ennerdale NWAC surface (2009, 2011 and 2013)

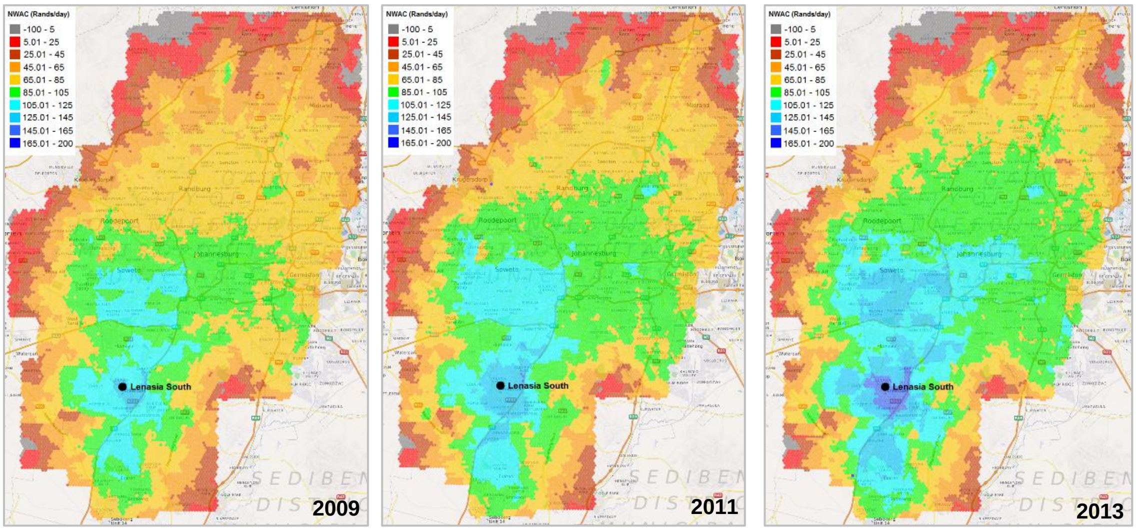

Figure 4-12: Lenasia South NWAC surface (2009, 2011 and 2013)

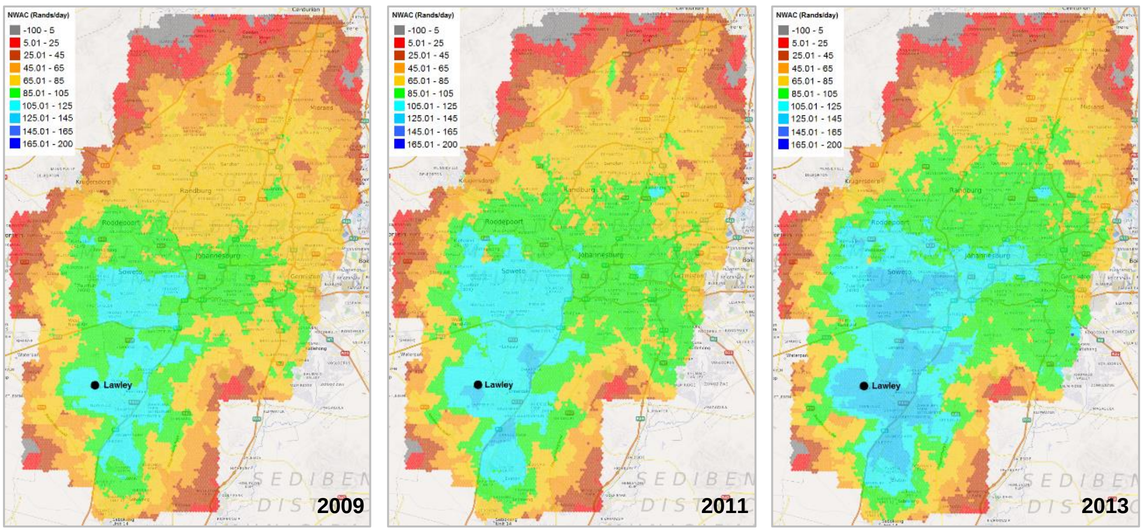

Figure 4-13: Lawley NWAC surface (2009, 2011 and 2013)

4.3 DISTRIBUTION OF ACCESSIBILITY

Figures 4-14 and 4-15 suggest that an increase in the relative affordability of public transport led to increased uniformity of the distribution of accessibility within each of the townships. The most significant improvement in accessibility distribution is observed for Diepsloot, reiterating the value of improved relative affordability of public transport, particularly if it is on the backdrop of the inherited locational advantage from the decentralisation of economic nodes to the north of the city.

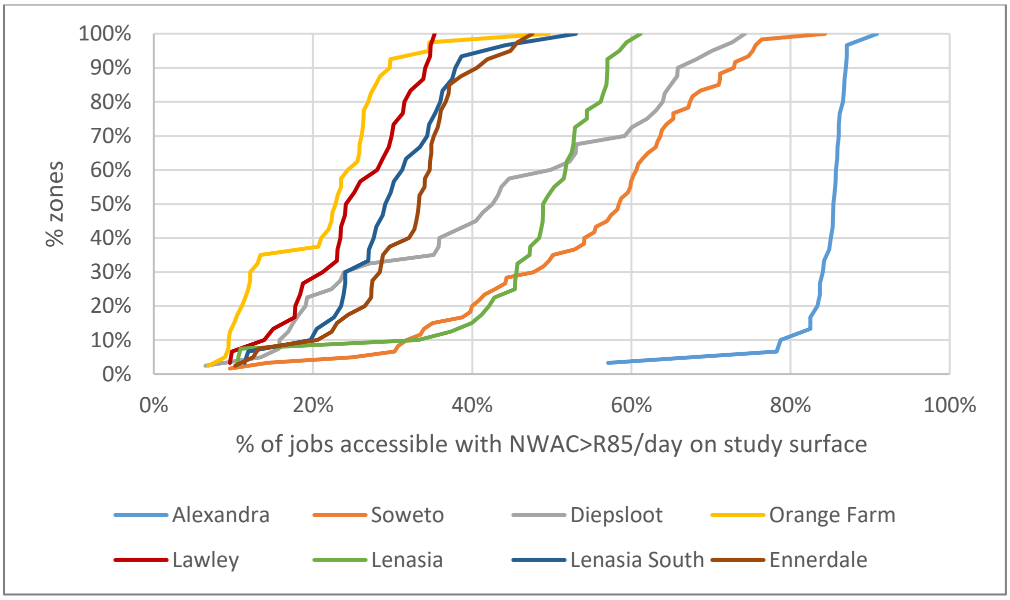

Figure 4-14: Distribution of accessibility within townships: 2009

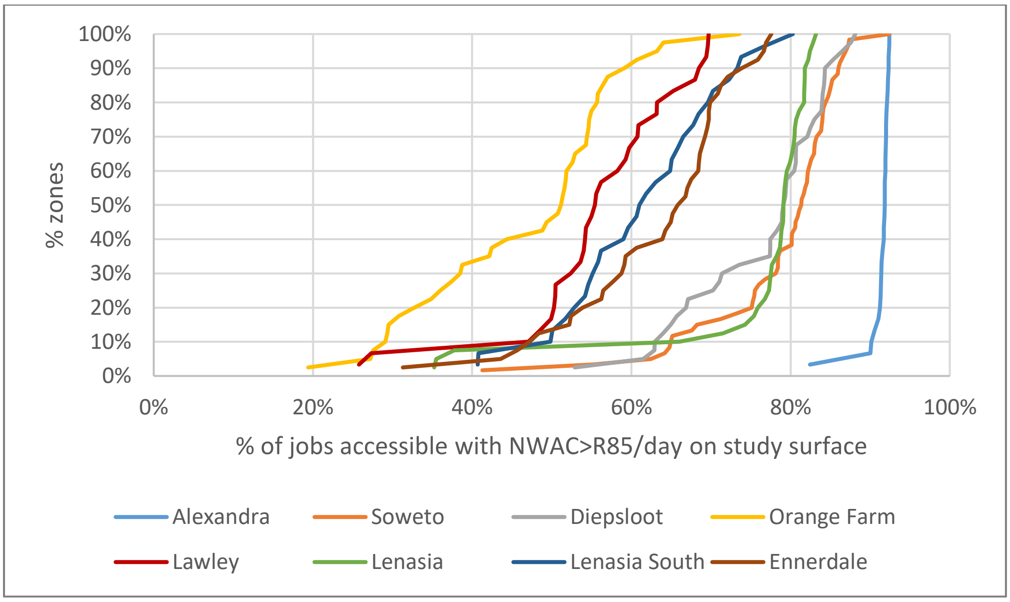

Figure 4-15: Distribution of accessibility within townships: 2013

Table 4-4 displays the uniformity index of each township which is expressed as the quotient of the average accessibility of the lowest 25% of accessibility measures and the average accessibility of the total sample for each township, see chapter 3.4.2. In Alexandra in 2013, the average accessibility of the bottom 25% of origin zones (in terms of accessibility) is just 2% shy of the computed average accessibility in the township. Alexandra not only has the highest level of accessibility but also the most uniform distribution of accessibility suggesting more equitable accessibility in regions with high accessibility. A number of factors could affect the distribution of accessibility within a township, these include: the size of the township, the geographical location of the township relative to the major economic nodes in the city, the modes that serve the township, and the relative affordability of these modes.

Table 4-4: Uniformity index from 2009 to 2013

Township	**Uniformity index 2009**	**Uniformity index 2013**	**Percentage change in uniformity index**
Alexandra	0.93	0.98	5.4%
Soweto	0.58	0.84	45%
Diepsloot	0.37	0.83	124%
Orange Farm	0.46	0.62	35%
Lawley	0.58	0.77	33%
Lenasia	0.63	0.80	27%
Lenasia South	0.64	0.79	23%
Ennerdale	0.63	0.76	21%

4.4 ACCESSIBILITY AND SOCIAL WELFARE

Table 4-5 reflects the results of the difference-in-differences negative binomial regression model. The parameter alpha in the last row of the table is the over-dispersion parameter, and it is clear that this parameter is significant at the 0.05 significance level, making the negative binomial regression model the more suitable model for this count data in comparison the Poisson regression model. In Table 4-5, the parameter estimates are interpreted as follows: for example, the parameter estimate of the variable $year$ is -0.4409. This means that for every unit increase in the variable $year$, the log count of the dependent variable dissatisfaction decreases by 0.4409. Typically, to aid interpretation of the results of such a regression model, the Incidence Rate Ratio (IRR) of each variable is determined through the exponentiation of the parameter estimates in Table 4-5.

Table 4-5: Negative binomial regression model results

Parameter	Variables	Estimate	Standard error	t Value	Pr > |t|	Lower 95% Confidence Limit	Upper 95% Confidence Limit
β_0	$intercept$	0.5553	0.2139	2.6	0.0098	0.1348	0.9757
β_1	$year$	-0.4409	0.1355	-3.25	0.0012	-0.7072	-0.1745
β_2	BRT	0.1561	0.1934	0.81	0.42	-0.224	0.5363
β_3	$PT\ user$	-0.3464	0.1281	-2.7	0.0071	-0.5982	-0.0945
β_4	SEI	0.1198	0.02544	4.71	<.0001	0.06982	0.1698
β_5	Acc	0.01877	0.009077	2.07	0.0392	0.000929	0.03661
β_6	$year.BRT$	0.04079	0.1919	0.21	0.8318	-0.3364	0.418
β_7	$BRT \cdot PT\ user$	0.01474	0.1743	0.08	0.9327	-0.3279	0.3574
β_8	$BRT \cdot AccBRT$	-0.07631	0.03437	-2.22	0.027	-0.1439	-0.0087
α	$alpha$	0.1366	0.04866	2.81	0.0052	0.041	0.2323

The equations for the exponentiation of the parameter estimates in Table 4-5 to determine: a) the IRR of each variable, b) the standard error of the IRR, c) the lower 95% confidence limit of the IRR and d) the upper 95% confidence limit of the IRR are displayed in equations 4-1, 4-2, 4-3 and 4-4, respectively.

$$IRR_i = e^{\beta_i} \tag{4-1}$$

$$IRRSE_i = IRR_i \cdot SE_i \tag{4-2}$$

$$IRRLCL_i = e^{LCL_i} \tag{4-3}$$

$$IRRUCL_i = e^{UCL_i} \tag{4-4}$$

Where:

IRR_i – Incidence rate ratio of variable *i*

$IRRSE_i$ – Standard error of IRR_i

SE_i – Standard error of the β_i in Table 4-5

$IRRLCL_i$ – Lower 95% confidence limit of IRR_i

LCL_i – Lower 95% confidence limit of β_i in Table 4-5

$IRRUCL_i$ – Upper 95% confidence limit of IRR_i

UCL_i – Upper 95% confidence limit of β_i in Table 4-5

The equations above are only applied to the coefficients of the independent variables, thus excluding the intercept and the over-dispersion parameter alpha. After exponentiation of the beta parameters, the results of the regression model are as displayed in Table 4-6. Excluding the intercept and the alpha parameter, all variables that had a statistically significant effect on the count variable are highlighted in green in Table 4-6.

Table 4-6: Results of negative binomial regression with IRRs of variables

Parameter	Variables	IRR	Standard error	t Value	Pr > |t|	Lower 95% Confidence Limit	Upper 95% Confidence Limit
β_0	$intercept$	0.555	0.214	2.600	0.010	0.135	0.976
β_1	$year$	0.643	0.087	-3.250	0.001	0.493	0.840
β_2	BRT	1.169	0.226	0.810	0.420	0.799	1.710
β_3	$PT\ user$	0.707	0.091	-2.700	0.007	0.550	0.910
β_4	SEI	1.127	0.029	4.710	<.0001	1.072	1.185
β_5	Acc	1.019	0.009	2.070	0.039	1.001	1.037
β_6	$year.BRT$	1.042	0.200	0.210	0.832	0.714	1.519
β_7	$BRT \cdot PT\ user$	1.015	0.177	0.080	0.933	0.720	1.430
β_8	$BRT \cdot AccBRT$	0.927	0.032	-2.220	0.027	0.866	0.991
α	$alpha$	0.137	0.049	2.810	0.005	0.041	0.232

The IRR of a variable is interpreted as follows: a positive or increasing effect on the count variable will be indicated by an IRR greater than 1, while a negative or decreasing effect is indicated by an IRR less than 1. For example, the IRR of the variable *SEI* is 1.127 which indicates an increasing effect on the count variable such that a unit increase in the *SEI* results in a 12.7% increase in dissatisfaction, while the IRR of the variable *PT user* is 0.707 indicating that the dissatisfaction of frequent public transport users was 29.3% less than that of those who were not frequent public transport users. The effect of each statistically significant variable on dissatisfaction, expressed as a percentage, is determined as follows:

$$E_i = (IRR_i - 1) \cdot 100 \qquad (4\text{-}5)$$

Where:

E_i – The effect, expressed as a percentage, of a unit increase in variable *i* on the count variable

IRR_i – The IRR of variable *i*

Table 4-6 displays that five of the eight variables had a statistically significant effect, at the 0.05 significance level, on dissatisfaction. Table 4-7 reflects the effect of a unit increase in each of these variables on dissatisfaction in the column titled *Effect*.

Table 4-7: The effect of a unit increase in the independent variables on dissatisfaction

Parameter	Variables	IRR	Standard error	Lower 95% Confidence Limit	Upper 95% Confidence Limit	Effect
β_0	$intercept$	0.555	0.214	0.135	0.976	-
β_1	$year$	0.643	0.087	0.493	0.840	-36%
β_3	$PT\ user$	0.707	0.091	0.550	0.910	-29%
β_4	SEI	1.127	0.029	1.072	1.185	13%
β_5	Acc	1.019	0.009	1.001	1.037	1.9%
β_8	$BRT \cdot AccBRT$	0.927	0.032	0.866	0.991	-7.3%
α	$alpha$	0.137	0.049	0.041	0.232	-

The results, as depicted in Table 4-6 reveal that of the individual independent variables, meaning those that are not interaction variables, BRT had no statistically significant relationship with the count variable, dissatisfaction. This suggests that there was no statistically significant difference between the control and treatment group pre-BRT implementation. This is corroborated by the Mann-Whitney U-test in chapter 3.5.1.

According to the IRR of the variable *year*, respondents in 2013 were 36% less dissatisfied than respondents in 2009, ceteris paribus. This could be due to general changes that took place over the 2009 to 2013 time period. There was significant investment in Soweto post-2000 from all spheres of government in an attempt to restructure the township by providing adequate amenities, housing, electricity, malls and places of leisure. Some of this investment was driven by the 2010 FIFA World Cup hosted in South Africa which required the upgrade of two stadiums within Soweto and the upgrade of a premier stadium just adjacent to the township; this is believed to have had spin-off benefits for the Soweto and its residents (Harrison & Harrison, 2014), possibly contributing to a reduction in dissatisfaction from 2009 to 2013.

The *PT user* IRR reveals that respondents who were frequent public transport users were 29% less dissatisfied than respondents who were not frequent public transport users, ceteris paribus. The 2011 QoL survey revealed that most low-income groups resort to NMT modes, not by choice, but because public transport is not affordable and/or it is not easily accessible (Gotz et al., 2014). This suggests inadequacies in the public transport systems in the CoJ with regards to serving the urban poor as well as their mobility and accessibility needs at a price affordable to them. According to Giuliano (2005), car ownership as a result of inadequate public transport services amongst lower-income households may result in an increased financial burden as necessities such as car maintenance are sacrificed in an attempt to meet mobility needs.

Therefore, resorting to NMT modes due to unaffordability or inaccessibility of public transport services or private vehicle ownership due to inadequacies of public transport supply has adverse effects on low-income groups and this could be the reason frequent PT users were less dissatisfied than non-frequent PT users. The β_7 parameter for the variable $BRT \cdot PT\ user$ is not statistically significant, indicating that post-treatment, there is no statistically significant difference between frequent PT users in the treatment group relative to those in the control group, taking into account pre-existing differences between the treatment and control group and pre-existing differences between frequent PT users and non-frequent PT users. Therefore, frequent PT users are less dissatisfied than non-frequent PT users, ceteris paribus, but there is no statistically significant evidence that this is due to proximity to the BRT post-BRT implementation. This may be due to the inefficacies of the BRT through its duplication of existing services along an already well-served route, thus not making a notable change to pre-existing accessibility patterns.

The IRR of the variable SEI, has a statistically significant effect on dissatisfaction. As expected, a unit increase in social exclusion, as defined by the index delineated in chapter 3.5.3 which comprises of factors that include employment and infrastructure and basic services available in a respondent's household, resulted in a 13% increase in dissatisfaction, ceteris paribus.

A counterintuitive result would be the *Acc* IRR of 1.019 as it suggests that a unit increase in the number of jobs accessible within one hour of travel time results in a 2% increase in dissatisfaction. Given that a unit increase in accessibility in this case is equivalent to an increase of 100,000 jobs, the 2% increase in dissatisfaction observed as a result of that unit increase can be considered negligible. Although this result is considered negligible, it could suggest that perhaps there is an optimum level of accessibility, beyond which this creates uncomfortable spaces to travel in and increased competition for services (Owen et al., 2017). This could also suggest that perhaps there is a difference between measured increases in accessibility and how a user experiences and/or perceives these increases, ultimately creating a disparity between the expected and actual implications of improved computed accessibility on the social welfare of the beneficiaries.

β_6 is the main parameter of interest as it estimates the effect of the treatment, taking into account pre-existing differences between the treatment and control group, as well as general changes over time. As indicated in Table 4-6, the treatment effect is not statistically significant, therefore the effect of BRT implementation on the social welfare of the served community (the treatment group) was not statistically significant. This could be due to the aforementioned shortcomings of the BRT such as the duplication of existing and more robust systems with larger catchment areas serving an already well-served route, as well as the provision of limited accessibility in comparison to the more widespread networks. This finding is somewhat consistent with findings in Latin America, particularly Santiago de Cali, Colombia where the BRT, which was implemented in 2009, improved the efficiency of public transport as a whole but this did not translate to wider social impacts such as a reduction in social exclusion. It is further consistent with findings of Venter and Vaz (2014) in which they observed the community members' perceptions of the Rea Vaya BRT, particularly in Orlando, Soweto where construction of the BRT was accompanied by upgrades to streets and the general service area of the routes. They found that although the community had positive perceptions of the service, there was no significant indication that proximity to the service improved their overall satisfaction. It was found that satisfaction was primarily driven by other factors such as housing and employment. However, β_8 reveals that a unit (equivalent to 100,000 jobs) increase in the computed accessibility afforded by the BRT results in a small but statistically significant 7.3% reduction in dissatisfaction for the treatment group relative to the control group, taking into account pre-existing differences between the treatment and control group. Based on the computed BRT accessibility values, an increase in the accessibility offered by the BRT improves the welfare of those within close proximity to the service more than it does the wider community, however, the experience of accessibility gains is only possible through actual use of the service. This suggests that: a) the accessibility gains offered by the BRT have the potential to improve the welfare of the served community (the treatment group), however, this does not extend equally to members of the community further removed from the service, and b) the social welfare benefits of the BRT are associated with the use of the service. This suggests that the BRT in Johannesburg is beneficial as a transport project with its associated improvements in accessibility, but not as a general urban intervention able to equitably improve the overall amenity of community members that do not reside within close proximity to the service and make use of it. Perhaps welfare benefits to the wider community will become evident as modal shifts from private vehicles to the BRT occur, reducing congestion on the roads, as well as through the densification of mixed land-use development and redistribution of opportunities along the trunk and feeder lines, each of which will take longer to manifest.

4.5 POLICY ALIGNMENT

4.5.1 Local and global development transport policy and agendas

The research reinforces the importance of making the improvement of accessibility a key policy and planning objective, both locally and globally, for land passenger or urban transport, as this research observes statistically significant evidence of wider social impacts as a result of accessibility improvements, particularly through the regression analysis in this study. However, further research is required to determine whether there is an optimum level of accessibility beyond which the marginal social benefits of accessibility improvements not only decrease but cease to be evident all together.

An accessibility measure such as the NWAC, which explicitly accounts for costs as a measure of travel impedance, is particularly relevant in the South African context where there is a pressing challenge of unaffordability of public transport services. This measure, once calibrated, can be used by planners to observe the marginal accessibility benefits of improved affordability of various modes, particularly for low-income groups, towards meeting Goal 11 of the United Nations (UN) Sustainable Development Goals (SDGs) (2015) and one of the transport infrastructure visions of the National Development Plan (2012) to provide affordable transport.

Goal 11 of the SDGs, focused on improving the safety, reliability, sustainability and inclusivity of human settlements, states the following: "By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all... notably by expanding public transport, with special attention to the needs of those in vulnerable situations…" The construction of the BRT, which is providing a public transport service superior to pre-existing services in terms of the quality of service, facilities, safety (NATMAP, 2016) and affordability (to some extent), was indeed an expansion of the public transport system in the CoJ and came with its accessibility benefits. However, the first phase of this system (Phase 1) will be linking economic hubs with high accessibility regions (refer to Figure 4-1), such as Soweto (Phase 1A and Phase 1B) and Alexandra (Phase 1C). Ultimately, the BRT aims to "place over 85% of the metropolitan city's population within 1km of an integrated rapid public transport network trunk or feeder route", where integrated rapid public transport networks refer to the BRT and rapid rail networks and feeder systems made up of both NMT and other motorised modes. However, there are two immediately apparent challenges with this development approach. The first being that by the BRT initially serving high accessibility townships, in the interim, this risks deepening the accessibility disparity between high and low accessibility townships, thus moving further away from providing equal access to opportunities for all. The second challenge is based on the evidence of decreasing marginal benefits of accessibility gains from regions with already high levels of accessibility. Amongst other shortcomings of the BRT, this may hamper the effectiveness of the service in significantly improving accessibility patterns of the served communities. This, together with the lack of integration of, and subsequent competition between the public transport modes in the city, present a challenge in meeting the New Urban Agenda (2017) vision of providing public transport that is effective in "… linking people, places, goods, services and economic opportunities". It is possible that the implementation of Rea Vaya may have been more effective in terms of altering accessibility patterns of the urban poor if implementation had begun by linking low accessibility regions to the economic nodes of the city, increasing the inclusivity of members of these communities in the social and economic fabric of the city and incentivising decentralisation towards the south of the city along the trunk line through Transit-Oriented Development. However, this would also present its own challenges that ought to be innovatively mitigated, regarding the efficient and feasible operation of the service if it is to remain affordable to users and government over long distances such as the roughly 45km distance between Orange Farm and the CBD. The mitigation strategies could include partial trunk sections, avoiding exorbitant construction costs which may result in higher fares from the construction of a dedicated bus lane along the entire trunk line. Alternatively, the use of existing modes as feeders to the BRT trunk line with the payment of a single fare, which could potentially make the trunk line shorter if the feeders can operate over longer distances. Furthermore, with the PRASA modernisation project underway, which will result in upgrades of the Metrorail service, Rea Vaya buses could become feeders to the low fare Metrorail that serves the townships located in the South of the city. This would be a step towards the integration of modes called for in the Reconstruction and Development Programme (1994), the White Paper on National Transport Policy (1996) and the National Development Plan (2012). The challenge in this regard is the nuance that must be given to integration in the South African context, where formal and informal services, which do not offer the same quality of service, will most likely be required to cooperate to improve the performance of the public transport system as a whole. The BRT brought with it mild forms of integration between the minibus taxi industry and the BRT when a few hundred minibus taxis were scrapped and affected minibus taxi operators became part of the formal economy as Rea Vaya bus operators, however, this approach alone does not appear to be a sustainable approach particularly due to the difficulty of regulating the route competition (NATMAP, 2016). However, this integration approach meets the New Urban Agenda (2017) allowing minibus taxi drivers to transition from the informal to formal employment arena and enjoy the benefits of formal employment thereof.

The lack of integration between the motorised public transport modes in the city produced results in which the NWAC maximising mode/s were either walking only or walking and a single motorised mode. This was driven by a lack of fare integration between the modes which results in the payment of an additional fare for each modal transfer. It may also be attributed to the lack of coordination between the schedules and routes of the various modes. An additional strength of the NWAC lies in its ability to allow decision makers to visualise the accessibility impacts of various integration strategies, including fare integration strategies, such as single-ticketing called for in the White Paper on National Transport Policy (1996).

4.5.2 Housing policy

The Reconstruction and Development Programme (1994) and Breaking New Ground (2004) call for the integration of spatial planning, housing delivery and transport planning in South Africa as a means to developing sustainable human settlements. Although housing delivery has been in effect since 1994, it has been criticised for perpetuating the apartheid spatial planning on the challenging backdrop of increasing urbanisation and rapid population growth (BNG, 2004; Todes, 2012; CoJ, 2013). Breaking New Ground (2004) calls for the necessity of government to locate and acquire "well-located" public and private land for housing delivery as areas to develop sustainable human settlements. "Well-located" land refers to that which is within close proximity to economic and social activities and services, with adequate access to public transport services, ultimately reducing travel times to opportunities cities. The Access Envelope Methodology and its ability to disaggregate the accessibility from a single region could assist, not only in spatial and transport planning, but also in housing supply by identifying these "well-located" areas relative to various economic and social opportunities.

4.6 SUMMARY

The discussion of the results unpacked the trends observed in the time-series analysis of accessibility, revealing some findings that are consistent with previous literature as well as alignments with local and global policy, programmes and plans of action. The findings include the Alexandra results that revealed that the marginal benefits associated with improving accessibility from a region with already high levels of accessibility are low. This then gives rise to concerns about the Rea Vaya Phase 1C line, which will run from the CoJ CBD, through Alexandra to Sandton, and its expected benefits to a region like Alexandra with already high levels of accessibility. In the work of Guzman et al. (2016), it is found that the concentration of economic opportunities in certain areas of a region reinforces the distribution and provision of public transport in those areas. This is no different in the CoJ and the staged implementation of the BRT in which the first phase is concentrated around the areas of high economic activity. With townships, such as Orange Farm in the southern peripheries, which are gravely dislocated from the major economic nodes of the city, this is likely to deepen disparities in terms of accessibility equity, which, at this stage, presents a challenge to meeting one of the visions of the New Urban Agenda (2017) by the United Nations to provide equal access for all to spatially distributed opportunities. However, we do observe adherence to global and local policy, particularly with regards to the expansion of the public transport system with the introduction of the Rea Vaya which resulted in some form of modal integration as minibus taxis along the planned BRT routes were scrapped and affected minibus taxi drivers absorbed into the operation of the BRT, moving these drivers from an informal to formal economy.

The results displayed the importance of decentralisation of economic activities and opportunities towards the improvement of accessibility patterns, particularly if the urban poor reside in the peripheries. The access envelope technique, which deliberately includes public transport fares as a measure of travel impedance, produced results that suggest that affordability should not be divorced from accessibility, particularly in the context of Gauteng cities such as the CoJ, which rank as the least affordable cities in Africa in terms of transport affordability as commuters spend 21% of their monthly income on transport (OECD, 2011).

From 2011 to 2013, the BRT increased the number of jobs accessible within 60 minutes from Soweto, however, this effect was fairly insignificant due to the stated shortfalls of the service, such as operating on a well-served route in competition and not in complementation with larger existing services. Although the BRT did expand the public transport system of the city, it was not particularly effective in terms of significantly improving or altering the accessibility patterns of the urban poor. This could be the reason there is no evidence of a statistically significant effect of BRT implementation on the social welfare of the served community in this study. The conclusions that follow in Chapter 5 will delineate all the findings associated with the corresponding objectives of this study and provide recommendations for both future research and transport policies.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The access envelope methodology was applied to: a) examine the time-series development of accessibility to jobs from selected townships in the CoJ, b) determine the extent to which the BRT contributed to changes in accessibility patterns and c) assess the impact of transport investment in the BRT in Johannesburg on the social welfare of Soweto residents.

Pertaining to the time-series development of accessibility to jobs from selected townships in the CoJ, the results revealed an increase in the number of jobs accessible from one analysis year to the next due to the increased relative affordability of public transport as a result of a larger monetary increase in wages relative to fares. This increased relative affordability of public transport generally permitted longer commutes within the city while retaining a reasonable take-home pay. However, the time-series analysis revealed a diminishing return of accessibility gains. This suggests that there will come a point when the marginal benefits of improving accessibility from regions with already high levels of accessibility are relatively low and this is clearly illustrated by the temporal accessibility changes from origins in Alexandra, the township with the highest accessibility figures. With an increase in the relative affordability of public transport from 2009 to 2011, the average trip distance to opportunities that retain a reasonable take-home pay increased by more than 10% for all township origins except Alexandra, which only increased by 5% (this decreased to 3% from 2011 to 2013), and the associated increase in the number of jobs accessible while retaining NWAC greater than R85 per day was also significantly lower than the values observed for the other township origins. This also suggests that for regions like Alexandra which are "well-located" in close proximity to the major economic nodes of the city relative to the other townships, improving accessibility to regions with limited economic activity will have an equally limited effect on accessibility patterns of this region. The reverse also holds true and it is clearly depicted by the low accessibility townships located in the south of the CoJ. An increase in the relative affordability of public transport increased trip lengths towards the economic hubs in the north and this had a significant effect on the accessibility patterns of these regions. However, under the current distribution of opportunities in the city, the townships located south of Lenasia are significantly disadvantaged in terms of job accessibility in comparison to those closer to the economic hubs.

The value of this analysis lies in its ability to inform whether or not accessibility is actually improving over time, as required by policy and informing, within the parameters of the measure, how accessibility can be improved even in the absence of transport investments. However, we do observe two accessibility summary measures that depict contrasting behaviour over time, making it challenging to conclusively state whether or not accessibility improved over the analysis years, with the exception of Soweto from 2011 to 2013. This suggests that the reported results are sensitive to the accessibility summary measures utilised and further research is necessary, particularly in terms of calibrating the tool to gain a deeper understanding of the behaviour of these two summary measures on the ground.

The results revealed that as the NWAC accessibility increased, so did the uniformity of the distribution of this accessibility within each region, and the region with the highest accessibility levels also displayed the most equitable distribution of accessibility. This could suggest that improvements in the accessibility to opportunities from a region also improves the equity of the accessibility distribution within that region. This also highlights the value in disaggregating the results from various regions as this allows one to observe the variation that exists within each region, not only between the regions.

The results also revealed the value of decentralisation in changing accessibility patterns in a region like the CoJ. Decentralisation of economic nodes allowed previously disadvantaged areas in the peripheries improved accessibility to key economic activities without the need for any considerable transport investment, simply by improving the relative affordability of the existing widespread public transport modes, this was illustrated by the Diepsloot results. Although Diepsloot, located in the northern peripheries, is as far removed from the CBD as what Orange Farm in the southern peripheries is, an increase in the relative affordability of public transport on the backdrop of the decentralisation of economic nodes towards the north of the city, resulted in Diepsloot reporting the largest observed increase in the NWAC index from 2009 to 2011, doubling the number of jobs accessible while retaining a reasonable take-home pay. This suggests that public transport interventions alone, may not efficiently correct the wrongs of apartheid spatial legacy. These interventions should be followed by deliberate transit-oriented development along major routes, decentralising the economic activity of the city towards the urban poor residing in the peripheries.

In a polycentric region like the CoJ, the highest levels of accessibility were observed for regions within close proximity to all economic nodes, not only the CBD. Therefore, in polycentric regions which grapple with poor modal integration, fixation on providing increased accessibility to an already well accessible CBD could potentially result in only minimal improvements in accessibility. Therefore, pertaining to the second objective, the notion aforementioned is supported by the computed accessibility values after the advent of the Rea Vaya BRT Phase 1A which operates between Soweto and the CoJ CBD. Generally, the results revealed a decreasing trend in the number of jobs accessible within 60 minutes from one analysis year to the next, however, Soweto displayed a deviation from this trend from 2011 to 2013 with the number of jobs accessible within 60 minutes increasing by 6,653 jobs, on average, instead of decreasing. This could be attributed to the speed improvement over NMT and rail provided by the BRT at a lower cost than the minibus taxi and Metrobus in 2013, thus providing an affordable alternative to walking trips within the township and motorised trips towards the CBD along the trunk route. However, this increase in TT accessibility from Soweto from 2011 to 2013 amounted to a 1% increase in TT accessibility, which is fairly insignificant, and this could be attributed to the lack of integration between the public transport modes in the city. On transport integration in the CoJ, Mokonyama and Mubiwa (2014) hold the view that: “For the city to be able to provide a world-class public transport system, public transport has to transcend the modes”. When the BRT was implemented it was competing against robust and widespread public transport networks with much larger catchment areas, in addition to that, it was serving a route already well-served by the pre-existing public transport modes. Perhaps greater efforts to integrate these modes would leverage the BRT to achieve one of the city’s mandates for the service which is to improve the accessibility of all residents to employment opportunities (CoJ, 2013). The challenge in this regard is the nuance that must be given to integration in the South African context, where formal and informal services will most likely be required to cooperate to effectively improve the performance of the public transport system as a whole. However, this is a necessary step to meeting local planning policies and programmes.

The evidence, in this research and previous research, of the decreasing marginal benefits of improving accessibility from regions with already high levels of accessibility raises concerns regarding the implementation of the first phase of the Rea Vaya BRT in Johannesburg. This is an expansion of the public transport system providing safe and affordable transport, it also comes in tandem with infrastructure upgrades along the routes in the townships it serves, thus in line with Goal 11 of the Sustainable Development Goals (United Nations General Assembly, 2015). However, based on the results, the service is ineffective in terms of significantly improving accessibility, one of the reasons being that it is attempting to do so from regions with already high levels of accessibility to the city’s CBD. This is likely to be perpetuated in the implementation of Phase 1C of the Rea Vaya which will run between Alexandra, a region with high levels of accessibility, and the CBD, potentially resulting in similarly underwhelming results in improving accessibility patterns of those residing in Alexandra.

Pertaining to the effect of the implementation of the BRT on the social welfare of Soweto residents, the regression model revealed that in terms of dissatisfaction, there was no statistically significant difference between those within close proximity to the BRT and those further out, before implementation. Furthermore, although respondents were less dissatisfied in 2013 than they were in 2009, there was no statistically significant evidence that this decrease in dissatisfaction was due to the BRT, particularly for those within close proximity to the service. This is consistent with findings of Venter and Vaz (2014) that although residents had positive perceptions of the service in Orlando, Soweto, there was no evidence that the service significantly contributed to the satisfaction of the community. It is also somewhat consistent with findings in Latin America, particularly Santiago de Cali, Colombia where the BRT, which was implemented in 2009, improved the efficiency of public transport as a whole but this did not result in any evidence of wider social impacts such as a reduction in social exclusion (Jaramillo et al., 2012). This suggests that further research is required to determine the contribution of the benefits of transport investments towards the perceived social welfare of served communities, and furthermore, whether this differs across income groups. Perhaps, for lower-income groups, other factors outweigh the benefits of transport investments with regards to significantly affecting their perceived welfare. Over and above that, social welfare is a subjective measure of well-being thus making it susceptible to large variation depending on a number of different factors that cannot always be accounted for and adaptation as one becomes accustomed to a certain way of life. What may be imperative to accurately capture the wider social benefits of transport investments is the collections of panel data that studies the social welfare of the same households over an extended period of time, as well as the factors that contribute to changes in their welfare.

The results also revealed that frequent public transport users were less dissatisfied than non-frequent public transport users, ceteris paribus. However, there was no statistically significant evidence that this was due to proximity to the BRT. This suggests that the service, as it was implemented on the backdrop of robust, widespread pre-existing systems, did not contribute significantly to the welfare of those who were even more likely to use the service.

There was no evidence of a decrease in dissatisfaction due to increased accessibility, ceteris paribus. However, when isolating the accessibility provided by the BRT, there was evidence that an increase in the accessibility offered by the service improved the welfare of those within close proximity to the service, however, this did not extend equally to members of the community further removed from the service. This suggests that the BRT in Johannesburg is beneficial as a transport project for those who reside within close proximity to the service and make use of it for the accessibility it provides within its service corridor, but it is not necessarily beneficial as a general urban intervention able to equitably improve the overall amenity of both the served and the larger community. Although minimal, accessibility did have an effect on social welfare, suggesting that perhaps a more immediate shift towards the use of accessibility as project evaluation criteria is more likely to achieve the social objectives of sustainable development such as the improvement in the quality of life of community residents.

With regards to metrics, the results suggest that in terms of metrics, proximity to public transport type of accessibility measures (such as distance to a BRT station) are not likely to adequately reflect benefits as experienced by communities; accessibility measures taking the actual generalised travel cost and distribution to opportunities into account are more powerful in this regard.

5.2 RECOMMENDATIONS

The following sub-chapters will provide a list of policy and research recommendations for future research based on the analysed results and conclusions of this research.

5.2.1 Policy recommendations

The policy recommendations are as follows:

- Restructuring of existing services, particularly the minibus taxi, is required to leverage the performance of the BRT in the CoJ, however, the restructuring must be skilfully executed so as to not leave the urban poor worse off than they were before. The consideration of using the minibus taxi industry to densify the feeder network of the BRT could be an option moving forward, and a step towards real modal integration and fare integration strategies that improve the affordability of public transport and subsequently improve accessibility. The Access Envelope Technique, once calibrated, can be used to analyse the accessibility impacts of various integration strategies across modes.
- Robust tools that assess the performance of land-use and transport policies must not be divorced from the implementation process of policy as well as policy reviews, so as to facilitate discussions around the effectiveness of policy over its implementation period.
- Considering decentralisation of economic nodes as a tool to improve accessibility of the urban poor residing in the peripheries.
- Consistent and accurate transport and land-use data collection should be a policy requirement and this data should be made available in the public domain to allow for such research to commence and produce reliable results that are up to date.
- Urging transport planners and decision makers that in pursuit of improved accessibility to public transport services and subsequently to opportunities, a cut-off point must be determined, that is a point of enough accessibility, which could potentially allow for earlier redistribution of transport investments and subsequently opportunities to more transport disadvantaged areas.

5.2.2 Research recommendations

The research recommendations are as follows:

- Evaluating the distribution of accessibility, not only across geographical locations but also across different income groups to gain an in-depth understanding of accessibility equity across these different groups within a study region, and to identify the extent of the accessibility disparity between the average high and low-income commuter.

- The access envelope technique requires an extensive amount of fairly accurate data to produce sound results, therefore it is necessary to firstly collect this data frequently and secondly to run a sensitivity analysis on some of the input parameters, such as the speed factors, fare structures and the reasonable take-home pay threshold, to determine the extent to which the results differ based on variations in the input data. This will facilitate in the development and refinement of the tool to assess the performance of land-use and transport policies, as well as to assist with housing delivery programmes which require the identification and acquisition of "well-located" land. The availability of up to date and robust public transport and land-use data is increasingly becoming essential for accessibility analysis and obtaining such data for the CoJ was a challenge. Therefore, it is necessary to collect public transport data, not just networks, but all the applicable routes and schedules as well as land-use data in order to allow for more robust analyses in the future. The frequent collection of land-use data is equally as imperative as this allows observations of accessibility implications of densification of opportunities and mixed land-use development along routes or around stations.
- The development of robust tools to measure the wider social impacts of public transport investment, as perceived by the users and the overall served community starting with the collection of panel data.
- Consider accessibility across the entire GCR particularly due to the volume of commutes that occur between the metropolitan municipalities of the city-region. This could provide a different perspective of the accessibility patterns, particularly of those who reside in the peripheries of the cities.
- There may be value in not only exploring the level of accessibility offered by public transport from selected origins but also the quality of accessibility. Quality, in this instance, refers to measures of comfort, safety, reliability, environmental impacts, the degree of universal access as well as other factors that may influence a rider's perception of, willingness and ability to use public transport services. This will also provide an idea of how transport development continues to meet the UN's SDGs (2015) and the White Paper on National Transport Policy (1996). Over and above that, it could provide an idea of how the global trend of rapid urbanisation affects how users experience public transport services.
- Calibration of the methodology to validate its use as a transport and land-use planning tool. This is a crucial step towards the use of accessibility measures for project evaluation and decision making. This is particularly applicable to the NWAC which, due its transparent

computation and understandable unit of measurement (Rands/day), can be easily interpreted by non-technical groups in comparison to more complex measures that either make use of exponential deterrence functions or introduce more complex parameters such as competition for opportunities.

6 REFERENCES

ABEYASEKERA, S., 2005. Chapter 18 Multivariate methods for index construction. *Household Surveys in Developing and Transition Countries: Design, Implementation and Analysis.* New York: United Nations, pp. 367-387.

AFRICAN NATIONAL CONGRESS, 2004. *The Reconstruction and Development Programme: A Policy Framework*. South Africa: African National Congress.

ANDREASEN, M.H. and MØLLER-JENSEN, L., 2017. *Access to the city: Mobility patterns, transport and accessibility in peripheral settlements of Dar es Salaam.*

AHMED, A. and STOPHER, P., 2014. Seventy minutes plus or minus 10. *Transport reviews,* **34**(5), pp. 607-625.

ANDELMAN, R., BOARD, R., CARMAN, L., CUMMINS, B., FERRISS, A., FRIEDMAN, P., MICHALOS, A., SAMLI, J., SHAPIRO, S., SIRGY, J., VITTERSO, J. and VEENHOVEN, R., 1998. *Quality of Life Definition and Terminology: A discussion document from The International Society of Quality-of-Life Studies.* The International Society of Quality-of-Life Studies.

AXHAUSEN, K., 2008. Accessibility: Long-term perspectives. *Journal of Transport and Land Use,* **1**(2), pp. 5-22.

BALLARD, R., HABIB, A., VALODIA, I. and ZUERN, E., 2005. Globalization, Marginalization, and Contemporary Social Movements in South Africa. *African Affairs,* **104**(417), pp. 615-634.

BALOGUN, O., 2008. The Idea of an 'Educated Person' in Contemporary African Thought. *The Journal of Pan African Studies,* **2**(3), pp. 117-128.

BARREIRO, P.L. and ALBANDOZ, J.P., 2001. *Population and sample. Sampling techniques.* Seville: Management Mathematics for European Schools.

BEALL, J., CRANKSHAW, O. and PARNELL, S., 2000. Local government, poverty reduction and inequality in Johannesburg. *Environment&Urbanization,* **12**(1), pp. 107-122.

BEAUMONT, R., 2012. *An introduction to Principal Component Analysis & Factor Analysis Using SPSS 19 and R (psych package).*

BICKFORD, G., 2013. *Literature review on public transport and mobility in municipalities.* Johannesburg: SACN.

BOCAREJO S., J.P. and OVIEDO H., D.R., 2012. *Transport accessibility and social inequities: a tool for identification of mobility needs and evaluation of transport investments.*

BODDY, M. and PARKINSON, M., eds, 2004. *City Matters: Competitiveness, Cohesion and Urban Governance.* Bristol: The Policy Press.

BOWLING, A., 1999. Health-Related Quality of Life: A discussion of the concept, its use and measurement background: the 'quality of life', *Adapting to Change Core Course,* September 1999 1999, Penguin Books Ltd.

BURNS, L.D. and GOLOB, T.F., 1976. The role of accessibility in basic transportation choice behavior. *Transportation,* **5**(2), pp. 175-198.

CARRIGAN, A., KING, R., VELASQUEZ, J.M., RAIFMAN, M. and DUDUTA, N., 2014. *SOCIAL, ENVIRONMENTAL AND ECONOMIC IMPACTS OF BRT SYSTEMS: Bus Rapid Transit Case Studies from Around the World.* EMBARQ.

CASS, N., SHOVE, E. and URRY, J., 2005. Social exclusion, mobility and access. *Sociological Review,* **53**(3), pp. 539-555.

CERVERO, R., 2005. *Accessible Cities and Regions: A Framework for Sustainable Transport and Urbanism in the 21st Century.* California: UC Berkeley Center for Future Urban Transport: A Volvo Center of Excellence.

CERVERO, R. and KANG, C.D., 2009. *Bus Rapid Transit Impacts on Land Uses and Land Values in Seoul, Korea.* 4. Berkeley: UCB-ITS-VWP.

CHAKWIZIRA, J., 2007. The question of road traffic congestion and decongestion in the greater Johannesburg area: some perspectives, *28th Southern African Transport Conference,* 9 - 12 July 2007 2007, Document Transformation Technologies, pp. 499.

CHURCH, A., FROST, M. and SULLIVAN, K., 2000. Transport and social exclusion in London. *Transport Policy,* **7**(3), pp. 195-205.

COJ, 2013. *Strategic Integrated Transport Plan Framework for the City of Joburg.* Johannesburg: CoJ.

COJ, 2011. *Joburg 2040 - Growth and Development Strategy.* Johannesburg: CoJ.

COMBS, T., 2017. Examining changes in travel patterns among the lower wealth households after BRT investments in Bogotá, Colombia. *Journal of Transport Geography,* **60**, pp. 11-20.

CONDEÇO-MELHORADO, A., ZOFÍO, J.L. and CHRISTIDIS, P., 2017. Drivers of changes in Spanish accessibility for the 1960–2010 period. *European Transport Research Review,* **9**(2), pp. 19.

CSIR, 2000. *Guidelines for human settlement planning and design.* Pretoria: CSIR Building and ConstructionTechnology.

DALVI, M.Q. and MARTIN, K.M., 1976. The measurement of accessibility: Some preliminary results. *Transportation,* **5**(1), pp. 17-42.

DELAMATER, P., MESSINA, J., SHORTRIDGE, A. and GRADY, S., 2012. Measuring geographic access to health care: raster and network-based methods. *International Journal of Health Geographics,* **11**(15),.

DELBOSC, A. and CURRIE, G., 2011a. The spatial context of transport disadvantage, social exclusion and well-being. *Journal of Transport Geography,* **19**, pp. 1130-1137.

DELBOSC, A. and CURRIE, G., 2011b. *Exploring the relative influences of transport disadvantage and social exclusion on well-being.*

DELBOSC, A. and CURRIE, G., 2011c. *Transport problems that matter – social and psychological links to transport disadvantage.*

DEPARTMENT OF TRANSPORT, 1996. *White Paper on National Transport Policy.* Pretoria, South Africa: Department of Transport.

DOI, K., KII, M. and NAKANISHI, H., 2008. An integrated evaluation method of accessibility, quality of life, and social interaction. *Environment and Planning B: Planning and Design,* **35**(6), pp. 1098-1116.

EC, 2013-last update, Annex 5: Principal Components Analysis and the wellbeing index [Homepage of EC], [Online].
Available: http://ec.europa.eu/fisheries/documentation/studies/socio_economic_dimension/files/annex-5-pca-and-wellbeing_en.pdf [03/30, 2016].

EL-GENEIDY, A. and LEVINSON, D., 2006. Mapping accessibility over time. *Journal of Maps,* , pp. 76-87.

EVERATT, D., 2015. Quality of Life in the Gauteng City-Region, South Africa. *Social Indicators Research,* .

EVERATT, D., 2014. Poverty and Inequality in the Gauteng City-Region. In: P. HARRISON, G. GOTZ, A. TODES and C. WRAY, eds, *Changing Space, Changing City: Johannesburg After Apartheid.* 1 edn. Johannesburg, South Africa: Wits University Press, pp. 63-82.

EVERATT, D., GOTZ, G., NYAR, A., PHAKATHI, S. and WRAY, C., 2011. *The Gauteng City-Region Review 2011.* Johannesburg: Gauteng City-Region Observatory.

FALAVIGNA, C. and HERNANDEZ, D., 2016. *Assessing inequalities on public transport affordability in two latin American cities: Montevideo (Uruguay) and Córdoba (Argentina).*

FALLOWFIELD, L., 2009. *What is quality of life?* 2 edn. Hayward: Hayward Medical Communications.

FARRINGTON, J. and FARRINGTON, C., 2005. Rural accessibility, social inclusion and social justice: towards conceptualisation. *Journal of Transport Geography,* **13**(1), pp. 1-12.

FELCE, D., 1997. Defining and applying the concept of quality of life. *Journal of Intellectual Disability Research,* **41**(2), pp. 126-135.

FORD, A., BARR, S., DAWSON, R. and JAMES, P., 2015. Transport accessibility analysis using GIS: Assessing Sustainable Transport in London. *ISPRS International Journal of Geo-Information,* **4**, pp. 124-149.

FOTH, N., MANAUGH, K. and EL-GENEIDY, A.M., 2013. Towards equitable transit: Examining transit accessibility and social need in Toronto, Canada, 1996-2006. *Journal of Transport Geography,* **29**, pp. 1-10.

GARRETT, M. and TAYLOR, B., 1999. Reconsidering Social Equity in Public Transit. *Berkeley Planning Journal,* **13**, pp. 6-27.

GCRO, 2016a-last update, Quality of Life (QoL) Survey Viewer [Homepage of GCRO], [Online]. Available: http://gcro1.wits.ac.za/qolviewer/ [03/24, 2016].

GCRO, 2016b-last update, State of the Gauteng City-Region Review 2013 [Homepage of GCRO], [Online]. Available: http://2013.legacy.gcro.unomena.net/ [03/24, 2016].

GCRO, 2014. *Gauteng City-Region Observatory Annual Report 2013/4.* 1 edn. Johannesburg: GCRO.

GEURS, K.T. and VAN WEE, B., 2004. Accessibility evaluation of land-use and transport strategies: Review and research directions. *Journal of Transport Geography,* **12**(2), pp. 127-140.

GIULIANO, G., 2005. Low income, Public Transit, and Mobility. *Transportation Research Record: Journal of the Transportation Research Board,* , pp. 63-70.

GOTZ, G., ABRAHAMS, C., BOBBINS, K., CHERUIYOT, K., CHIKOZHO, C., CULWICK, C., EVERATT, D., KATUMBA, S., MUSHONGERA, D., PEBERDY, S., TRANGOS, G. and WRAY, C., 2015. *Gauteng City-Region Observatory Quality of Life Survey 2013: City Benchmarking Report.* Johannesburg: Gauteng City Region Observatory.

GOTZ, G., WRAY, C. and MUBIWA, B., 2014a. The 'thin oil of urbanisation'? Spatial change in Johannesburg and the Gauteng City-Region. In: P. HARRISON, G. GOTZ, A. TODES and C. WRAY, eds, *Changing Space, Changing City: Johannesburg After Apartheid.* 1 edn. Johannesburg, South Africa: Wits University Press, pp. 42-62.

GOTZ, G., WRAY, C., VENTER, C., BADENHORST, W., TRANGOŠ, G. and CULWICK, C., 2014b. *Mobility in the Gauteng City-Region.* Johannesburg: GCRO.

GPG, 2012. *Gauteng 2055: A discussion document on the long-term development plan for the Gauteng City-Region.* Johannesburg: GPG.

GREENBERG, S., 2010. *The political economy of the Gauteng city-region.* Johannesburg: GCRO.

GREYLING, T., 2013. *A composite index of quality of life for the Gauteng city-region: a principal component analysis approach.* Johannesburg: Gauteng City Region Observatory.

GUTIÉRREZ, J., CONDEÇO-MELHORADO, A. and MARTÍN, J.C., 2010. Using accessibility indicators and GIS to assess spatial spillovers of transport infrastructure investment. *Journal of Transport Geography,* **18**, pp. 141-152.

GUZMAN, L.A., OVIEDO, D. and RIVERA, C., 2017. *Assessing equity in transport accessibility to work and study: The Bogotá region.*

HANSEN, W.G., 1959. How Accessibility Shapes Land Use. *Journal of the American Planning Association*, **25**(2), pp. 73-76.

HARRISON, P., GOTZ, G., TODES, A. and WRAY, C., 2014. Materialities, subjectivities and spatial transformation in Johannesburg. In: P. HARRISON, G. GOTZ, A. TODES and C. WRAY, eds, *Changing Space, Changing City: Johannesburg After Apartheid.* 1 edn. Johannesburg, South Africa: Wits University Press, pp. 2-39.

HARRISON, P. and HARRISON, K., 2014. Soweto: A study of socio-spatial differentiation. In: P. HARRISON, G. GOTZ, A. TODES and C. WRAY, eds, *Changing Space, Changing City: Johannesburg After Apartheid.* 1 edn. Johannesburg, South Africa: Wits University Press, pp. 293-318.

HART, G.H.T., 1984. Urban transport, urban form and discrimination in Johannesburg. *South African Geographical Journal*, **66**(2), pp. 152-167.

HIGGS, N., 2007. Measuring and understanding the well-being of South Africans: Everyday Quality of Life in South Africa. *Social Indicators Research,* **81**, pp. 331-356.

HOUSING DEVELOPMENT AGENCY, 2014. *"BREAKING NEW GROUND" A COMPREHENSIVE PLAN FOR THE DEVELOPMENT OF SUSTAINABLE HUMAN SETTLEMENTS*. Johannesburg, South Africa: HOUSING DEVELOPMENT AGENCY.

HOWE, L., HARGREAVES, J., DE STAVOLA, B. and HUTTLY, S., 2008. *Using Principal Components Analysis to construct a wealth index.* London School of Hygiene and Tropical Medicine.

IACONO, M., KRIZEK, K.J. and EL-GENEIDY, A., 2010. Measuring non-motorized accessibility: issues, alternatives, and execution. *Journal of Transport Geography,* **18**(1), pp. 133-140.

JÜRGENS, U., DONALDSON, R., RULE, S. and BÄHR, J., 2013. Townships in South African cities - Literature review and research perspectives. *Elsevier,* (39), pp. 256-260.

KENYON, S., 2003. Understanding social exclusion and social inclusion. *Proceedings of the Institution of Civil Engineers: Municipal Engineer,* **156**(2), pp. 97-104.

KENYON, S., LYONS, G. and RAFFERTY, J., 2002. Transport and social exclusion: investigating the possibility of promoting inclusion through virtual mobility. *Journal of Transport Geography,* **10**(3), pp. 207-219.

KETT, M. and DELUCA, M., 2016. Transport and Access to Inclusive Education in Mashonaland West Province, Zimbabwe. *Social Inclusion,* **4**(3), pp. 61-71.

KOOPMANS, C., GROOT, W., WARFFEMIUS, P., ANNEMA, J.A. and HOOGENDOORN-LANSER, S., 2013. *Measuring generalised transport costs as an indicator of accessibility changes over time.*

LANDAU, L. and GINDREY, V., 2008. *Migration and population trends in Gauteng Province 1996-2055.* Johannesburg: University of Witwatersrand.

LAWTON, M.P., MOSS, M. and GLICKSMAN, A., 1990. The quality of the last year of life of older persons. *Milbank Quarterly,* **68**(1), pp. 1-28.

LITMAN, T., 2016. *Transport Affordability: Evaluation and Improvement strategies.* Canada: Victoria Transport Policy Institute.

LÓPEZ, E., 2007. *Assessment of Transport Infrastructure Plans: a strategic approach integrating environmental, efficiency and cohesion aspects.*, Universidad Politécnica de Madrid.

LUCAS, K., 2011. Making the connections between transport disadvantage and the social exclusion of low income populations in the Tshwane Region of South Africa. *Journal of Transport Geography,* **19**(6), pp. 1320-1334.

LUCAS, K., 2012. Transport and social exclusion: Where are we now? *Transport Policy,* **20**, pp. 105-113.

LUTERO, G., 2010. The aggregation problem in its historical perspective: a summary overview, *Global Conference on Agricultural and Rural Household Statistics,* 24-25 May 2010 2010, ISTAT.

MANASE, I., 2014. Everyday Experiences and Aspirations in Selected Lower Class Townships of Johannesburg. *J Hum Ecol,* **1**(47), pp. 65-72.

MARTENS, K., 2017. *Transport Justice.* 1 edn. New York: Routledge.

MARTIN, J.C. and VAN WEE, B., 2011. Guest Editorial: What Can We Learn from Accessibility Modelling? *ETJIR,* **11**(4), pp. 346-349.

MASSAM, B.H., 2002. Quality of life: Public planning and private living. *Progress in Planning,* **58**(3), pp. 141-227.

MELBYE, D.C., MØLLER-JENSEN, L., ANDREASEN, M.H., KIDUANGA, J. and BUSCK, A.G., 2015. *Accessibility, congestion and travel delays in Dar es Salaam – A time–distance perspective.*

MERVEN, B., STONE, A., HUGHES, A. and COHEN, B., 2012a. *Quantifying the energy needs of the transport sector for South Africa: A bottom-up model.* Cape Town: University of Cape Town.

MILLER, H. and WU, Y., 2000. GIS Software for measuring space-time accessibility in transportation planning and analysis. *GeoInformatica,* **4**(2), pp. 141-159.

MOBERG, D.O. and BRUSEK, P.M., 1978. Spiritual Well-Being: A Neglected Subject in Quality of Life Research. *Social Indicators Research,* **5**, pp. 303-323.

MOKONYAMA, M. and MUBIWA, B., 2014. Transport in the shaping of space. In: P. HARRISON, G. GOTZ, A. TODES and C. WRAY, eds, *Changing Space, Changing City: Johannesburg After Apartheid.* 1 edn. Johannesburg, South Africa: Wits University Press, pp. 194-214.

MØLLER, V., 2013. South African Quality of Life Trends Over Three Decades, 1980-2010. *Social Indicators Research,* **113**(3), pp. 915-940.

MØLLER, V., 2007. Satisfied and Dissatisfied South Africans: Results from the general household survey in international comparison. *Social Indicators Research,* **81**, pp. 389-415.

MORRIS, J.M., DUMBLE, P.L. and WIGAN, M.R., 1979. Accessibility indicators for transport planning. *Transportation Research Part A: General,* **13**(2), pp. 91-109.

MUSHONGAHANDE, R., CLOETE, C. and VENTER, C., 2014. Impact of the Gautrain on property development around station precincts. *Journal of the South African Institute of Civil Engineering,* **56**(1), pp. 2-10.

MUSHONGERA, D., ZIKHALI, P. and NGWENYA, P., 2015. A multidimensional poverty index for Gauteng province, South Africa: Evidence from Quality of Life Survey data. *Social Indicators Research,* , pp. 1-27.

NATIONAL DEPARTMENT OF HUMAN SETTLEMENTS, 2010. *National housing policy and subsidy programmes.* South Africa: National Department of Human Settlements.

NATIONAL PLANNING COMMISSION, 2012. *National Development Plan 2030 Our Future-make it work.* South Africa: National Planning Commission.

NAUDÉ, S., 2015. Exploring potential of public transport systems to facilitate development in the SA context, *34th Southern African Transport Conference*, 2015 2015, SATC, pp. 363.

NOBLE, A. and BICKFORD, G., 2013. *City of Johannesburg Public Transport Record: Summary of data Draft 2.* Johannesburg: ARUP.

NYAR, A., 2013. *GCRO Data Brief: No. 4 Transformation of Higher Education for Development in the Gauteng City-Region (GCR).* Johannesburg: GCRO.

OECD, 2011. Quality of Life. *Compendium of OECD Well-Being Indicators.* Paris: OECD, pp. 35.

OECD, 2008. *Handbook on Constructing Composite Indicators Methodology and User Guide.* OECD.

OLVERA, L.D., PLAT, D. and POCHET, P., 2008. Household transport expenditure in Sub-Saharan African cities: measurement and analysis. *Journal of Transport Geography,* **16**(1), pp. 1-13.

ONDERWATER, P., 2012. Make the Metrorail Work Better (Dutch measures for Durban Metrorail), *31st Southern African Transport Conference (SATC 2012)*, 9-12 July 2012 2012, SATC, pp. 222.

OVIEDO HERNANDEZ, D. and TITHERIDGE, H., 2016. *Mobilities of the periphery: Informality, access and social exclusion in the urban fringe in Colombia.*

OWEN, A., MURPHY, B. and LEVINSON, D., 2017. *Access Across America: Transit 2016.* Minneapolis, Minnesota: Center for Transportation Studies.

PEBERDY, S., 2013. *GCRO Data Brief: No. 5 Gauteng: a province of migrants.* Johannesburg: GCRO.

PERRY, J. and FELCE, D., 1995. Objective assessment of quality of life: How much do they agree with each other? *Journal of Community and Applied Social Psychology,* **5**, pp. 1-19.

PIKE, A., RODRIGUEZ-POSE, A. and TOMANEY, J., 2006. *Local and Regional Development.* New York: Routledge.

PRASA, 2015a-last update, Fleet Renewal Programme [Homepage of PRASA], [Online]. Available: https://www.prasa.com/Fleet%20Renewal%20Programme.html [03/28, 2016].

PRASA, 2015b. *Portfolio Committee on Trade and Industry: Impact of IPAP on the PRASA Rolling Stock Fleet Renewal Programme.* PRASA.

PRESTON, J. and RAJÉ, F., 2007. Accessibility, mobility and transport-related social exclusion. *Journal of Transport Geography,* **15**(3), pp. 151-160.

REARDON, M. and DYMÉN, C., 2015. Towards the just city: Addressing poverty and social exclusion in the Stockholm Region. *Local Economy,* **30**(7), pp. 838-856.

ROBINSON, J.C., 1990. Philosophical origins of the social rate of discount in cost-benefit analysis. *Milbank Quarterly,* **68**(2), pp. 245-265.

RODGERS, W.L. and CONVERSE, P.E., 1975. Measures of the perceived overall quality of life. *Social Indicators Research,* **2**, pp. 127-152.

ROGERSON, C., 2009. The Turn to 'New Regionalism': South African Reflections. *Urban Forum,* **20**, pp. 111-140.

ROGERSON, R.J., 1999. Quality of Life and City Competitiveness. *Urban Studies,* **36**(5-6), pp. 969-985.

RUBULOTTA, E., IGNACCOLO, M., INTURRI, G. and ROFÉ, Y., 2013. Accessibility and centrality for sustainable mobility: Regional planning case study. *Journal of Urban Planning and Development,* **139**(2), pp. 115-132.

SCHILLER, P.L., BRUUN, E.C. and KENWORTHY, J.R., 2010. Chapter 2: Automobile cities, the car culture and alternative possibilities. *An introduction to sustainable transportation: Policy, planning and implementation.* London: earthscan, pp. 25-29.

SCHWANEN, T., LUCAS, K., AKYELKEN, N., SOLSONA, D.C., CARRASCO, J. and NEUTENS, T., 2015. Rethinking the link between social exclusion and transport disadvantage through the lens of social capital. *Transportation Research Part A: Policy and Practice,* **74**, pp. 123-135.

SCORCIA, H. and MUNOZ-RASKIN, R., 2017. WHY SOUTH AFRICAN CITIES ARE DIFFERENT? COMPARING JOHANNESBURG REA VAYA BUS RAPID TRANSIT SYSTEM WITH ITS LATIN AMERICAN SIBLINGS, *Southern African Transport Conference*, 10 - 13 July 2017 2017.

SCOTT, A.J., 2002. Regional push: towards a geography of development and growth in low- and middle-income countries. *Third World Quarterly*, **23**(1), pp. 137-161.

SEU, 2003. *Making the Connections: Final Report on Transport and Social Exclusion.* England: SEU.

SOUTH AFRICA TOURS AND TRAVEL, 2017-last update, Interactive Map of Johannesburg South Africa. Available: https://www.south-africa-tours-and-travel.com/map-of-johannesburg-south-africa.html [01/10/, 2017].

STASSEN, W., October, 2015-last update, Gauteng's mine dumps brimming with radioactive uranium. Available: https://www.health-e.org.za/2015/10/15/gautengs-mine-dumps-brimming-with-radioactive-uranium/#lightbox/0/[01/11, 2017].

STATSSA, 2017. *Poverty trends in South Africa: An examination of absolute poverty between 2006 and 2015.* Pretoria: StatsSA.

STATSSA, 2014a. *National Household Travel Survey 2013.* Pretoria: StatsSA.

STATSSA, 2014b. *Poverty Trends in South Africa: An examination of absolute poverty between 2006 and 2011.* Statistics South Africa.

STEPSA, May, 2016-last update, Spatial Indicators: Socio-economic indicators [Homepage of CSIR], [Online]. Available: http://www.stepsa.org/socio_econ.html [10/16, 2016].

STEWART, A.F. and ZEGRAS, P.C., 2016. CoAXs: A Collaborative Accessibility-based Stakeholder Engagement System for communicating transport impacts. *Research in Transportation Economics*, (59), pp. 423-433.

SUMNER, A., 2004. *Economic Well-being and Non-economic Well-being: A Review of Meaning and Measurement of Poverty.* Helsinki: UNU-WIDER.

TCRP, 2004. *Chapter 12 - Transit Pricing and Fares.* Washington DC: Transportation Research Board.

THEOFILOU, P., 2013. Quality of Life: Definition and Measurement. *Europe's Journal of Psychology,* **9**(1), pp. 150-162.

TODES, A., 2014. The impact of policy and strategic spatial planning. In: P. HARRISON, G. GOTZ, A. TODES and C. WRAY, eds, *Changing Space, Changing City: Johannesburg After Apartheid.* 1 edn. Johannesburg, South Africa: Wits University Press, pp. 83-100.

TODES, A., 2012. Urban growth and strategic spatial planning in Johannesburg, South Africa. *Elsevier,* (29), pp. 158-165.

UNITED NATIONS, 2017. *New Urban Agenda.* Republic of Ecuador.: United Nations.

UNITED NATIONS GENERAL ASSEMBLY, 2015. *Transforming our world: the 2030 Agenda for Sustainable Development.* United Nations.

VAN DEN BERGH, J. and ANTAL, M., 2014. *Evaluating Alternatives to GDP as Measures of Social Welfare/Progress.* Spain: WWW for Europe.

VENTER, C., JENNINGS, G., HIDALGO, D. and PINEDA, A.F.V., 2017a. The equity impacts of bus rapid transit: a review of the evidence and implications for sustainable transport. *International Journal of Sustainable Transportation*.

VENTER, C. and CROSS, C., 2014. Access envelopes: A new accessibility mapping technique for transport and settlements planning. *SSB/TRP/MDM,* (64), pp. 43-52.

VENTER, C. and VAZ, E., 2014. Transformation through transportation: Some early impacts of Bus Rapid Transit in Orlando, Soweto. In: P. HARRISON, G. GOTZ, A. TODES and C. WRAY, eds, *Changing Space, Changing City: Johannesburg After Apartheid.* 1 edn. Johannesburg, South Africa: Wits University Press, pp. 443-455.

VENTER, C., 2016. Assessing the potential of bus rapid transit-led network restructuring for enhancing affordable access to employment -The case of Johannesburg's Corridors of Freedom. *Research in Transportation Economics,* **59**, pp. 441-449.

VYAS, S. and KUMARANAYAKE, L., 2006. *Constructing socio-economic status indices: how to use principal components analysis.* London: Advance Access.

WHO, 2015. *Global reference list of 100 core health indicators.* Geneva: WHO Press.

WILLIAMS, B., BROWN, T. and ONSMAN, A., 2010. Exploratory factor analysis: A five-step guide for novices. *Journal of Emergency Primary Health Care,* **8**(3),.

WOOLDRIDGE, J., 2007. *Difference-in-Differences Estimation.* National Bureau of Economic Research.

WORLD BANK, 2012. *South Africa Economic Update: Focus on Inequality of Opportunity.* Washington, DC 20433, USA: The International Bank for Reconstruction and Development/THE WORLD BANK.

WRAY, C., 2010. *Working towards a successful Gauteng City-Region.* Johannesburg: GCRO.

APPENDIX A

RAW DATA: TAXI FARES IN THE COJ

NOTES ON APPENDIX A

INTRODUCTION

This appendix contains the collected minibus taxi fares from minibus taxi operators and drivers at the Bree and Noord taxi ranks in the Johannesburg CBD in September 2016.

COLLECTED TAXI FARES

Table A-1 reflects the fares collected from the Noord taxi rank and Table A-2 reflects the fares collected from Bree taxi rank.

Table A-1: Collected taxi fares from Noord taxi rank, Johannesburg

Destination	Bypass a second station	Fare 1	Fare 2	Total fare
Alexandra		R11.00		R11.00
Baragwanath Hospital		R10.00		R10.00
Booysens		R10.00		R10.00
Diepkloof		R10.00		R10.00
Fourways		R14.00		R14.00
Halfway House (Midrand)		R16.00		R16.00
Modderfontein		R13.00		R13.00
Orlando		R10.00		R10.00
Sandton		R12.00		R12.00
Southgate		R10.00		R10.00
Eikenhof		R13.00		R13.00
Lenasia		R15.00		R15.00
Orange farm (Ext 2)		R15.00		R15.00
Orange Farm (Drieziek)		R20.00		R20.00
Vosloorus		R18.00		R18.00
Dobsonville	Baragwanath Hospital	R10.00	R8.50	R18.50
Dube	Baragwanath Hospital	R10.00	R8.50	R18.50
Kliptown	Baragwanath Hospital	R10.00	R8.50	R18.50
Mafalala I	Baragwanath Hospital	R10.00	R8.50	R18.50
Naledi	Baragwanath Hospital	R10.00	R8.50	R18.50
Protea Glen	Baragwanath Hospital	R10.00	R8.50	R18.50
Senaoane	Baragwanath Hospital	R10.00	R8.50	R18.50
Zola	Baragwanath Hospital	R10.00	R8.50	R18.50

Table A-2: Collected taxi fares from Bree taxi rank, Johannesburg

Destination	Bypass a second station	Fare 1	Fare 2	Total fare
Rooderport		R12.50		R12.50
Rosebank		R9.50		R9.50
Norwood		R9.00		R9.00
Sandton		R12.00		R12.00
Randburg		R11.00		R11.00
Ennerdale		R20.00		R20.00
Lenasia South		R15.00		R15.00
Lawley		R20.00		R20.00
Edenpark		R16.00		R16.00
Greenfields		R16.00		R16.00
Alberton		R12.00		R12.00
Booysens		R10.00		R10.00
Freedom Park		R10.50		R10.50
Eldorado Park (Main Road)		R11.00		R11.00
Palm ridge		R16.00		R16.00
Southgate		R10.00		R10.00
Baragwanath Hospital		R10.00		R10.00
Diepkloof		R10.00		R10.00
Merafe		R12.00		R12.00
Pimville		R11.00		R11.00

APPENDIX B

SAMPLE ZONES AND CONFIDENCE INTERVALS

NOTES ON APPENDIX B

INTRODUCTION

This appendix contains available information on the townships and the sample size associated with each. The average summary measures of each township and their upper and lower bound 95% confidence intervals are also tabulated.

TOWNSHIPS AND SAMPLE SIZES

Table B-1 reflects available information on the selected townships and the number of sample zones randomly selected from each township.

Table B-1: Township descriptions and sample sizes

Township	Population	Area (km^2)	Description	Number of sample zones for study
Alexandra	179624	6.91	Established in 1912 and close to the CoJ CBD	30
Soweto	1271628	200.03	Largest township in the CoJ	60
Diepsloot	138329	12.00	One of the city's newest townships	40
Orange Farm	76767	12.16	Established in 1989, previously used as a citrus farm	40
Lawley	33136	5.40	Named after Sir Arthur Lawley, Lieutenant-Governer of Transvaal from 1902 to 1906	30
Lenasia	89714	20.28	Indian township in the apartheid era	40
Lenasia South	37110	13.98	Indian township in the apartheid era	30
Ennerdale	71815	21.33	Coloured group area under the apartheid era	40

AVERAGE SUMMARY MEASURES AND CONFIDENCE INTERVALS

Table B-2, Table B-3 and Table B-4 reflect the average summary measures and the 95% double sided confidence interval per summary measure for each township for the years 2009, 2011 and 2013, respectively.

Table B-2: Average summary measures and confidence intervals (2009)

Township	Number of jobs accessible with NWAC > R85/day			Number of jobs accessible within 60 minutes of travel time			Average NWAC of the closest 200,000 jobs		
	Lower bound	Average	Upper bound	Lower bound	Average	Upper bound	Lower bound	Average	Upper bound
Alexandra	2730462	2797603	2864745	2055729	2127204	2198680	109	111	113
Soweto	1687463	1820715	1953967	1031234	1167064	1302895	108	109	110
Diepsloot	1208881	1415563	1622244	509314	694942	880570	85	87	88
Orange Farm	609769	703991	798213	155929	231846	307763	85	86	87
Lawley	741549	829868	918187	319582	411555	503528	94	95	95
Lenasia	1440452	1565859	1691266	1113316	1220327	1327338	103	104	105
Lenasia South	886636	990088	1093540	374241	518026	661812	88	90	91
Ennerdale	968716	1054307	1139897	565680	691362	817045	90	90	91

Table B-3: Average summary measures and confidence intervals (2011)

Township	Number of jobs accessible with NWAC > R85/day			Number of jobs accessible within 60 minutes of travel time			Average NWAC of the closest 200,000 jobs		
	Lower bound	Average	Upper bound	Lower bound	Average	Upper bound	Lower bound	Average	Upper bound
Alexandra	2938155	2972036	3005916	1991031	2070056	2149080	122	124	126
Soweto	2252797	2353611	2454424	944216	1078963	1213710	118	120	122
Diepsloot	1997188	2161365	2325543	490578	674090	857603	93	94	95
Orange Farm	989432	1097955	1206478	144395	219560	294725	90	91	92
Lawley	1216181	1339127	1462073	308967	397209	485451	103	104	105
Lenasia	2064287	2191871	2319455	1085478	1192779	1300079	113	115	116
Lenasia South	1409482	1538237	1666993	299059	433138	567217	96	97	99
Ennerdale	1499317	1610339	1721361	462150	576268	690386	98	99	100

Table B-4: Average summary measures and confidence intervals (2013)

Township	Number of jobs accessible with NWAC > R85/day			Number of jobs accessible within 60 minutes of travel time			Average NWAC of the closest 200,000 jobs		
	Lower bound	Average	Upper bound	Lower bound	Average	Upper bound	Lower bound	Average	Upper bound
Alexandra	3017904	3039218	3060532	1960201	2042292	2124382	131	133	136
Soweto	2543641	2617321	2691001	951596	1085616	1219636	126	128	130
Diepsloot	2459068	2547222	2635375	490715	673564	856413	99	100	102
Orange Farm	1428861	1555700	1682540	141974	214261	286548	96	97	98
Lawley	1734418	1858505	1982592	304687	393047	481408	110	111	112
Lenasia	2397508	2519733	2641958	1079823	1186559	1293295	121	122	123
Lenasia South	1925057	2042223	2159389	295401	430108	564814	102	104	105
Ennerdale	1994358	2100525	2206692	457919	571374	684828	104	105	106

APPENDIX C

SAS SCRIPT AND RESULTS

NOTES ON APPENDIX C

INTRODUCTION

This appendix contains the raw data, the script used in SAS to run the regression model as well as the complete set of outcomes for this model.

RAW DATA

Table C-1: Raw data for regression model

Respondent	Zone	Year	BRT	PT user	SEI	Acc	AccBRT	Dissatisfaction
1	7582	2009	Control	1	5.555556	1394961.532	0	4
2	7582	2009	Control	1	3.333333	1394961.532	0	1
3	7583	2009	Control	1	2.962963	2074798.739	0	2
4	7583	2009	Control	1	2.592593	2074798.739	0	0
5	7583	2009	Control	1	5.555556	2074798.739	0	4
6	7747	2009	Control	1	2.222222	2121629.082	0	2
7	7747	2009	Control	1	3.703704	2121629.082	0	5
8	7747	2009	Control	1	0.740741	2121629.082	0	3
9	7826	2009	Control	1	2.962963	2026173.387	0	1
10	7826	2009	Control	0	4.444444	2026173.387	0	2
11	7826	2009	Control	1	4.444444	2026173.387	0	5
12	7827	2009	Control	1	3.333333	2071763.432	0	1
13	7827	2009	Control	1	2.592593	2071763.432	0	1
14	8065	2009	Control	0	7.777778	1887092.497	0	4
15	8065	2009	Control	1	4.814815	1887092.497	0	0
16	8378	2009	Control	0	1.481481	794031.605	0	2
17	8695	2009	Control	1	1.111111	1431657.711	0	7
18	8695	2009	Control	0	4.074074	1431657.711	0	7
19	8695	2009	Control	0	0	1431657.711	0	0
20	8695	2009	Control	1	1.481481	1431657.711	0	2
21	8695	2009	Control	1	4.814815	1431657.711	0	5
22	8695	2009	Control	1	4.814815	1431657.711	0	6
23	8695	2009	Control	0	2.962963	1431657.711	0	1
24	8695	2009	Control	1	3.703704	1431657.711	0	4
25	9160	2009	Control	1	4.444444	209199.599	0	3
26	9405	2009	Control	0	2.222222	1552020.991	0	2
27	9405	2009	Control	0	1.481481	1552020.991	0	7
28	9405	2009	Control	1	4.444444	1552020.991	0	6
29	9405	2009	Control	1	0	1552020.991	0	2
30	9405	2009	Control	1	2.962963	1552020.991	0	6
31	9405	2009	Control	0	4.444444	1552020.991	0	6
32	9405	2009	Control	0	0	1552020.991	0	3

Respondent	Zone	Year	BRT	PT user	SEI	Acc	AccBRT	Dissatisfaction
33	9556	2009	Control	0	4.444444	448106.305	0	0
34	9556	2009	Control	1	0	448106.305	0	1
35	9936	2009	Control	0	0	1316523.151	0	0
36	10323	2009	Control	1	3.703704	1273100.278	0	0
37	10323	2009	Control	1	2.222222	1273100.278	0	0
38	10323	2009	Control	0	2.222222	1273100.278	0	0
39	10323	2009	Control	1	2.222222	1273100.278	0	0
40	10640	2009	Control	0	3.703704	225007.261	0	0
41	10640	2009	Control	1	5.185185	225007.261	0	4
42	10640	2009	Control	0	6.296296	225007.261	0	3
43	10640	2009	Control	1	1.481481	225007.261	0	2
44	12490	2009	Control	1	2.222222	1309400.988	0	1
45	12490	2009	Control	1	4.444444	1309400.988	0	1
46	12658	2009	Control	1	2.592593	1549680.364	0	5
47	6013	2013	Control	1	5	284066.506	16067.67	0
48	6013	2013	Control	0	3.571429	284066.506	16067.67	0
49	6013	2013	Control	1	5.357143	284066.506	16067.67	2
50	6013	2013	Control	1	2.142857	284066.506	16067.67	2
51	6168	2013	Control	1	3.571429	959472.062	20485.18	1
52	6168	2013	Control	1	3.571429	959472.062	20485.18	1
53	6168	2013	Control	1	2.142857	959472.062	20485.18	1
54	6168	2013	Control	0	5	959472.062	20485.18	1
55	6168	2013	Control	1	5	959472.062	20485.18	0
56	6242	2013	Control	1	0.714286	2103460.865	19621.71	0
57	6399	2013	Control	1	2.142857	1677956.128	27593.49	1
58	6399	2013	Control	1	2.857143	1677956.128	27593.49	1
59	6553	2013	Control	1	4.285714	2003672.175	25152.13	1
60	6699	2013	Control	1	6.071429	1111703.095	23127.52	2
61	6699	2013	Control	1	6.785714	1111703.095	23127.52	2
62	6699	2013	Control	0	5.357143	1111703.095	23127.52	2
63	7249	2013	Control	1	3.571429	1050906.025	24639.6	3
64	7582	2013	Control	1	2.857143	1321634.735	59261.65	2
65	7582	2013	Control	0	4.285714	1321634.735	59261.65	3
66	7583	2013	Control	1	3.571429	2132435.688	60085.53	2
67	7583	2013	Control	1	2.5	2132435.688	60085.53	2
68	7583	2013	Control	0	4.285714	2132435.688	60085.53	5
69	7583	2013	Control	0	6.428571	2132435.688	60085.53	2
70	7585	2013	Control	0	4.642857	1763649.144	87877.8	8
71	7585	2013	Control	0	3.214286	1763649.144	87877.8	3
72	7585	2013	Control	1	3.928571	1763649.144	87877.8	1
73	7585	2013	Control	1	2.142857	1763649.144	87877.8	1
74	7585	2013	Control	1	3.928571	1763649.144	87877.8	1

Respondent	Zone	Year	BRT	PT user	SEI	Acc	AccBRT	Dissatisfaction
75	7585	2013	Control	0	5.357143	1763649.144	87877.8	2
76	7667	2013	Control	1	3.571429	1511085.399	341241.6	2
77	7667	2013	Control	1	2.857143	1511085.399	341241.6	1
78	7667	2013	Control	1	3.571429	1511085.399	341241.6	1
79	7667	2013	Control	0	3.571429	1511085.399	341241.6	0
80	7747	2013	Control	1	2.142857	1963566.892	381521.6	1
81	7747	2013	Control	1	3.571429	1963566.892	381521.6	1
82	7747	2013	Control	1	2.142857	1963566.892	381521.6	1
83	7747	2013	Control	1	3.571429	1963566.892	381521.6	1
84	7747	2013	Control	0	5.357143	1963566.892	381521.6	2
85	7747	2013	Control	1	0.714286	1963566.892	381521.6	1
86	7747	2013	Control	1	2.142857	1963566.892	381521.6	3
87	7826	2013	Control	0	2.857143	1762000.203	56840.39	1
88	7826	2013	Control	0	4.642857	1762000.203	56840.39	3
89	7826	2013	Control	1	1.785714	1762000.203	56840.39	1
90	7826	2013	Control	1	5.714286	1762000.203	56840.39	0
91	7826	2013	Control	0	2.142857	1762000.203	56840.39	0
92	7826	2013	Control	1	3.928571	1762000.203	56840.39	2
93	7826	2013	Control	1	3.571429	1762000.203	56840.39	4
94	7826	2013	Control	0	2.142857	1762000.203	56840.39	1
95	7827	2013	Control	1	2.142857	1807326.961	252803.4	1
96	7827	2013	Control	1	0	1807326.961	252803.4	2
97	7827	2013	Control	1	2.857143	1807326.961	252803.4	1
98	7827	2013	Control	1	3.928571	1807326.961	252803.4	1
99	7827	2013	Control	1	2.857143	1807326.961	252803.4	1
100	7827	2013	Control	0	1.428571	1807326.961	252803.4	1
101	8065	2013	Control	0	2.142857	1890455.894	42252.56	3
102	8065	2013	Control	1	1.428571	1890455.894	42252.56	0
103	8065	2013	Control	1	5.357143	1890455.894	42252.56	0
104	8065	2013	Control	0	3.571429	1890455.894	42252.56	5
105	9160	2013	Control	1	2.142857	184991.991	50802	1
106	9160	2013	Control	1	3.571429	184991.991	50802	1
107	9160	2013	Control	1	0.714286	184991.991	50802	0
108	9160	2013	Control	1	5	184991.991	50802	2
109	9160	2013	Control	1	3.571429	184991.991	50802	1
110	9405	2013	Control	1	3.928571	1507380.809	299164.5	3
111	9405	2013	Control	1	2.857143	1507380.809	299164.5	1
112	9405	2013	Control	0	5	1507380.809	299164.5	3
113	9405	2013	Control	0	2.142857	1507380.809	299164.5	5
114	9405	2013	Control	1	3.928571	1507380.809	299164.5	2
115	9482	2013	Control	1	6.071429	1444662.422	243951.4	3
116	9482	2013	Control	1	4.642857	1444662.422	243951.4	4

Respondent	Zone	Year	BRT	PT user	SEI	Acc	AccBRT	Dissatisfaction
117	9482	2013	Control	0	5	1444662.422	243951.4	4
118	9482	2013	Control	1	4.285714	1444662.422	243951.4	3
119	9482	2013	Control	0	5.357143	1444662.422	243951.4	3
120	9482	2013	Control	0	3.214286	1444662.422	243951.4	3
121	9482	2013	Control	1	2.142857	1444662.422	243951.4	3
122	9482	2013	Control	1	1.785714	1444662.422	243951.4	7
123	9482	2013	Control	0	6.071429	1444662.422	243951.4	2
124	9482	2013	Control	0	4.642857	1444662.422	243951.4	1
125	9482	2013	Control	0	3.214286	1444662.422	243951.4	6
126	9482	2013	Control	1	3.214286	1444662.422	243951.4	2
127	9482	2013	Control	1	2.857143	1444662.422	243951.4	1
128	9482	2013	Control	0	3.571429	1444662.422	243951.4	5
129	9482	2013	Control	0	2.857143	1444662.422	243951.4	2
130	9482	2013	Control	1	6.071429	1444662.422	243951.4	4
131	9482	2013	Control	0	5.357143	1444662.422	243951.4	2
132	9482	2013	Control	1	6.071429	1444662.422	243951.4	2
133	9482	2013	Control	0	3.214286	1444662.422	243951.4	1
134	9556	2013	Control	1	3.214286	354060.003	93284.4	2
135	9556	2013	Control	1	2.5	354060.003	93284.4	0
136	9556	2013	Control	1	3.571429	354060.003	93284.4	1
137	9556	2013	Control	1	1.071429	354060.003	93284.4	1
138	9556	2013	Control	1	3.928571	354060.003	93284.4	0
139	9556	2013	Control	1	2.5	354060.003	93284.4	0
140	9637	2013	Control	1	5.357143	1199838.947	111794.9	1
141	9637	2013	Control	1	5	1199838.947	111794.9	1
142	9637	2013	Control	1	1.428571	1199838.947	111794.9	0
143	9637	2013	Control	1	5	1199838.947	111794.9	1
144	9936	2013	Control	1	3.571429	1314413.281	52673.34	1
145	9936	2013	Control	1	2.142857	1314413.281	52673.34	1
146	9936	2013	Control	1	5	1314413.281	52673.34	1
147	9936	2013	Control	1	1.428571	1314413.281	52673.34	2
148	9936	2013	Control	1	2.142857	1314413.281	52673.34	1
149	10322	2013	Control	1	0.714286	1043532.582	46331.52	1
150	10323	2013	Control	0	2.142857	1225843.351	58993.49	5
151	10325	2013	Control	0	5	1464504.415	69779.46	0
152	10325	2013	Control	1	2.142857	1464504.415	69779.46	0
153	10478	2013	Control	1	5	981581.127	49484.05	1
154	10478	2013	Control	1	3.571429	981581.127	49484.05	1
155	10480	2013	Control	0	2.142857	364489.175	44691.84	1
156	10480	2013	Control	1	1.428571	364489.175	44691.84	1
157	10640	2013	Control	1	1.428571	183036.227	34172.66	1
158	10640	2013	Control	1	1.785714	183036.227	34172.66	0

Respondent	Zone	Year	BRT	PT user	SEI	Acc	AccBRT	Dissatisfaction
159	10808	2013	Control	1	2.857143	52029.102	28304.83	2
160	10808	2013	Control	1	2.142857	52029.102	28304.83	3
161	10808	2013	Control	1	3.928571	52029.102	28304.83	0
162	10808	2013	Control	1	5	52029.102	28304.83	0
163	10808	2013	Control	1	5	52029.102	28304.83	0
164	10890	2013	Control	0	3.571429	618070.631	40260.79	3
165	10890	2013	Control	1	4.285714	618070.631	40260.79	0
166	10890	2013	Control	1	5	618070.631	40260.79	4
167	10890	2013	Control	0	2.5	618070.631	40260.79	7
168	10890	2013	Control	0	5	618070.631	40260.79	3
169	10890	2013	Control	1	2.857143	618070.631	40260.79	3
170	10968	2013	Control	1	0	353179.346	21671.5	1
171	11563	2013	Control	0	3.928571	27440.233	27440.23	2
172	12490	2013	Control	0	3.214286	1290485.298	27436.28	0
173	12490	2013	Control	0	3.214286	1290485.298	27436.28	1
174	12490	2013	Control	0	1.785714	1290485.298	27436.28	0
175	12656	2013	Control	0	3.571429	641525.75	23992.07	0
176	12656	2013	Control	1	2.142857	641525.75	23992.07	0
177	12656	2013	Control	0	5	641525.75	23992.07	2
178	12658	2013	Control	1	3.214286	1535875.009	30677	3
179	12658	2013	Control	0	2.857143	1535875.009	30677	5
180	7332	2009	Treatment	1	4.814815	1693089.656	0	2
181	7332	2009	Treatment	0	4.444444	1693089.656	0	1
182	7332	2009	Treatment	0	3.333333	1693089.656	0	2
183	7332	2009	Treatment	1	4.814815	1693089.656	0	3
184	7819	2009	Treatment	0	0.37037	947918.049	0	0
185	7819	2009	Treatment	1	1.481481	947918.049	0	4
186	7819	2009	Treatment	1	1.851852	947918.049	0	4
187	7819	2009	Treatment	1	1.851852	947918.049	0	4
188	7899	2009	Treatment	1	3.703704	632649.198	0	4
189	7899	2009	Treatment	1	2.222222	632649.198	0	5
190	8384	2009	Treatment	1	2.222222	857244.074	0	0
191	8384	2009	Treatment	0	0	857244.074	0	1
192	8546	2009	Treatment	1	0	1082466.411	0	2
193	8546	2009	Treatment	0	1.481481	1082466.411	0	4
194	8550	2009	Treatment	1	1.481481	1649570.206	0	1
195	8623	2009	Treatment	1	0	1378127.49	0	0
196	8623	2009	Treatment	1	3.703704	1378127.49	0	4
197	8623	2009	Treatment	1	5.925926	1378127.49	0	6
198	8629	2009	Treatment	1	0.37037	1597488.599	0	4
199	8698	2009	Treatment	0	2.962963	1565310.736	0	1
200	8782	2009	Treatment	1	2.962963	1518023.588	0	4

Respondent	Zone	Year	BRT	PT user	SEI	Acc	AccBRT	Dissatisfaction
201	8782	2009	Treatment	1	3.333333	1518023.588	0	4
202	8782	2009	Treatment	1	0	1518023.588	0	4
203	8939	2009	Treatment	0	3.703704	1594680.298	0	6
204	8939	2009	Treatment	0	1.481481	1594680.298	0	3
205	8939	2009	Treatment	1	2.962963	1594680.298	0	1
206	9008	2009	Treatment	1	5.185185	1153820.959	0	5
207	9008	2009	Treatment	1	6.666667	1153820.959	0	3
208	9008	2009	Treatment	0	1.481481	1153820.959	0	1
209	9008	2009	Treatment	1	1.481481	1153820.959	0	3
210	9008	2009	Treatment	1	1.481481	1153820.959	0	5
211	9091	2009	Treatment	1	0.37037	1416480.41	0	3
212	9091	2009	Treatment	0	5.925926	1416480.41	0	5
213	9315	2009	Treatment	1	1.851852	413004.855	0	3
214	9470	2009	Treatment	1	1.481481	723088.19	0	5
215	9470	2009	Treatment	0	0	723088.19	0	0
216	9470	2009	Treatment	1	0	723088.19	0	0
217	9546	2009	Treatment	1	0	566236.049	0	1
218	9546	2009	Treatment	0	1.481481	566236.049	0	1
219	9546	2009	Treatment	1	4.814815	566236.049	0	1
220	9546	2009	Treatment	1	5.555556	566236.049	0	1
221	9557	2009	Treatment	0	5.185185	1512793.283	0	5
222	9557	2009	Treatment	0	1.481481	1512793.283	0	3
223	9557	2009	Treatment	0	5.925926	1512793.283	0	3
224	9557	2009	Treatment	1	1.481481	1512793.283	0	1
225	9557	2009	Treatment	1	1.481481	1512793.283	0	2
226	9557	2009	Treatment	1	3.333333	1512793.283	0	5
227	9557	2009	Treatment	1	3.333333	1512793.283	0	1
228	9557	2009	Treatment	0	1.481481	1512793.283	0	1
229	9709	2009	Treatment	0	1.481481	1581893.489	0	0
230	9709	2009	Treatment	1	4.444444	1581893.489	0	5
231	9713	2009	Treatment	1	2.962963	1373327.973	0	3
232	9713	2009	Treatment	1	2.962963	1373327.973	0	5
233	9713	2009	Treatment	1	1.481481	1373327.973	0	2
234	9780	2009	Treatment	1	6.296296	994005.107	0	5
235	9780	2009	Treatment	1	1.481481	994005.107	0	3
236	9780	2009	Treatment	1	2.962963	994005.107	0	0
237	9780	2009	Treatment	1	4.444444	994005.107	0	7
238	9787	2009	Treatment	0	4.444444	1519640.442	0	1
239	9862	2009	Treatment	1	1.481481	1079920.578	0	3
240	10011	2009	Treatment	1	2.962963	877429.457	0	0
241	10016	2009	Treatment	1	5.555556	1330260.188	0	7
242	6701	2013	Treatment	1	3.571429	1655413.993	28298	2

Respondent	Zone	Year	BRT	PT user	SEI	Acc	AccBRT	Dissatisfaction
243	6701	2013	Treatment	1	0.714286	1655413.993	28298	1
244	6701	2013	Treatment	1	3.571429	1655413.993	28298	1
245	6932	2013	Treatment	0	2.857143	1276442.893	38758.41	2
246	6932	2013	Treatment	1	3.571429	1276442.893	38758.41	1
247	6932	2013	Treatment	1	0.714286	1276442.893	38758.41	1
248	6932	2013	Treatment	1	0.714286	1276442.893	38758.41	0
249	6932	2013	Treatment	1	4.285714	1276442.893	38758.41	1
250	7088	2013	Treatment	1	2.142857	1499287.514	42492.11	0
251	7088	2013	Treatment	1	0.714286	1499287.514	42492.11	1
252	7088	2013	Treatment	0	5	1499287.514	42492.11	3
253	7332	2013	Treatment	1	2.142857	1598443.401	86352.6	3
254	7332	2013	Treatment	1	0.714286	1598443.401	86352.6	0
255	7332	2013	Treatment	1	3.571429	1598443.401	86352.6	1
256	7332	2013	Treatment	1	2.857143	1598443.401	86352.6	1
257	7658	2013	Treatment	1	1.428571	1042990.903	122268.5	1
258	7658	2013	Treatment	1	0.714286	1042990.903	122268.5	0
259	7658	2013	Treatment	1	2.142857	1042990.903	122268.5	2
260	7658	2013	Treatment	1	2.142857	1042990.903	122268.5	2
261	7819	2013	Treatment	1	5	963233.892	519098.5	1
262	7819	2013	Treatment	0	5	963233.892	519098.5	1
263	7819	2013	Treatment	1	3.571429	963233.892	519098.5	2
264	7899	2013	Treatment	0	6.428571	540557.937	138895.9	5
265	7899	2013	Treatment	0	6.071429	540557.937	138895.9	6
266	7899	2013	Treatment	0	6.428571	540557.937	138895.9	4
267	7899	2013	Treatment	1	3.571429	540557.937	138895.9	2
268	7899	2013	Treatment	1	3.571429	540557.937	138895.9	1
269	7899	2013	Treatment	1	0.714286	540557.937	138895.9	2
270	7899	2013	Treatment	1	6.428571	540557.937	138895.9	2
271	7899	2013	Treatment	1	5	540557.937	138895.9	2
272	8220	2013	Treatment	1	3.571429	940957.128	139268.7	1
273	8220	2013	Treatment	1	3.571429	940957.128	139268.7	1
274	8220	2013	Treatment	0	3.571429	940957.128	139268.7	2
275	8220	2013	Treatment	1	2.857143	940957.128	139268.7	4
276	8220	2013	Treatment	1	3.571429	940957.128	139268.7	1
277	8220	2013	Treatment	1	0.714286	940957.128	139268.7	3
278	8220	2013	Treatment	1	0	940957.128	139268.7	2
279	8220	2013	Treatment	1	2.142857	940957.128	139268.7	3
280	8384	2013	Treatment	1	5	790278.382	541547.7	1
281	8384	2013	Treatment	1	3.928571	790278.382	541547.7	1
282	8384	2013	Treatment	0	3.571429	790278.382	541547.7	2
283	8384	2013	Treatment	1	1.785714	790278.382	541547.7	1
284	8388	2013	Treatment	0	4.642857	1357604.024	477598.2	6

Respondent	Zone	Year	BRT	PT user	SEI	Acc	AccBRT	Dissatisfaction
285	8388	2013	Treatment	0	3.214286	1357604.024	477598.2	1
286	8546	2013	Treatment	1	2.142857	831039.197	123917.7	2
287	8550	2013	Treatment	1	2.142857	1678351.724	466059.3	1
288	8550	2013	Treatment	1	1.428571	1678351.724	466059.3	4
289	8550	2013	Treatment	1	2.142857	1678351.724	466059.3	1
290	8550	2013	Treatment	1	6.071429	1678351.724	466059.3	3
291	8623	2013	Treatment	1	0	1108694.422	126609.4	0
292	8623	2013	Treatment	1	3.571429	1108694.422	126609.4	0
293	8623	2013	Treatment	1	3.571429	1108694.422	126609.4	2
294	8623	2013	Treatment	1	2.857143	1108694.422	126609.4	3
295	8623	2013	Treatment	1	2.142857	1108694.422	126609.4	1
296	8629	2013	Treatment	1	0	1573789.657	591955.6	0
297	8629	2013	Treatment	1	3.571429	1573789.657	591955.6	0
298	8629	2013	Treatment	0	5.714286	1573789.657	591955.6	3
299	8629	2013	Treatment	0	2.142857	1573789.657	591955.6	0
300	8629	2013	Treatment	1	5.714286	1573789.657	591955.6	0
301	8629	2013	Treatment	1	2.142857	1573789.657	591955.6	0
302	8629	2013	Treatment	1	3.571429	1573789.657	591955.6	1
303	8629	2013	Treatment	1	2.857143	1573789.657	591955.6	1
304	8629	2013	Treatment	0	6.428571	1573789.657	591955.6	2
305	8629	2013	Treatment	1	2.142857	1573789.657	591955.6	0
306	8698	2013	Treatment	1	0.714286	1463853.708	97612.5	1
307	8698	2013	Treatment	1	2.142857	1463853.708	97612.5	4
308	8769	2013	Treatment	1	0.714286	427534.472	67730.62	1
309	8769	2013	Treatment	1	1.428571	427534.472	67730.62	0
310	8769	2013	Treatment	1	2.142857	427534.472	67730.62	0
311	8769	2013	Treatment	1	4.285714	427534.472	67730.62	1
312	8772	2013	Treatment	1	3.571429	929729.722	81658.43	0
313	8772	2013	Treatment	1	2.142857	929729.722	81658.43	1
314	8772	2013	Treatment	0	2.142857	929729.722	81658.43	7
315	8772	2013	Treatment	1	3.571429	929729.722	81658.43	1
316	8772	2013	Treatment	0	6.785714	929729.722	81658.43	4
317	8772	2013	Treatment	1	4.285714	929729.722	81658.43	3
318	8782	2013	Treatment	1	3.928571	1250573.447	614203.3	1
319	8782	2013	Treatment	0	4.642857	1250573.447	614203.3	2
320	8782	2013	Treatment	1	2.5	1250573.447	614203.3	2
321	8784	2013	Treatment	1	2.142857	1235634.52	737933.7	0
322	8784	2013	Treatment	1	2.142857	1235634.52	737933.7	0
323	8784	2013	Treatment	1	2.142857	1235634.52	737933.7	1
324	8784	2013	Treatment	1	2.142857	1235634.52	737933.7	1
325	8852	2013	Treatment	0	2.142857	953374.733	145735.2	1
326	8852	2013	Treatment	1	3.571429	953374.733	145735.2	3

Respondent	Zone	Year	BRT	PT user	SEI	Acc	AccBRT	Dissatisfaction
327	8852	2013	Treatment	1	3.571429	953374.733	145735.2	2
328	8852	2013	Treatment	1	3.928571	953374.733	145735.2	1
329	8852	2013	Treatment	1	2.5	953374.733	145735.2	4
330	8939	2013	Treatment	1	2.142857	1571527.592	615645.4	1
331	9007	2013	Treatment	1	5	885765.459	128677.2	2
332	9007	2013	Treatment	1	3.571429	885765.459	128677.2	2
333	9007	2013	Treatment	1	3.571429	885765.459	128677.2	1
334	9007	2013	Treatment	1	3.571429	885765.459	128677.2	0
335	9007	2013	Treatment	1	0.714286	885765.459	128677.2	2
336	9007	2013	Treatment	1	3.571429	885765.459	128677.2	1
337	9007	2013	Treatment	1	3.571429	885765.459	128677.2	1
338	9008	2013	Treatment	0	2.142857	946895.485	170975.8	0
339	9008	2013	Treatment	0	6.428571	946895.485	170975.8	3
340	9008	2013	Treatment	0	2.857143	946895.485	170975.8	3
341	9008	2013	Treatment	1	2.142857	946895.485	170975.8	2
342	9008	2013	Treatment	1	0.714286	946895.485	170975.8	2
343	9082	2013	Treatment	1	0.714286	833419.425	116795.6	2
344	9082	2013	Treatment	1	3.571429	833419.425	116795.6	0
345	9091	2013	Treatment	0	3.928571	1163623.189	570028	5
346	9091	2013	Treatment	1	2.142857	1163623.189	570028	1
347	9091	2013	Treatment	1	2.142857	1163623.189	570028	1
348	9091	2013	Treatment	0	2.142857	1163623.189	570028	4
349	9315	2013	Treatment	1	2.142857	339293.729	57741.63	1
350	9315	2013	Treatment	1	2.142857	339293.729	57741.63	0
351	9398	2013	Treatment	1	0.714286	847308.634	99885.21	2
352	9398	2013	Treatment	1	2.857143	847308.634	99885.21	1
353	9398	2013	Treatment	1	5	847308.634	99885.21	0
354	9398	2013	Treatment	0	2.142857	847308.634	99885.21	3
355	9398	2013	Treatment	1	5	847308.634	99885.21	0
356	9470	2013	Treatment	1	6.428571	502809.927	70525.13	1
357	9470	2013	Treatment	0	3.214286	502809.927	70525.13	3
358	9470	2013	Treatment	1	5	502809.927	70525.13	1
359	9470	2013	Treatment	1	1.428571	502809.927	70525.13	0
360	9474	2013	Treatment	1	3.571429	1246611.821	135739.5	2
361	9476	2013	Treatment	1	2.142857	1127912.967	136426.7	1
362	9476	2013	Treatment	0	3.571429	1127912.967	136426.7	3
363	9476	2013	Treatment	1	4.285714	1127912.967	136426.7	1
364	9546	2013	Treatment	1	3.571429	570312.704	45607.03	3
365	9546	2013	Treatment	0	3.571429	570312.704	45607.03	1
366	9557	2013	Treatment	1	5	1526346.74	494999.2	1
367	9557	2013	Treatment	1	3.571429	1526346.74	494999.2	2
368	9557	2013	Treatment	1	2.142857	1526346.74	494999.2	1

Respondent	Zone	Year	BRT	PT user	SEI	Acc	AccBRT	Dissatisfaction
369	9557	2013	Treatment	1	2.142857	1526346.74	494999.2	1
370	9557	2013	Treatment	1	4.285714	1526346.74	494999.2	0
371	9557	2013	Treatment	1	3.571429	1526346.74	494999.2	2
372	9557	2013	Treatment	1	3.571429	1526346.74	494999.2	1
373	9698	2013	Treatment	1	1.428571	208638.865	40603.97	2
374	9709	2013	Treatment	1	3.571429	1443966.475	340545.4	1
375	9709	2013	Treatment	1	1.785714	1443966.475	340545.4	1
376	9709	2013	Treatment	1	3.571429	1443966.475	340545.4	2
377	9709	2013	Treatment	1	3.571429	1443966.475	340545.4	1
378	9710	2013	Treatment	1	3.571429	1621202.633	132661.5	2
379	9710	2013	Treatment	1	1.428571	1621202.633	132661.5	0
380	9710	2013	Treatment	1	3.928571	1621202.633	132661.5	3
381	9710	2013	Treatment	1	1.785714	1621202.633	132661.5	2
382	9713	2013	Treatment	1	1.428571	1365069.149	529934.5	2
383	9713	2013	Treatment	1	3.571429	1365069.149	529934.5	1
384	9713	2013	Treatment	1	2.142857	1365069.149	529934.5	0
385	9713	2013	Treatment	1	2.142857	1365069.149	529934.5	0
386	9713	2013	Treatment	0	1.428571	1365069.149	529934.5	2
387	9780	2013	Treatment	1	1.428571	723927.112	54936.23	0
388	9780	2013	Treatment	0	0.714286	723927.112	54936.23	0
389	9780	2013	Treatment	1	4.285714	723927.112	54936.23	0
390	9780	2013	Treatment	0	3.571429	723927.112	54936.23	1
391	9786	2013	Treatment	1	5	1082593.386	142713.8	1
392	9786	2013	Treatment	1	2.857143	1082593.386	142713.8	1
393	9787	2013	Treatment	1	2.142857	1404111.031	251364.1	2
394	9787	2013	Treatment	1	2.142857	1404111.031	251364.1	1
395	9787	2013	Treatment	1	4.285714	1404111.031	251364.1	0
396	9787	2013	Treatment	1	5	1404111.031	251364.1	1
397	9787	2013	Treatment	0	2.857143	1404111.031	251364.1	4
398	9862	2013	Treatment	0	2.5	1010744.98	101164.9	2
399	9862	2013	Treatment	1	2.142857	1010744.98	101164.9	2
400	9862	2013	Treatment	0	2.857143	1010744.98	101164.9	1
401	9862	2013	Treatment	0	4.642857	1010744.98	101164.9	2
402	10011	2013	Treatment	1	3.571429	615033.822	56836.33	1
403	10011	2013	Treatment	1	6.428571	615033.822	56836.33	6
404	10011	2013	Treatment	1	2.857143	615033.822	56836.33	2
405	10011	2013	Treatment	0	2.857143	615033.822	56836.33	2
406	10011	2013	Treatment	0	3.571429	615033.822	56836.33	5
407	10011	2013	Treatment	0	3.571429	615033.822	56836.33	5
408	10011	2013	Treatment	1	6.428571	615033.822	56836.33	3
409	10016	2013	Treatment	1	3.571429	1262273.415	92792.14	2
410	10016	2013	Treatment	0	7.5	1262273.415	92792.14	3

Respondent	Zone	Year	BRT	PT user	SEI	Acc	AccBRT	Dissatisfaction
411	10016	2013	Treatment	0	3.214286	1262273.415	92792.14	0
412	10016	2013	Treatment	1	1.428571	1262273.415	92792.14	2
413	10016	2013	Treatment	0	5	1262273.415	92792.14	4
414	10016	2013	Treatment	1	4.285714	1262273.415	92792.14	1
415	10016	2013	Treatment	0	3.571429	1262273.415	92792.14	1
416	10016	2013	Treatment	1	3.928571	1262273.415	92792.14	2
417	10016	2013	Treatment	0	2.5	1262273.415	92792.14	5
418	10018	2013	Treatment	1	3.571429	1423679.885	86798.06	1
419	10018	2013	Treatment	0	5	1423679.885	86798.06	4
420	10096	2013	Treatment	1	3.571429	1491547.532	372334.5	0
421	10096	2013	Treatment	1	2.5	1491547.532	372334.5	3
422	10096	2013	Treatment	1	6.428571	1491547.532	372334.5	1
423	10096	2013	Treatment	1	3.928571	1491547.532	372334.5	3

SAS SCRIPT

Below is the script used in SAS to conduct the regression analysis. The predictor variables are represented slightly differently to those shown in Equation 3-7, such that:

- Year_D = *year* in Equation 3-10
- BRT_D = *BRT* in Equation 3-10
- FPTU_D = *PT user* in Equation 3-10
- SEI is represented the same in both cases
- TT_S = *Acc* in Equation 3-10
- TTBRT_S = *AccBRT* in Equation 3-10

```
proc nlmixed data = Regress.DiffinDiff;
log_mu = intercept + b_year*Year_D + b_brt*BRT_D + b_fptu*FPTU_D +
b_sei*SEI + b_tt*TT_S + b_by*BRT_D*Year_D + b_bf*BRT_D*FPTU_D +
b_bytt*Year_D*BRT_D*TTBRT_S;
mu = exp(log_mu);
het = 1/alpha;
ll = lgamma(Dis+het)-lgamma(Dis+1)-lgamma(het)-
het*log(1+alpha*mu)+Dis*log(alpha*mu)-Dis*log(1+alpha*mu)-
log(((1+alpha*mu)**-
het)+((gamma(het+1)/(gamma(2)*gamma(het)))*((1+alpha*mu)**-
het)*((alpha*mu)/(1+alpha*mu))**1) +
((gamma(het+2)/(gamma(3)*gamma(het)))*((1+alpha*mu)**-
het)*((alpha*mu)/(1+alpha*mu))**2) +
((gamma(het+3)/(gamma(4)*gamma(het)))*((1+alpha*mu)**-
het)*((alpha*mu)/(1+alpha*mu))**3) +
((gamma(het+4)/(gamma(5)*gamma(het)))*((1+alpha*mu)**-
het)*((alpha*mu)/(1+alpha*mu))**4) +
((gamma(het+5)/(gamma(6)*gamma(het)))*((1+alpha*mu)**-
het)*((alpha*mu)/(1+alpha*mu))**5) +
((gamma(het+6)/(gamma(7)*gamma(het)))*((1+alpha*mu)**-
het)*((alpha*mu)/(1+alpha*mu))**6) +
((gamma(het+7)/(gamma(8)*gamma(het)))*((1+alpha*mu)**-
het)*((alpha*mu)/(1+alpha*mu))**7) +
((gamma(het+8)/(gamma(9)*gamma(het)))*((1+alpha*mu)**-
het)*((alpha*mu)/(1+alpha*mu))**8) +
((gamma(het+9)/(gamma(10)*gamma(het)))*((1+alpha*mu)**-
het)*((alpha*mu)/(1+alpha*mu))**9));
model Dis ~ general(ll);
run;
```

REGRESSION ANALYSIS OUTPUT

The SAS System

The NLMIXED Procedure

Specifications	
Data Set	REGRESS.DIFFINDIFF
Dependent Variable	Dis
Distribution for Dependent Variable	General
Optimization Technique	Dual Quasi-Newton
Integration Method	None

Dimensions	
Observations Used	423
Observations Not Used	0
Total Observations	423
Parameters	10

Initial Parameters										
intercept	**b_year**	**b_brt**	**b_fptu**	**b_sei**	**b_tt**	**b_by**	**b_bf**	**b_bytt**	**alpha**	**Negative Log Likelihood**
1	1	1	1	1	1	1	1	1	1	973.907

Iteration History					
Iteration	**Calls**	**Negative Log Likelihood**	**Difference**	**Maximum Gradient**	**Slope**
1	4	892.2912	81.61588	78.9687	-1455.48
2	8	873.1038	19.1874	12.4893	-14.699
3	12	872.1147	0.989155	0.65565	-1.10829
4	14	872.1113	0.003378	0.093979	-0.00585
5	16	872.1111	0.000154	0.046096	-0.00023
6	18	872.1109	0.000268	0.13315	-0.00014
7	22	872.1086	0.002219	0.75768	-0.0006
8	36	865.5627	6.54597	62.1187	-0.00484
9	40	865.321	0.241634	20.5324	-64.5084
10	44	860.8547	4.466343	134.473	-2.2604
11	46	853.3561	7.498631	19.2472	-5.76037
12	49	850.8416	2.514506	23.8285	-8.77924
13	51	848.6522	2.18934	17.5307	-21.1835
14	53	845.0814	3.570856	13.638	-7.22163
15	55	841.9699	3.111489	207.726	-6.99415
16	59	834.4423	7.527541	23.1188	-23.5266
17	67	803.2873	31.15506	53.451	-22.5589
18	71	800.9681	2.319198	152.916	-56.2312
19	75	785.4028	15.56529	952.26	-75.9963
20	79	749.0933	36.30948	647.929	-155.589
21	82	734.647	14.44625	376.41	-187.976
22	87	728.1473	6.499742	280.172	-51.015
23	90	725.6095	2.537795	64.2281	-17.0058
24	95	725.2904	0.319106	127.247	-4.86436
25	97	724.7402	0.550227	27.1878	-2.572
26	100	724.4884	0.251745	45.9232	-1.06506
27	103	724.4417	0.046703	17.679	-0.12619
28	106	724.4308	0.010974	12.6644	-0.03151
29	109	724.4234	0.007382	15.681	-0.01531
30	111	724.4133	0.010053	2.45482	-0.01531
31	114	724.4124	0.000929	1.17981	-0.00202
32	117	724.4121	0.000298	0.79892	-0.00053
33	120	724.412	0.000081	0.05021	-0.00012
34	123	724.412	1.10E-06	0.003669	-2.30E-06

NOTE: GCONV convergence criterion satisfied.

Fit Statistics	
-2 Log Likelihood	1448.8
AIC (smaller is better)	1468.8
AICC (smaller is better)	1469.4
BIC (smaller is better)	1509.3

Where:

b_year - β_1

b_brt - β_2

b_fptu - β_3

b_sei - β_4

b_tt - β_5

b_by - β_6

b_bf - β_7

b_bytt - β_8