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MASTER OF ENGINEERING SPECIALISING IN TRANSPORT STUDIES

MINOR DISSERTATION

**INVESTIGATING THE INTRODUCTION OF
ECONOMIC LAND USE DEVELOPMENTS TO
CREATE RAIL CONTRA-FLOW USING A
STRATEGIC MODEL: A CASE STUDY OF
JOHANNESBURG.**

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Abstract

South Africa is still recovering from the effects of the apartheid government and spatial design that marginalises the demographic that resides at the edges and outskirts of cities. The country has come a long way from where it was, but still has a long way to go to eradicate the effects this fragmentation has had on access to socio economic opportunities.

Diversifying land use and creating localised economic hubs may provide a helping hand in reducing the need to travel far distances to seek opportunity, and by extension create an attraction for surrounding communities.

The dual role of nullifying past prejudice implemented through strategic spatial design while introducing the perspective of using the relationship between land use and transport to create rail contra flow and localised socio-economic hubs is one that can be achieved strategically. The modelling software that will help to demonstrate the model output of the research, which will be a simulation of contra-flow after the introduction of economic land use developments, is PTV VISUM.

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1 INTRODUCTION

1.1 Background

One of South Africa's Apartheid intents was to implement laws prohibiting where black people could and couldn't live, which has subsequently resulted in urban sprawl amongst many other issues (Lawton, 2014). Black people were not allowed to live in places near the city centre, which affected the way they travelled, and still does to a large extent today. Trip making behaviour is influenced by socio-economic status, opportunities, and the (spatial) constraints of the environment that people live in (Wang & Lin, 2013). Living far from the city centre means people have to commute longer distances to the city for work and shopping purposes than others who live closer by.

The effects of urban sprawl caused by apartheid still exist in a democratic South Africa (Lawton, 2014). The spatial landscape of transport in South Africa isn't fully comprehended (Lawton, 2014), which is why the country has struggled to solve these spatial inequalities and travel imbalances (Pirie, 2007).

This research models and analyses the introduction of economic land use developments in areas far from the Johannesburg city centre, that were intentionally built in peripheral regions enforced by apartheid laws, to potentially counter the effects of spatial fragmentation that has caused rail travel to be primarily unidirectional towards the city centre in the mornings and away from the city in the evenings. This is achieved with the use of a strategic transport model, modelled in PTV Visum.

1.2 Problem Statement

Given the history of South Africa and the effects of an apartheid driven agenda where spatial planning and rail transport is concerned, it is important to acknowledge how far South Africa has come in trying to eradicate the effects of that fragmentation, but more so important is to see how far South Africa still has to go, acknowledge the work to be done in this regard - and do the work.

Public transport travel in South Africa is defined by long distance trips, unidirectional travel as well as high peak passenger volumes coupled with low off-peak passenger volumes (van Ryneveld, 2014). Both long distance rail trips and unidirectional travel can be attributed to the design of historic South African cities. Unidirectional travel means that passengers go to work or school in the morning, and then come back in the evenings, with no significant travel in the opposite direction i.e. no contra-flow.

1.3 Aims and Objectives

- a) The purpose of the study is to create rail contra-flow by introducing economic opportunities in Soweto and immediate areas, because of their remoteness to the central business district i.e. Johannesburg city centre.

- There is therefore a need to:
 - Better understand the relationship between land use and rail transport;
 - Develop a rail strategic transport model to:
 - Simulate a base model of the status quo;
 - Validate the base model;
 - Simulate a future scenario model with an introduction of new developments that provide mixed land use diversity and;
 - Simulate and analyse a contra-flow scenario.

1.4 Research Questions

The research questions for the study are:

- a) How can the relationship between land use and rail transport in the context of a post-apartheid South African city be modelled?
- b) Can strategic planning interventions be used to induce rail contra-flow?
- c) Can unidirectional rail traffic flow be minimized by creating contra-flow by introducing economic developments?

1.5 Scope and Limitations

The study is limited to two focus areas in Gauteng i.e. Soweto and the Johannesburg City Centre and the areas along the rail route between these two areas.

Even though the study area is situated in the Gauteng Province, literature highlighting South African research has been used with the assumption that it applies to all provinces, unless otherwise stated.

Seeing that not a lot of information is known about the spatial patterns of social activities and travel and the factors that affect it because no substantial research has focussed a lot on social activities as extensively as work or shopping related activities (Kowald *et al.*, 2013), this study will then focus on rail related travel only.

The study seeks to show proof of the concept of land use and transport integration in South Africa practice; however, the study suffers issues of scale and resolution.

1.6 Structure of Dissertation

Chapter 1: Introduction – The first chapter summaries the problem statement, research objectives, aims and objectives of the research as well as the scope and limitations.

Chapter 2: Literature Review – Chapter two of this research paper summaries reviewed research applicable to the study and its objectives i.e. Relationship between land use and transport, Land use and Transport integration enabling policies and development of a strategic transport model.

Chapter 3: Case Study – Chapter 3 gives a descriptive summary of the study area and highlights its population, rail infrastructure, current land use and future developments in the area.

Chapter 4: Modelling Methodology – Chapter 4 outlines the methodology and modelling assumptions. It highlights the modelling principles adopted for this research, data requirements and the data used as well as modelled scenarios.

Chapter 5: Research Findings and Recommendations – The results of the overall research are then discussed in Chapter 5. Recommendations emanating from the results are also provided.

Chapter 6: Conclusion – The conclusions of the study are stipulated in Chapter 6.

2 LITERATURE REVIEW

In order to better understand the effects of land use on rail transport and how the two concepts interact, it is necessary to gather the relevant research. This chapter reviews literature on land use and transport interaction, the theory behind strategic transport models and how they are developed, as well as the state of rail transport in South Africa in relation to land use in order to better understand and validate the research problem.

The following will be covered in the literature review:

- Literature on Land use and Transport
 - Relationship between Land Use and Transport
 - Land Use and Transport Policies
- Literature on Contra-Flow Traffic
- Transport Modelling
 - Four Step Model
 - Different Transport Models
 - Strategic Modelling
 - Data Requirements
 - Model Development
 - Shortcomings of Strategic Transport Models
- South African Context
 - Legacy of Apartheid
 - Rail History and Status Quo
 - Land-Use Transport Integration Relevant Policies.

2.1 Literature on Land Use and Transport

The main purpose of transportation is the movement of people and goods from one point to the next. Further to the primary purpose, transport systems contribute to how communities function as well as influence the communities' economic development form (Acheampong & Silva, 2015).

Land use refers to all activity locations, namely — residential, commercial, institutional, recreational - just to name a few. Land Use and Transport research focuses on understanding the long-term behaviour of households with regards to residential location and employment location and how each of these locations depend on each other. Residential location determines how an individual or household travels as well as the travel options available to them. Residential location combined with employment location form the choice set that leads us to the crux of understanding commuting

possibilities as well as the commuting implications of the urban spatial structure over time (Acheampong & Silva, 2015).

Transportation and land use work hand in hand and exist symbiotically. This is to say that regional travel patterns are inclined to be affected by development location as well as density, which then causes the level to which accessibility is made available by the transportation system to become a prevalent influence where land use and development patterns are concerned. It is also worth noting that urban, community or spatial design, to a large degree, informs the transportation systems put in place and can facilitate alternative travel modes. An example of this would be non-motorised transport i.e. walking and bicycles, and public transportation being facilitated by connected streets that exist in residential area with high densities and mixed-land uses. Conversely, private vehicle use becomes the preferred mode of choice where there are land development patterns that are spread out and not connected. This reduces the viability of other modes of travel (Acheampong & Silva, 2015).

Figure 1 shows that the land use locations determine where people do activities i.e. work, with the aid of transport systems. This relationship is reciprocal because the development of transport systems makes the different land use locations appealing and accessible (Bertolini, 2012).

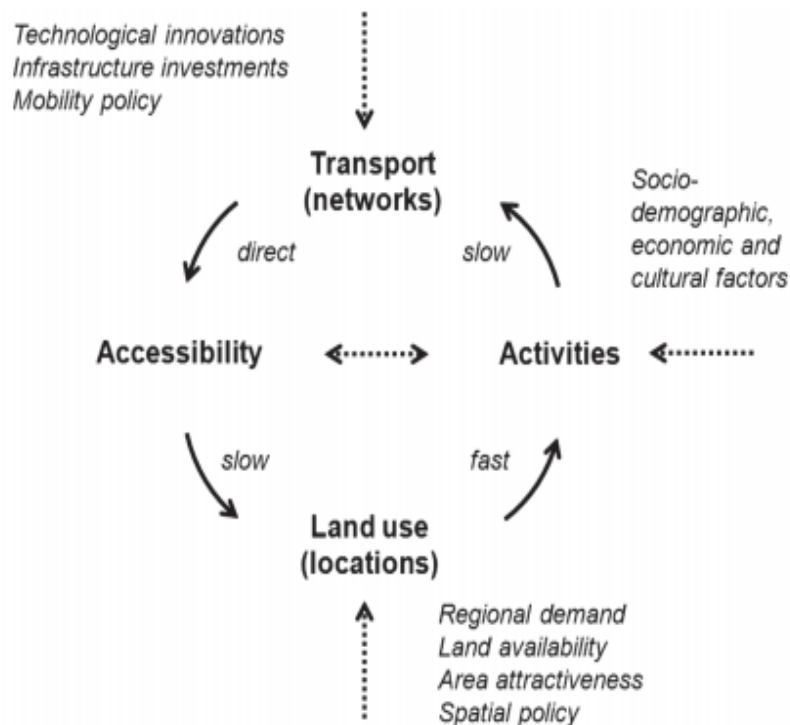


Figure 1: Transport land-use feedback

(Bertolini, 2012)

These activities and interactions by the community are to some extent influenced by whether there is a transportation connection or not. This relationship is crucial in determining whether transport interventions put in place have the desired outcome in terms of providing the kinds of options that these activities require, as opposed to just ensuring there is mobility (Department for Transport, 2014).

Review of existing literature refers to three land use characteristics that have the strongest relationship with rail transport quality and efficiency. The three land use characteristics are; land use mix, polycentrism and urban density (Cooke & Behrens, 2014) . Where land use mix speaks to the various types of land uses that are in close proximity to each other. It can occur at various scales and can also mean having different types of housing typologies and price ranges that accommodate varied demographics and income groups (Litman & Steele, 2011). Polycentrism promotes spatial equity by ensuring that there is nearby access to jobs for residential areas.

Urban density refers to the volume of commuters that use a particular public transport service (Cooke & Behrens, 2014). Density is also one of the “Three D’s” that are used to influence travel demand by changing land uses, with the two other D’s being: Diversity and Design (Ewing & Cervero, 2010). The “Three D’s” are illustrated in **Figure 2**.

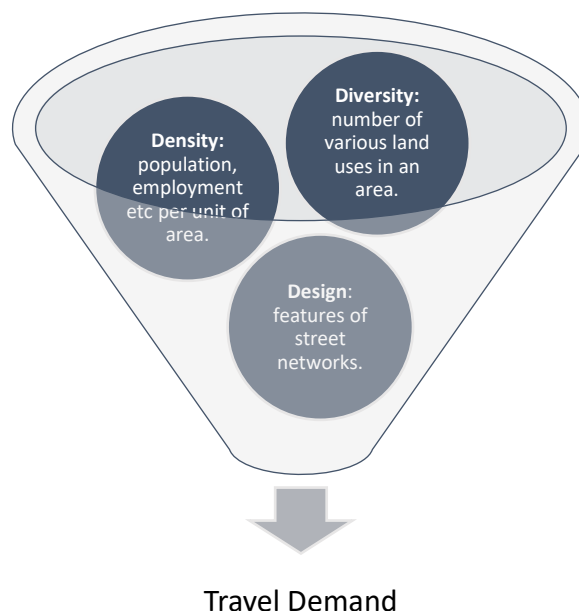


Figure 2: Three D's of land use and transport transformation
(Ewing & Cervero, 2010)

The “Three D’s” are also the main fundamentals of Transit-Oriented Development (TOD) (Gilat & Sussman, 2003). TODs provide opportunities to create local economies in communities, which will

result in a travel behaviour change because there will now be reasons to travel both to the already established cities, and the areas that are on the edges of cities that are work related. Once this need arises, there will be a need to have rail transportation modes in place to facilitate such behaviour.

It is said that the formulation of Transit Oriented Development appears to have originally come from the United States during the late 1970's and early 1980's. Transit Oriented Development can be defined as a strategic tool to improve public transport and reorganization of the spatial form of an area (McLeod, Scheurer & Curtis, 2017).

In China, the megacities have been using Transit Oriented Development along their rail stations in order to ensure that there is ridership as land use plays a significant role in influencing and ensuring an increase in passenger volumes. In Transit Oriented Development planning, the densities of developments and the built environment influence land use (Pan *et al.*, 2017).

What would it look like to place Transit Oriented Developments in the South African urban policy context? At its core, the main aim of Transit Oriented Development is supported by the underlying devotion to eradicating the socio-spatial separation resulting from the apartheid era planning (McLeod, Scheurer & Curtis, 2017). In recent times, it has been determined that there needs to be extensive research and investigation into the spatial design of urban economies as well as the spatial influence on poverty in South African cities. This also includes investigating the role that public transportation will play in the future with regards to city-planning processes as well as integrated planning in order to accomplish the desired spatial vision in a post-apartheid South African context (Grant, 2015). This is an apt conclusion, given the current landscape and geography of South African cities. Integrated public transport systems are complex all over the world, but more so in South Africa, because of the apartheid spatial legacy that has caused spatial fragmentation, this observation renders the conclusion for further research very fitting. With the severity of the spatial issues experienced in South African already recognized, there is a huge opportunity to reimagine, create and reinvent a South Africa that is has spatial equity (Beg *et al.*, 2014).

For the past 20 years, American cities have introduced light rail transit and travel oriented development in a number of communities as an integrated development strategy (Arrington, n.d.), and it is said to have had a dual function of people-moving and community-building; and has further highlighted the importance in elevating effective land use. This is an important point to consider, as an economy that is seen to be a first world country has identified a link between rail and transit orientated development not only as a tool for futuristic spatial design but also a community building catalyst. The concept of transit-oriented development is better understood by taking into consideration it's applications in America even though America is a developed country, with a different

spatial history to South Africa, because that is where the origin of transit-oriented development came from.

The integration of the different travel modes and services has been of paramount importance in trying to transform public transportation in South Africa, in order to address the issues of mobility and accessibility caused by the fragmentation of the public transport services provided, however, this has shown to be very difficult (Beg *et al.*, 2014). Hence the need for linking rail transportation with Travel Oriented Development to assist with public transport transformation and creating economically self-sustained communities that may not be in the central business districts of the cities, and to further create a need for commuters to travel in the opposite direction because there are opportunities there. This will serve as a tool for alleviating the densification of one-way traffic on rail travel.

It has been suggested before that 'urban growth management', which consists of improving road and rail access management, enables a rather reasonable envisioning of the urban spatial reform, which focuses on more paced alterations and modifications to systems that currently exist. As opposed to relying on uncertain population and employment predictions that in turn inform long-term planning (Grant, 2015).

Travel Oriented Development can be seen as a tool for social inclusion and radical spatial transformation. Its significance can be bolstered by paring it with rail transit and effective land use to modify and reimagine the urban space as we know it and turn South Africa into a more progressive and futuristic country.

2.2 Land Use and Transport Policies

The bottom line of integrated long-term land use and transport strategies cites three main sectors as key focus areas, namely; economic, social and environmental (Stanley, 2014). In light of having multiple long-term objectives, the importance of policy packaging is stressed (Stanley, 2014).

Comments on the need and advantages of integrating land use and transport planning have been of considerable importance. The development of cities around the world is hugely impacted by resolutions and commitments concerning transportation developments, location and different travel modes (Planning Institute of Australia, 2008). Integrated land use and transportation planning is ensuring that there is collaboration in land use planning and transportation infrastructure facilities and amenities that discourages the use of private vehicles (Stanley, 2014), and in turn increases public transportation usage, by grouping complementary land uses with residential areas that have high densities and are easily accessible. It also gives preference to public transportation development resources by making it the focal point of spatial design instead of new road construction that promotes private vehicle usage (Pedler & Paulley, n.d.).

The main reasons that people need to travel in regions, urban areas and cities is to access education, services, family and friends, employment, cultural and recreational opportunities. This can be viewed as a reflection of the demand for most travel. Accessibility then, is the link that holds land use and transport together. Land use and transport policy then fundamentally becomes about integration to enhance accessibility (Stanley, 2014). Other land use activities and alternative functions that serve the community are important elements in shaping a city, distributing economic opportunities, growing accessibility, limiting the need for people to travel long distances and the consolidation of communities (Stanley, 2014).

Some of the benefits of land use and transport policy integration being implemented include the following:

- Sustainable use of land.
- Low intensity and high intensity use respectively in accordance with the location and the resources and activities associated with it.
- An improved quality living environment.
- Increased productivity of the community.
- Higher public transport prevalence and less need for private vehicle use

(MoUD, 2013).

It has been concluded in the past that land use and transport integration are only effective, with regards to sustainable public transportation, if they portray private vehicle usage as less appealing. Further conclusions have been made to say that transport policies that have attempted to improve the desirability of public transport have generally failed to have a significant impact in the effective reduction of private car usage (Pedler & Paulley, n.d.).

2.3 Contra-Flow Traffic

The traffic flow in the mornings has a high volume of commuters traveling urban-region inbound and urban-region outbound in the evenings, leaving spare capacity for traffic flow in the opposite direction – which is what is referred to as contra-flow (Gauteng Department of Roads and Transport, 2013)

Current urban designs are due to the effects of spatial inequalities and colonial policies of the past that inspires an urgent need to address the social and economic injustices that exist as a result of this (Winkler, 2012). This brings about the need for contra-flow to be created to elevate this strain on our public transport systems and transport infrastructure.

The concept of contra-flow can be adopted and applied by eliminating spatial inequalities and creating multiple economic nodes in different regions. The introduction of multiple urban and economic nodes facilitates accessibility to the previously marginalized due to spatial inequalities and opens up opportunity for the need of travel in multiple directions, thus relieving congestions on the main urban networks.

Benefits can include widespread economic nodes, job creation in regions outside of urban areas, and good quality recreational centers.

In an instance that contra-flow has successfully been created, a need for infrastructure upgrades may arise. In South-East Queensland, there was an Integrated Regional Transport plan released in 1997 that highlights improvements to the public transport system since the introduction of high residential and employment densified areas. These improvements include extension and upgrade of the rail network, expansion of the busway network to cover a larger geographical area and upgrading bus and rail stations (Department of Transport and Main Roads, 2011) . As a result, these services are able to handle high volumes of commuters in either direction during peak periods, lending itself to the aforementioned contra-flow benefits.

2.4 Transport Modelling

2.4.1 The Four Step Model

Transportation planning applications have been used since the 1950s in the United States and have been progressing and improving with time (McNally, 2007). Planners have historically used approaches such as the gravity-based model for traffic estimations and later progressed to the aggregate four-step model approach in the mid-twentieth century (Sivakumar, 2007). The evolution of transportation planning has seen expansions and improvements in procedures and processes, which is what then resulted in the four-step model. The first application of the four-step model was by the Chicago Area Transport Study in 1955 as it used trip generation, trip distribution, modal split as well as traffic assignment to predict and forecast travel. This spearheaded the development and refinement of the four-step model as we know it today (Weiner, 2007). Integrated Land Use Transport Models were also developed in the 1950s and 60s due to the realisation that urban systems are intricate, and although advanced Land Use Models are disaggregate, many models also still follow the four-step model approach (Sivakumar, 2007).

The current four-step model as we know it today is illustrated in **Figure 3** and traditionally includes:

1. Trip Generation – determination of the number of trips produced by and attracted to each zone.

2. Trip Distribution – prediction of origin-destination flows.
3. Modal Split – prediction of travel demand that will use a certain type of mode between the origin and destinations.
4. Trip Assignment – placing respective modes on specific route in the network.

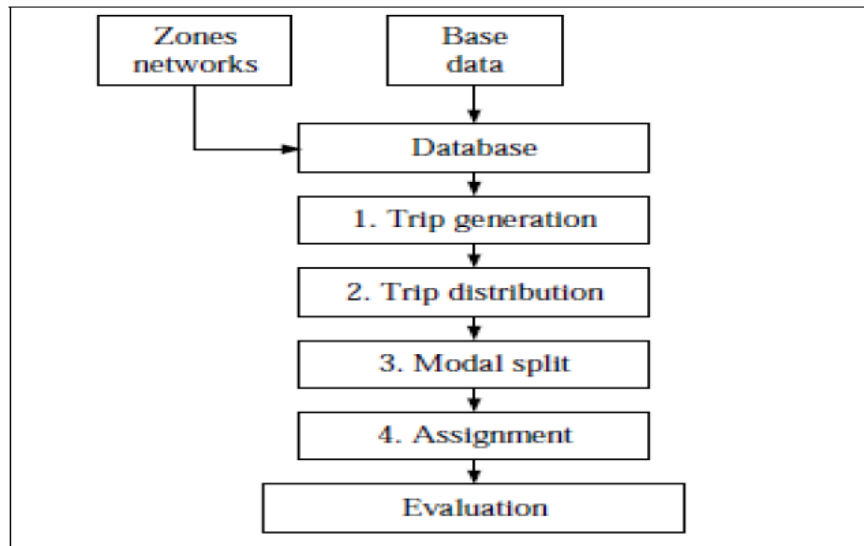


Figure 3: The traditional four-step transport planning model

(Tsekeris & Tsekeris, 2011)

In aggregate models, there is direct proportionality between the trips a zone generates and the population of the zone, as well as direct proportionality between the trips a zone attracts and the number of attractions in the zone, however, there is inverse proportionality between travel and distance between zones. Disaggregate models are different to aggregate models in the sense that they consider individual characteristics for the model as opposed to zonal characterisation of aggregate models (Sivakumar, 2007). This approach is useful when there are data limitations as it can happen because it isn't always possible to get that level (individual) of data. The different models according to their aggregation are listed in the next section **2.4.2.1**.

2.4.2 Strategic Transport Modelling

Strategic Modelling is used when investigating policy development and planning of strategies (ATAP, 2016). Strategic transport models are typically models that cover large areas at an aggregate level (Smith & Blewitt, 2010). They are used for investigating metropolitan or regional transport projects (Perold & Andersen, 2000) like building new roads by predicting travel demand and traffic conditions for future scenarios (Flügel *et al.*, 2014).

In a South African context, a rail strategic modelling approach will depend on the circumstances, constraints as well as the needs of the area the modelling is based on (Perold & Andersen, 2000), these can range from spatial considerations to socio-economic factors.

Strategic transport modelling can be developed using the four-step model approach (Flügel *et al.*, 2014, ATAP, 2016).

2.4.2.1 Different Transport Models

There are five transport models i.e. sketch planning models, macroscopic models, mesoscopic models, microscopic models as well as nanoscopic models (Vanderschuren, 2006). These models mainly differ in the extent as to which they model areas geographically and the level of detail that's being modelled. Macroscopic models are used to model large areas like regional networks, whereas mesoscopic models are representations of models somewhere in-between macro and micro models. They can represent individual road links and tend to be more precise. Microscopic models are used to model smaller networks like a section of road (Hardy & Wunderlich, 2007). Nanoscopic models are an extension of microscopic models in that they are used for more detailed models and are also specific to a certain road section or corridor, where sketch planning models are also an extension of macroscopic models but less detailed. They are both based on the four-step model but can be custom-made as desired (Vanderschuren, 2006).

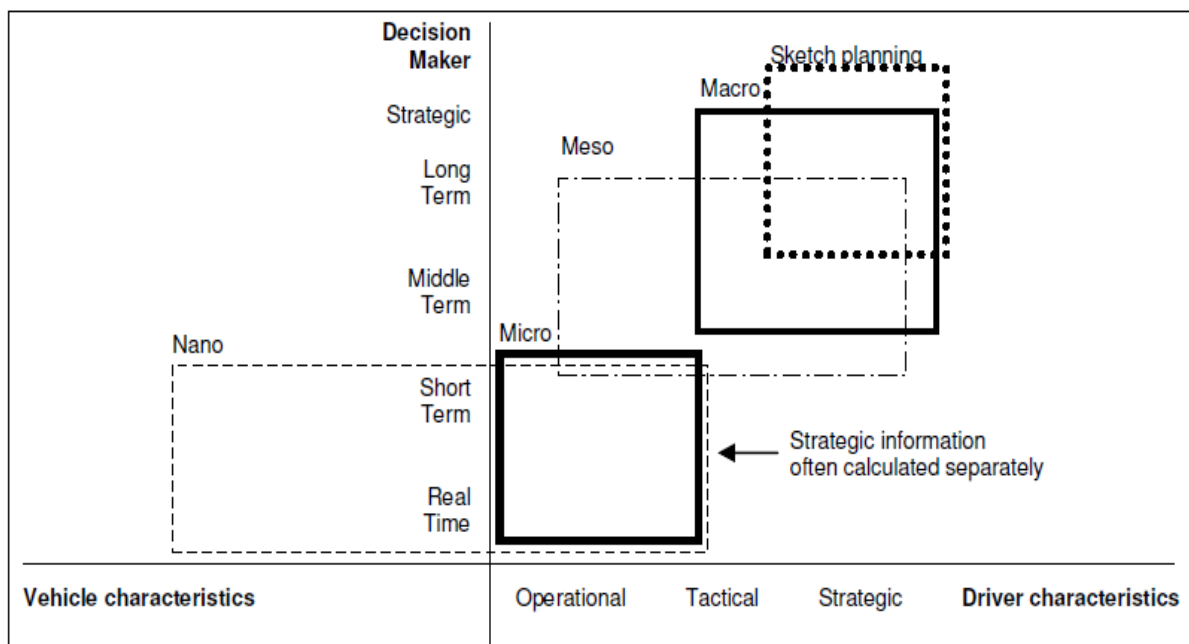


Figure 4: Different Modelling Approaches

(Vanderschuren, 2006)

Figure 4 shows that both macroscopic and sketch planning models are ideal for strategic modelling as they can be used to assist with decision making for policy making and evaluation of strategies that need to be implemented. These models are used to investigate alternative land use scenarios (NASEM, 2018) and are used to model provincial and metropolitan changes (Vanderschuren, 2006).

A macroscopic strategic model is best suited for this dissertation because the case study is large-scale i.e. metropolitan and also seeks to develop various development scenarios that are informed by planned strategies and policies that alter the land-use of the study area. A sketch planning model would not be ideal for this dissertation as it estimates the overall impact of strategies and are highly aggregated.

2.4.2.2 Data Requirements

Strategic models mainly require planning information like future land use and population that is usually used to determine trip matrices for different development scenarios (Perold & Andersen, 2000). Exact data requirements are determined by a specific model's objectives and desired outputs, similarly, a model is also influenced by the type of information that is available. (Department for Transport, 2014).

Below is the list of the type of data needed:

- Input data for the base model;
- Additional data to calibrate the base model;
- Input data for the future scenario and;
- Policies that can be tested if the model requires.

Typical specific data requirements are:

- Population
- Household income
- Employment status etc.

2.4.2.3 Model Development

Strategic models require the study area to be divided into zones (Flügel *et al.*, 2014). This is done upon establishing the problem statement and research methodology, and the individual zones are called Transport Analysis Zones (TAZs) (McNally, 2007). This is the first step of developing the model network. The number of the TAZs is determined by the nature and extent of the model i.e. the amount of data available. Even though the study area has boundaries, areas outside of the study areas can

influence the model, it is therefore at the modeller's discretion to include the area and to what extent (Smith & Blewitt, 2010).

2.4.2.3.1 Base Model

Base Modelling is a prerequisite for any traffic modelling exercises to take place effectively. In initiating the process of predicting how future traffic systems will operate and perform. There is a need to have an accurate view of current conditions, which will provide a benchmark to measure future traffic scenarios against (Smith & Blewitt, 2010). Having an accurate and validated representation of current conditions will allow effective assessments of traffic modelling predictions and take into account all influencing factors of a site, area or region.

2.4.2.3.1.1 Base Model Calibration

It is important to note that the base model must accurately represent reality. To ensure that the results reflect the observed behaviour and data well enough, calibration is employed (Cisilia & Stina, 2014). It is crucial that, data that is collected provides a clear picture of travel behaviour (McNally, 2007). Because calibration precedes the traffic models, it is the accuracy standard, and therefore the modellers techniques must be carefully considered, and great care must be taken with the methods of gathering the data (Smith & Blewitt, 2010).

There is a variety of methods to gather data. One method is that of surveys. An example being household travel surveys, where much of the data that is to be calibrated is obtained by means of travel activity diaries. These provide different categories of data. Namely, activity travel data, which refers to departure and arrival times, duration of travel, mode of travel, and distance of travel amongst other things; household vehicle data; and household socio economic status, referring to income, members of household and more (McNally, 2007).

With these different methods of data collection, data that is collected must be verifiable and quantifiable. This is important because the requirement to adjust model parameters may arise to accurately recreate observed behaviour (Smith & Blewitt, 2010).

The data collected for base model calibration also gives us some of the data needed for base model validation.

2.4.2.3.1.2 Base Model Validation

The process of validation is undertaken to ensure that the model calibrated has been calibrated correctly and by this virtue has the ability to sufficiently create valid predictions for future scenarios. Validation is achieved by measuring base model calibration output against observed data that is not the same as the data used in calibration, comparing the two and evaluating accuracy (Smith & Blewitt,

2010). Accuracy must take priority in order to have a credible benchmark for creating future scenarios and to inform the efficiency with which parameters may be adjusted when and as needed.

Macroscopic validation can help us improve the model (Knoop & Buisson, 2013). This highlights that the various methods of data collection may return results that are contrary to one another and cause the calibration to have seemingly inaccurate parameters and predictions. There are tools at the disposal of the modeller to reconcile the model results using macroscopic validation.

2.4.2.3.2 Scenario Model

Strategic transport models are used to interrogate future scenarios. They take into account particulars such as evolved land use, and future spatial patterns to predict future traffic conditions and travel demands (Flügel *et al.*, 2014). These strategic transport models rely heavily on scenario models.

To effectively understand the development of future scenario models. The comprehension of the relationship between new proposals and assumptions is imperative. New proposals may arise as a result of new infrastructure development or existing infrastructure modification. The nature of new proposals is such that, traffic behaviour cannot be observed or tracked from reality. Thus, creating the need to formulate assumptions based on these new proposals. Each and every assumption must be determined utilising an approach that is logical, informed by data that is already available that may be applicable to the new proposal (Smith & Blewitt, 2010). Once logical assumptions have been established, future scenarios may be predicted, derived from the base model, in a manner that is coherent.

2.4.2.3.3 Modelling Results

The modelling results of a strategic land use model include:

- Base Model
 - A model depicting reality of the status quo and
 - A detailed assessment of the status quo
- Future Model
 - Model depicting the impact of a change in land use and
 - A detailed assessment of the future scenario

2.4.2.4 Shortcomings of Strategic Transport Models

Sivakumar (2007) lists the following as flaws associated with Strategic Transport Models:

- A limited demonstration of individuals travel behaviour because of their aggregate nature i.e. modelling of households.

- Extreme spatial aggregation

However, these shortcomings will not affect nor impact this research because this dissertation does not seek to investigate the isolated travel behaviour of individuals or households.

2.5 South African Context

2.5.1 Legacy of Apartheid

The legacy of apartheid has been a huge contributor to the problems that South Africa faces in relation to transport because a large population of Black People in South Africa still live in areas far from the city centre (Stanley, Janet & Lucas, 2013a)

For most part of the South African history, there is a reflection of the discriminatory planning of the apartheid government, with the government's stance made clear in May of 1952 by the then Minister of Native Affairs, Dr Hendrick F Verwoerd in a speech that stipulated that settlement areas assigned or set aside for black dwellers must be situated outside of the central business district, or the city as it were. Further to this, these settlements which are more commonly referred to as townships, it was specified that the black townships must be very far from the city and that there must be no possibility of them spilling over into areas with people of other races in them (Williams, 2000).

Special care was taken with the risk of black townships spilling over into particularly white areas so there were additions to the aforementioned stipulations. Above and beyond the distance from the white areas and the cities, and the space allowed for expansion, the design was to include industrial sites between the black townships and the cities to stretch this distance further. Further to all of this, black people were to be obliged to make use of trains (Williams, 2000) as they were placed very far from national roads or roads that would lead to town.

The spatial issues in the Gauteng Province are further worsened by new influx caused by migration as many people travel to the province in search of better economic opportunities i.e. employment (Gauteng Department of Human Settlements, 2014). The main spatial problems the city struggles with are:

- Highly fragmented spatial developments, socio-economic disintegration that sees poor people still located further away from economic hubs and,
- Weak integration between land use and transport (Gauteng Provincial Government, 2016).

2.5.1.1 *Spatial Effects of Apartheid on Transport*

South Africa's public transport system is heavily influenced and shaped by these spatial policies that were in place during apartheid. These policies placed people of low-income groups in the outskirts of

cities (Salazar Ferro, Behrens & Wilkinson, 2013). About 30% of South African households have access to a car (Stanley, Janet & Lucas, 2013b). This means that more than half the population is reliant on public transport to get around, i.e. minibus taxis, trains, buses, and non-motorised transport. However, from the late 90's, rail and bus services have witnessed a rapid decline in service quality (Salazar Ferro, Behrens & Wilkinson, 2013).

2.5.2 Rail History and Status Quo

South Africa's current rail systems are still feeding into a network that is being transformed to counter the effects of the afore mentioned spatial fragmentation, however, there is an opportunity to align the future of rail in the direction of the changing and evolving cities in South Africa where spatial design is concerned.

South Africa's rail system has significantly reached and passed its peak when it comes to passenger transport (Department of Transport, 2017), even though it still services the country's metropolitan areas.

"Rail serves an important travellers' market in metropolitan areas." (Onderwater, 2012). 39.1% of the South African metropolitan population use public transport for work purposes, with 9.2% using trains as their chosen mode of transport. 5.5% of the metropolitan population uses trains for educational purposes. No train trips have been recorded for social and leisure purposes (StatsSA, 2014).

In comparison to the first half of 2014/15, Metrorail has recorded a loss of 73 million passengers in the first half of 2016/17. PRASA has highlighted the lack of co-ordination, integration and alignment of rail planning and development with land-use planning as one of the main issues contributing to the state of rail service and utilisation in the main urban areas (PRASA, 2017). This also influences the lack of rail network connectivity to growing and emerging centres. It is, however, envisioned that by 2050 all high-density Metropolitan areas in South Africa will be commuter rail connectivity i.e. residential areas will be now be connected to central business districts (Department of Transport, n.d.).

To contextualise the lack of coordination, integration and alignment of rail planning and development in tandem with land-use, the history of South African rail is highlighted.

The South African rail infrastructure was developed in the 1860s. Though built by the Cape and Natal Railway Companies they were soon taken over by the government. And as is well known that the government of South Africa in this era prioritized the minority white population where access to socio economic services and opportunities is concerned (Perkins, n.d.). This is important to note because rail was pivotal in the building of the South African economic infrastructure in these times. The

economic development of South Africa was largely contributed to by the inception of rail (Department of Transport, 2017).

Rail transport was primarily developed out of the need for a more efficient form of mass transport to fully take advantage of moving and exporting the then newly discovered mineral richness of South Africa, at this point largely based on agriculture (TFR, n.d.). The demand and intensity increased in 1868 when diamonds and further in 1886 when gold was discovered. Though early development was in the coastal cities, the gold rush of the then Witwatersrand, Transvaal, inspired Cecil John Rhodes of the British South Africa Company in 1889 to enter into contractual agreement with the Cape Government for the construction of the railway from Kimberly Vryburg. The first of many developments eventually resulting in the completion and opening of a railway line from Natal to the boarder of the Transvaal by April 1891 (TFR, n.d.).

The Netherlands Railway Company was at the helm of the construction of this railway line, until the government imposed itself and assumed the role of finishing off whatever construction was outstanding and manning the operations (Perkins, n.d.).

Alternative forms and avenues of transport did in this time arise and some demand switched the methods of transportation however a lot of infrastructure, time and money had already been invested in rail network as the backbone.

Subsequent to the above-mentioned diversification, what had been known in the 1970's as South African Railways and Harbours (SAR&H) was implored by the government to pivot into a stream of funnelled business focus. With change like this, a name change was almost an inevitability, and in 1981 SAR&H became South African Transport Services (SATS) with a renewed mandate of focusing localised infrastructure and management to match the need to transport people locally without forsaking the transportation of goods over long distances (TFR, n.d.). We understand rail to be a mode of transport to be safe, however, there are technologies that are outdated that put in jeopardy this safety and reliability (Department of Transport, 2017). In 1990 SATS was changed from being a state owned and run enterprise into a limited organization named Transnet, the rail business division being Spoornet to be later renamed to Transnet Freight Rail (TFR, n.d.). We can presume this to have been a concerted effort in aligning with policies constructed in this era of transition aimed at restoring integrity and confidence in the rail system. Along with the pressure of being labelled the backbone of South Africa's transports sector, comes a socio-economic responsibility that expects rail to provide unsurpassed quality of service in certain areas or corridors of travel, without compromising capacity and efficiency targets and have ease of access to and from other modes of travel in cases where this is needed (Department of Transport, 2015).

With the long history of the development of rail, it is only fair that the perspective of the commuter and their interaction with rail transport be explored for us to fully comprehend the current status of rail, it's relation to land use and impact on commuters. This view equips us with the necessary knowledge to recommend solutions that will consider the rail history that birthed the current rail network along with its accomplishments and shortcomings.

The current Gauteng rail network speaks to the historical spatial design and fragmentation of the Apartheid Regime where the primary concern was getting workers from townships to the CBD and back home seamlessly, a relationship between rail and land-use that in the present-day impacts rail commuter behaviour. We can see this in **Figure 5** by the way in which the network seems to converge between Germiston Station and Johannesburg Park station. This leaves room for new policies for integrated land-use and transport policies to be explored and the feasibility thereof implemented (Vanderschuren & Van Maarsseveen, 2001).

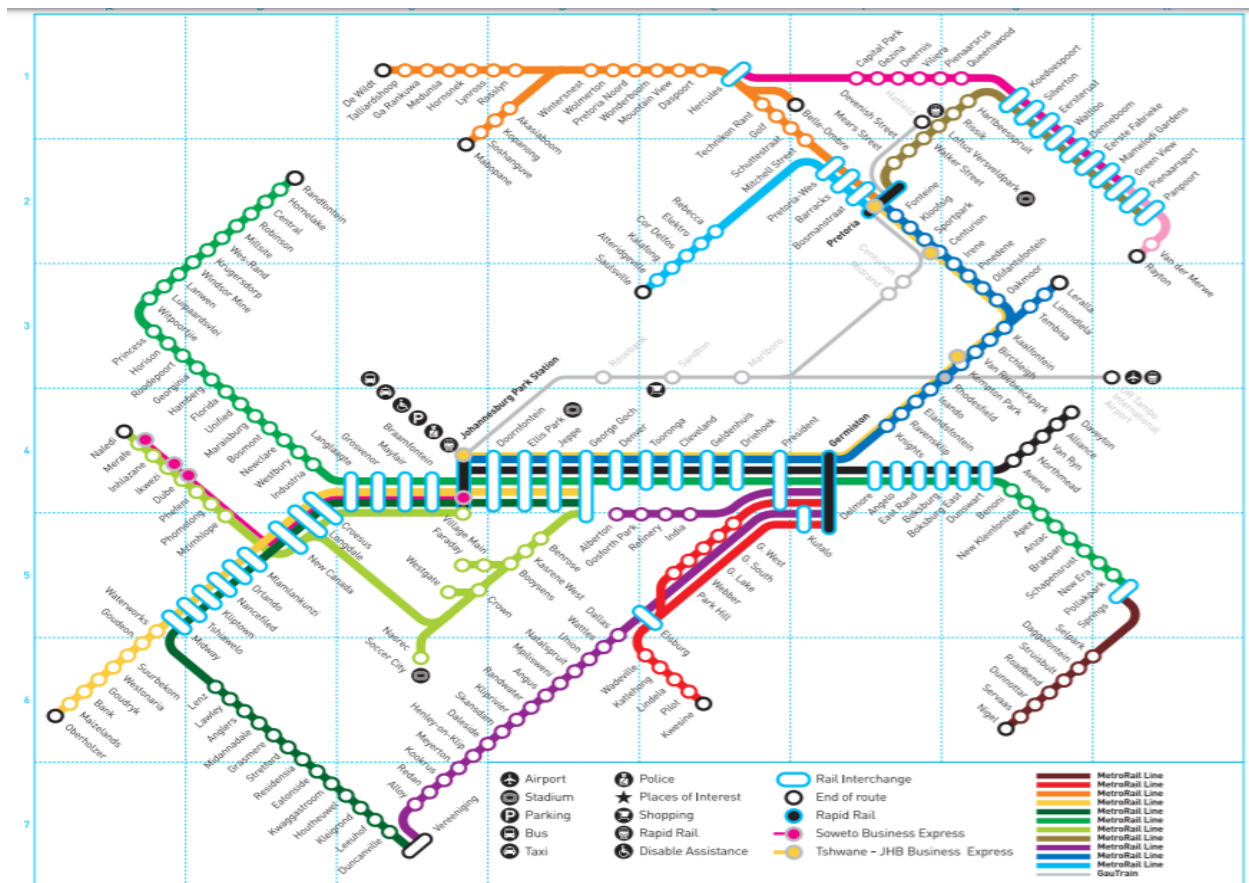


Figure 5: Gauteng Rail Network
(Metrorail, 2018)

2.5.3 Land-use Transport Integration relevant Policies

In most parts of the world, public transport, and rail systems in particular, are the responsibility of the government and they rely on the government for their strategy (Nash, 2014). It is therefore crucial that relevant policies, strategies, and legislation put in place by the government are well planned and implemented adequately.

Sub-Saharan Africa still experiences meagre performance of spatial planning and this can be attributed to factors like insufficient planning systems, planning regulations, a colonial legacy, building standards, ineffective urban land strategies, as well as the scarcity of skilled professionals in the build environment field of work, among others. While in the former colonial governance, the planning legislation was revised frequently and there was no shortage of the above-mentioned tools and skills (Silva, 2012).

Post the apartheid era, South Africa produced transport policies that prioritise affordable, fair, efficient, viable and sustainable public transportation - the first policy was the White Paper on National Transport Policy. This White Paper stated that public transport is to be encouraged over private mobile vehicle use, and travel time & distance must be limited to a maximum of one hour or forty kilometres in each direction (Cooke & Behrens, 2014).

The relevant policies that will be covered in this paper are:

- National Development Plan
- National Land Transport Act (No.5 of 2009)
- National Land Transport Strategic Framework
- White Paper on National Transport Policy

These documents stipulate the necessity to have excellence public transport in order to ensure that South Africans have access to employment, education and other crucial services and activities. Each policy is briefly highlighted in **Table 1** in terms of its objectives on land and transport integration.

Table 1: Policies and Land Use - Transport Objectives

Policy	Land Use – Transport Objectives
National Development Plan	<ul style="list-style-type: none"> • Ensure that all informal settlements are upgraded and are located on suitable land by the year 2030. • Make sure that there are more people who live in areas close to where they work. • Ensure that there is better quality public transport.

	<ul style="list-style-type: none"> • Ensure that there are more job opportunities in close proximity to townships.
National Land Transport Act (No.5 of 2009)	<p>Integrate land transport with land use and economic planning and development by:</p> <ul style="list-style-type: none"> • Corridor development • Densification • Infilling • Guiding land use planning and development planning through transport planning.
National Land Transport Strategic Framework	Seeks to promote the development of urban land use restructuring programmes i.e. Urban Renewal Strategy
White Paper on National Transport Policy	<ul style="list-style-type: none"> • Encourages efficient urban land use structures • Supports spatial equity

Though there is evidence of spatial transformation and strategic tools for transportation in place. South Africa needs stricter and more rigid compliance policies where the monitoring of the progress of these transformations and the implementations of these strategies are concerned. A process to identify the right talent and skillset to carry out the implementation and policing of these policies must be established and acted upon with haste.

3 STUDY AREA

Chapter 3 of this research paper provides a description of the study area and its characteristics, that will be considered when developing the strategic transport model. The extents of the study area are shown in **Figure 6**. The study area was chosen because it is perfectly located for the purposes of this study i.e. there is a central business district with surrounding peripheral residential areas. The area is located in the City of Johannesburg and is primarily made up of the following areas: Johannesburg Inner City, Soweto, and immediate surrounding areas.

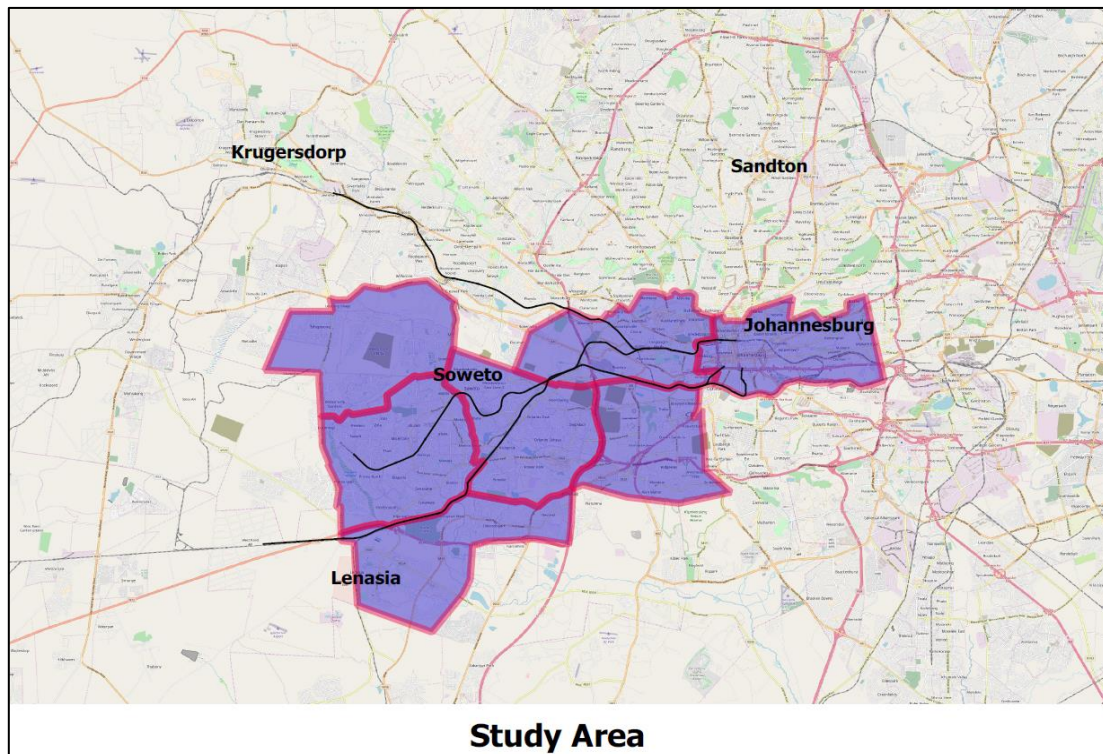


Figure 6: Study Area Locality

The City of Johannesburg is located in the Gauteng Province and has seven regions i.e. Region A: Midrand, Region B: Sandton, Region C: Roodepoort, Region D: Soweto, Region E: Alexandra, Region F: Johannesburg Inner City and Region G: Ennerdale. The locality of the regions is shown in **Figure 7**. The regions of concern for this dissertation are Region D: Soweto and Region F: Johannesburg Inner City.

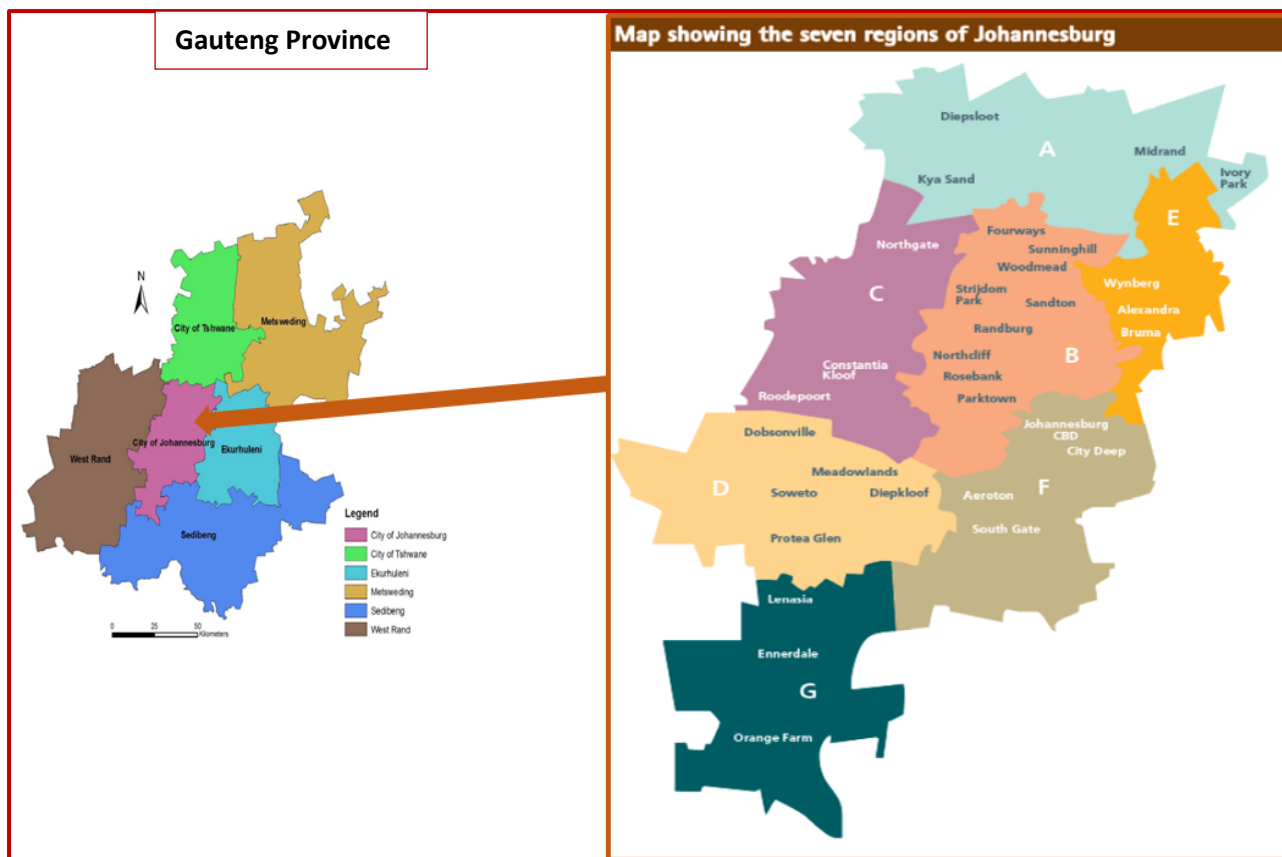


Figure 7: City of Johannesburg and its seven regions

3.1 Population

The relationship between land-use and transport infrastructure would be incomplete without exploring the influence of population on this relationship. Ergo, it is fitting that the study area, Johannesburg, with 5.4 million people is the biggest metropolitan municipality in South Africa forecasted to reach 7.6 million people within the next 20 years. Between 2001 and 2017, population density climbed from 1 962 people per kilometer squared to what some may view as a staggering 2 698 people per kilometer squared (City of Johannesburg, 2019).

The people of Johannesburg, the capital city of one of nine South African provinces Gauteng, account for 36% of the province and 8% of the country where population is concerned. The estimation of number of households in 2016 was at 1.85 million projected to reach 2.16 million by 2021. And of the 1.85 Million, there is a 36% female headed to 62% male headed split (City of Johannesburg, 2019).

In a country as big and as diverse as South Africa, from landscape to the people that occupy the physical environment, Johannesburg albeit recording an average of 3.01% growth in population every year between the years of 2007 to 2017, the city was perceived to be relatively steady in this time period estimating each household to have 3 individuals with this number estimated to decline (City of Johannesburg, 2019).

3.2 Employment Rates

Inherent within the diverse and colourful nature of Johannesburg, is the element of inequality. Speculated to be amongst the cities with the highest propensity of inequality, and with a history associated with spatial design that fragmented people by race, Johannesburg is seemingly fighting a losing battle against poverty and inequality. Unemployment plagues the city with about 40% of it being classified as youth unemployment. It should come as no surprise that 37% of the population of Johannesburg survives below the poverty line. The barriers to meaningful transformation could be attributed to a number of factors, but amongst the largest is the persisting spatial inequality, less than desirable skills at the disposal of the city and a disconnect between opportunity and population competency (City of Johannesburg, 2019).

Table 2 illustrates the employment statistics of the two main areas of the study area i.e. Soweto and the Johannesburg Inner City. The table shows that 44% of the Johannesburg Inner City population is employed versus 29% of the Soweto population. 54% of the Soweto population is not economically active, whereas 46% of the Johannesburg Inner City is economically inactive.

Table 2: Employment Statistics of Soweto and the Johannesburg City Centre

Employment Statistics 2011	Johannesburg Inner City	Soweto
Employed	266883	319935
Unemployed	58974	186015
Not Economically Active	282699	593037

Source: www.joburg.org.za

3.3 Land Use Patterns

The city of Johannesburg is riddled with spatial inequality and that has seen disparities between the city's location of jobs and location of where people live. This has resulted in many of the city's residential communities experiencing long distance commuting because they have little land use diversity and are located the furthest from economic opportunities (City of Johannesburg, 2016). The city's current monocentric nature is illustrated in **Figure 8** and shows how townships are separated from economic hubs. (City of Johannesburg, 2016)

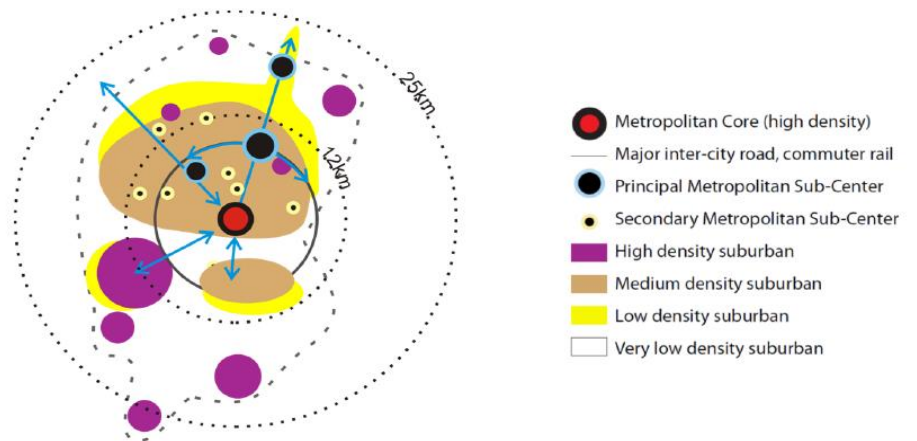


Figure 8: Johannesburg's Current Metropolitan Structure
(City of Johannesburg, 2016)

However, the city's spatial transformation vision of the SDF 2040 is aimed at eliminating these disparities by transforming the city using the compact polycentric growth model that will see the city bringing jobs to residential areas and also introducing house in economic hubs (City of Johannesburg, 2016). This will ensure that people live close to where they work. This is illustrated in **Figure 9**.

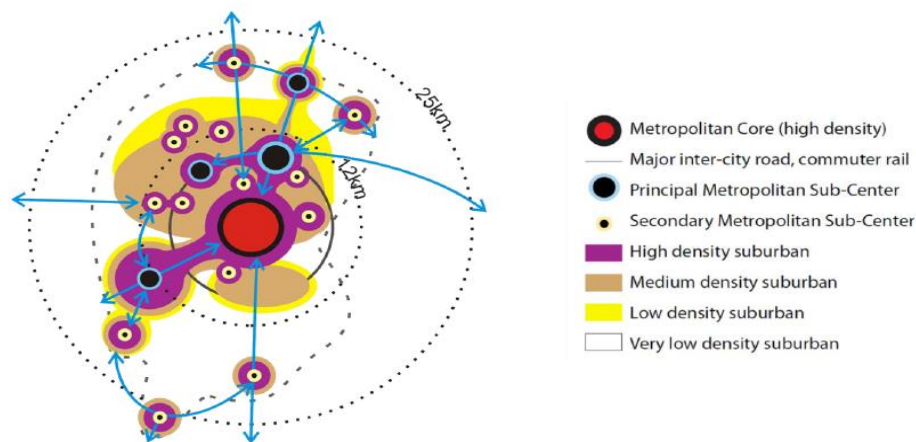


Figure 9: Johannesburg's Future City Model: Compact Polycentric Urban Form
(City of Johannesburg, 2016)

Spatial transformation in Johannesburg has been prevalent since the post-apartheid era after 1994, characterised by the introduction of newly developed suburban nodes and cities on the peripheries, as well as the development of gated communities. There has also been an increase in the number of housing provided by the government as well as informal settlements. There has been a shift in the densification and racial change in the city, however this level of de-racialisation mostly happened in middle class extents, with lower class areas still experiencing immense spatial separations (Todes, 2012).

Development in the Johannesburg inner city shows the transformation, redevelopment and re-envisioning of the spatial form of the city – and by extension, the transformation of the spatial design of its surrounding areas which is evident in the history and current developments in the city (Bremner, 2000). But what of spatial planning in relation to forms of transport? The means with which the people employ to commute in this transforming urban and township landscape. Public transport plays a role in ensuring that there is social inclusion. The relationship between people who are deprived of mobility and the risk of having reduced economic opportunities has been determined by understanding transport in terms of the concept of social exclusion (Stanley & Lucas, 2013).

It is acknowledged that the envisaged polycentric spatial network for the city will take years or even decades. The spatial development strategies will facilitate or support the development of the polycentric spatial form (Gauteng Provincial Government, 2016):

- Taking advantage of proximity – this means ensuring that there are higher densities that are close to economic hubs and good public transport systems;
- Managing new settlement development – moving away from expanding residential developments outwards and focusing on infill development and densification. This will ensure that new settlements feed into the polycentric provincial network.

These settlements that already exist, the spatial redevelopment will be achieved by employing the strategies below:

- Economic Consideration – Ensuring that township redevelopment, where there are high densities, are connected to economic hubs through public transport in order to develop diverse economic activities.
- Social and Local Economic Support – social and local economic support will focus on skills development in the areas and development of local economies and ensuring that township with fewer densities have strengthened public transport connections.

3.4 Economic Activity Areas

The City of Johannesburg CBD is considered one of the core economic activity areas in the Gauteng Province along with the City of Tshwane CBD and the OR Tambo International Airport. The Johannesburg CBD houses a significant portion of the retail and office sector businesses. The remaining bulk of these sectors are situated in Sandton, Fourways and Sandton. (Gauteng Department of Roads and Transport, 2013). **Figure 10** shows the location of all the economic nodes in the Gauteng Province. The majority of the economic nodes are situated in the north of Johannesburg whereas Soweto and Orange Farm are home to the biggest population of underprivileged societies which are

located south west and south of Johannesburg, respectively. This further perpetuates the marginalisation of these less economically disadvantaged areas. Some of the nodes situated in the north include Midrand, Kyalami, Marlboro and Linbro Park (Gauteng Department of Roads and Transport, 2013).

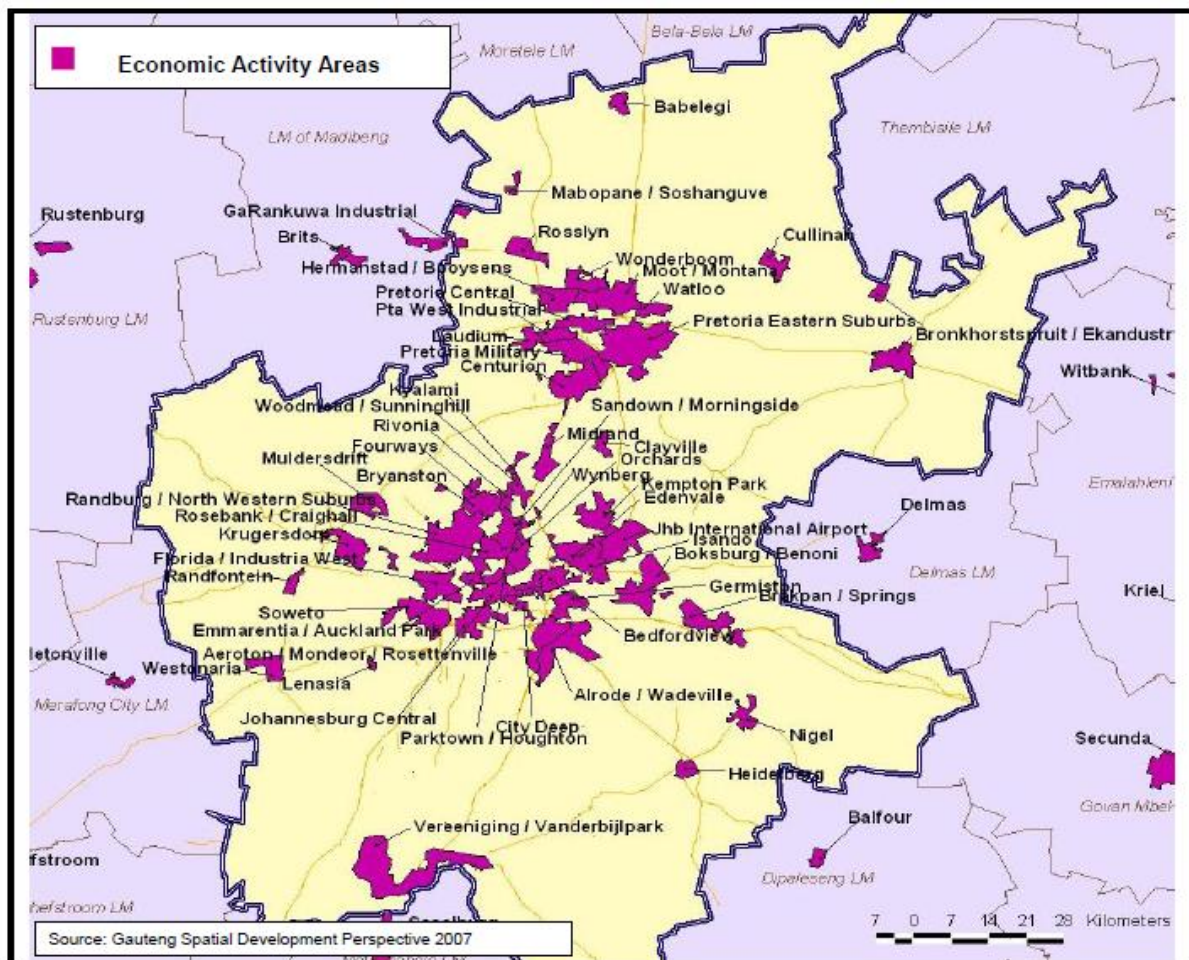


Figure 10: Gauteng Economic Areas
 Source: (Gauteng Department of Roads and Transport, 2013)

3.5 Transport Modes

The main modes of transport covered in this section are Commuter Rail, Buses, Minibus Taxis and Non-Motorised Transport.

3.5.1 Commuter Rail

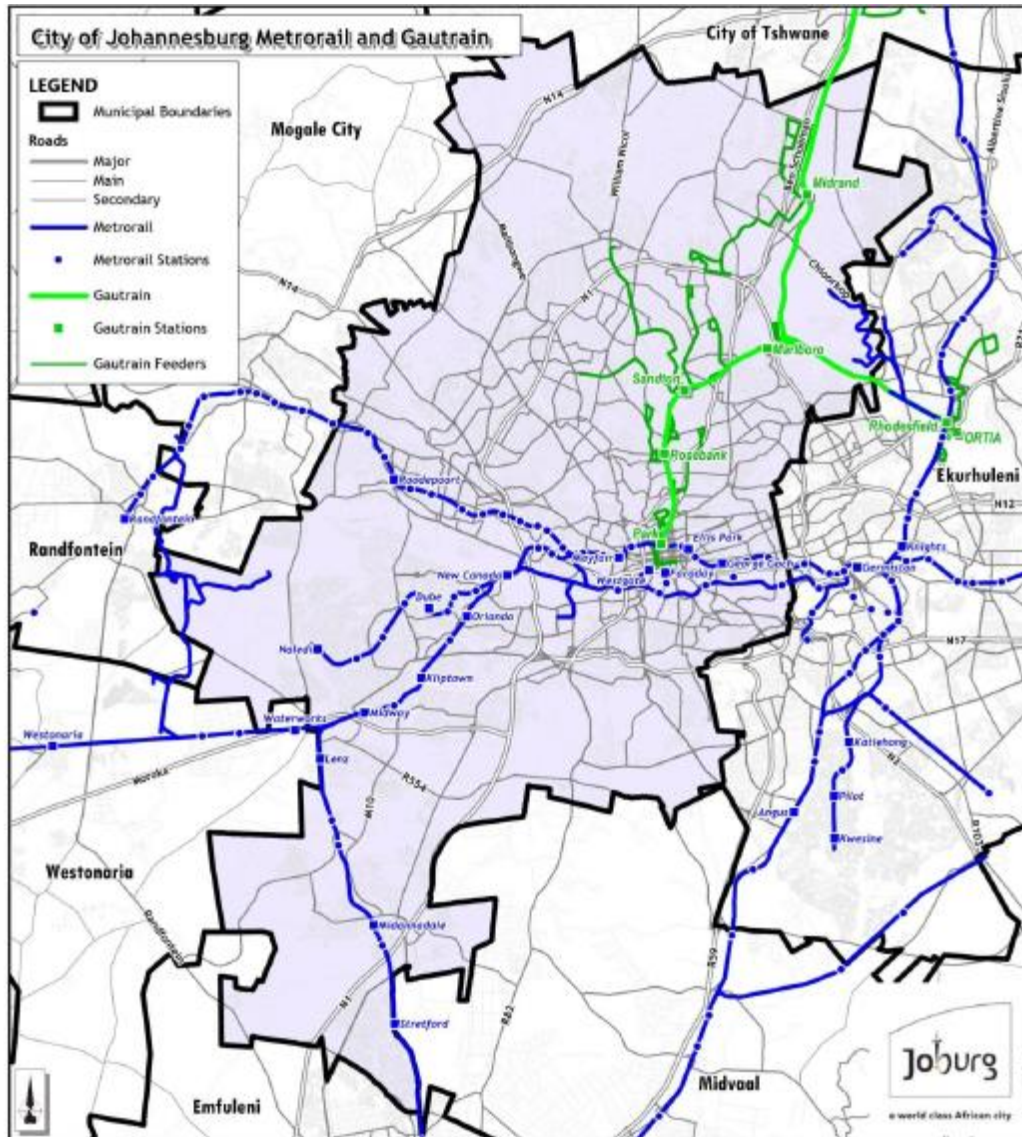


Figure 11: Metrorail and Gautrain Networks and Stations

Source: (City of Johannesburg, 2013)

The City of Johannesburg has a total of 55 train stations (City of Johannesburg, 2013). The Naledi – Joburg railway line is considered one of the busiest in South Africa (Gauteng Department of Roads and Transport, 2013). Naledi station is situated in Soweto and Joburg Station (Park Station) is situated in the Johannesburg Inner City. The Johannesburg railway network is illustrated in **Figure 11** and shows that the Gautrain services the northern part of Johannesburg, whereas Metrorail is the primary rail service in the southern part of Johannesburg. The Joburg – Randfontein line runs through the mining belt that the Gauteng Province seeks to redevelop into residential, commercial and industrial land uses (Gauteng Department of Roads and Transport, 2013).

3.5.2 Buses and Bus Rapid Transit System

The City of Johannesburg Bus Rapid Transit System as well as the Bus Route Network are shown in **Figure 13** and **Figure 14** respectively.

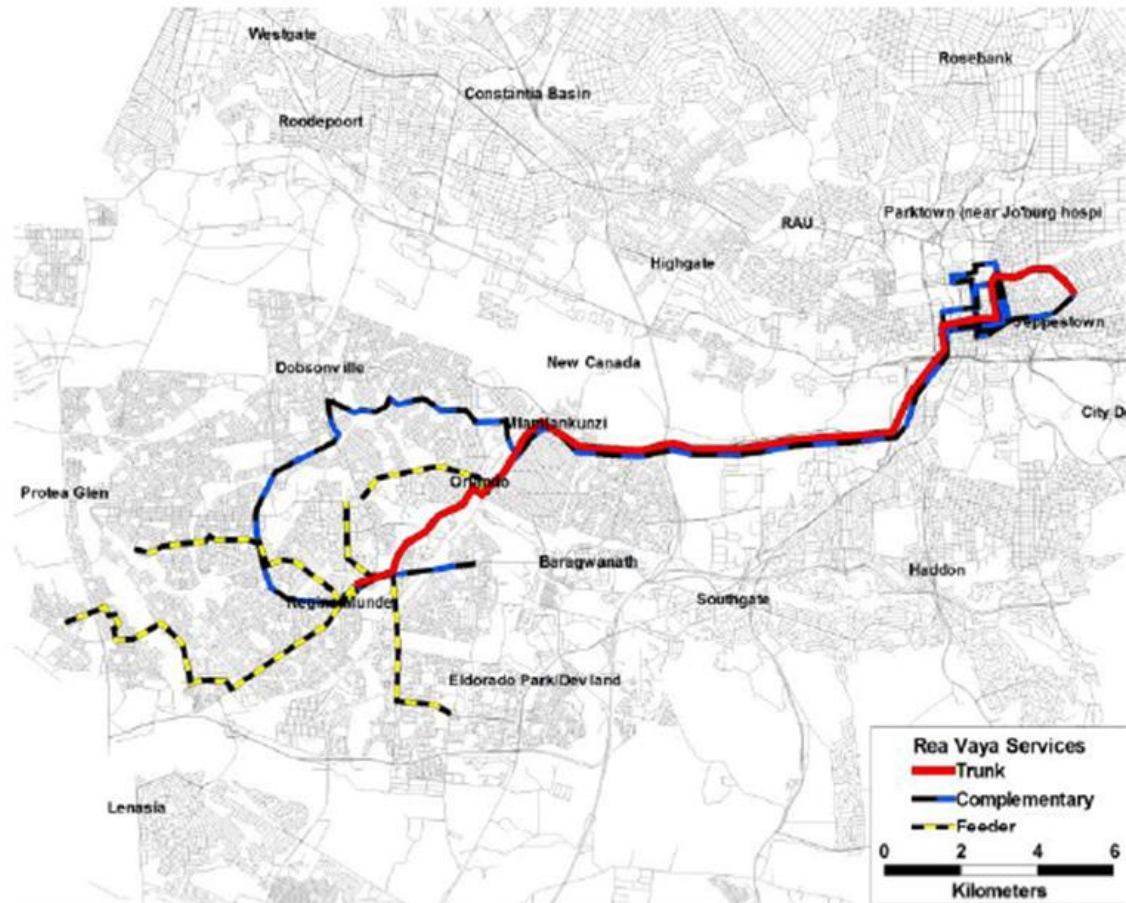


Figure 13: City of Johannesburg BRT Network

Source: (City of Johannesburg, 2013)

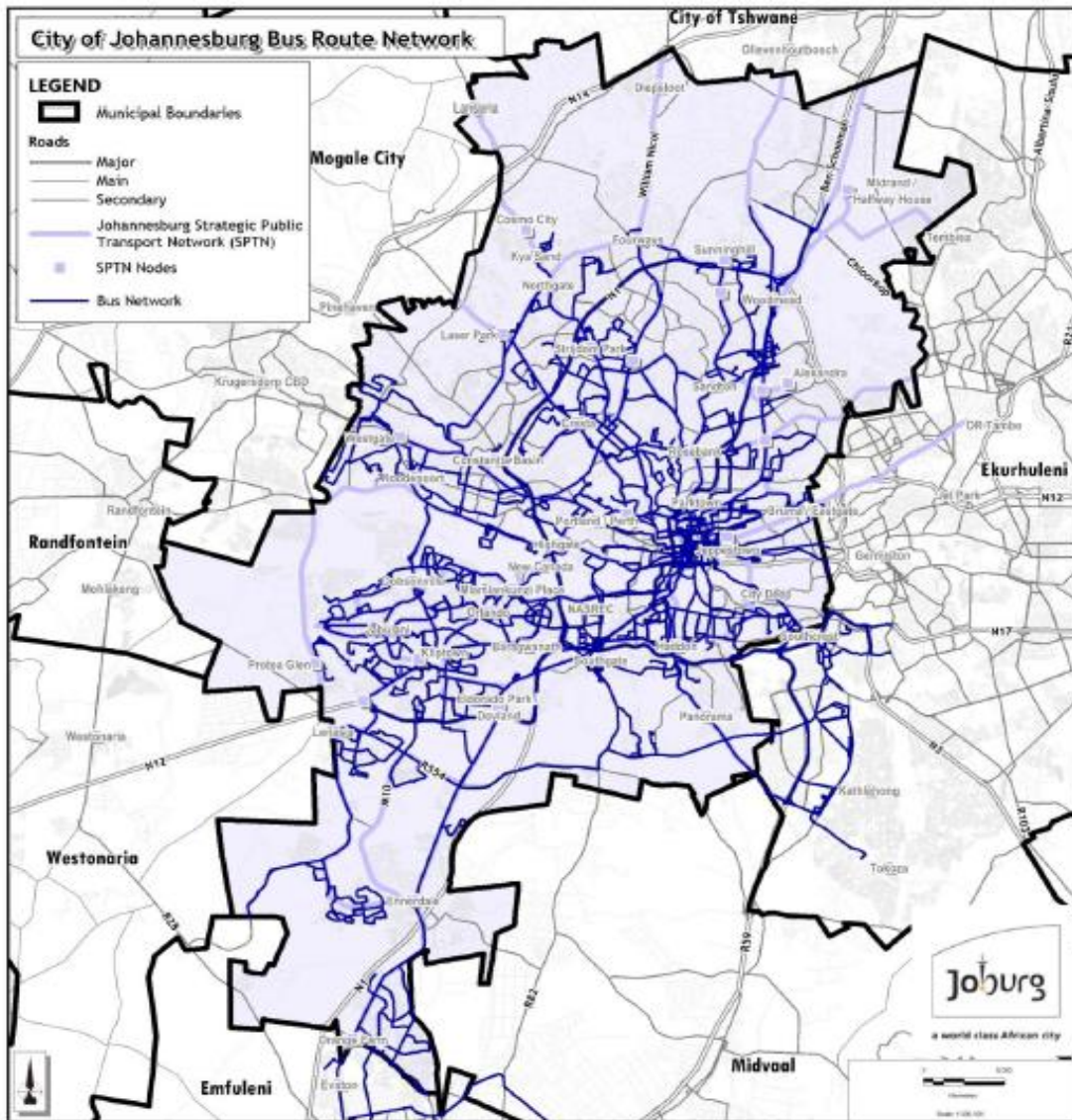


Figure 14: City of Johannesburg Bus Route Network
 Source: (City of Johannesburg, 2013)

3.5.3 Minibus Taxis

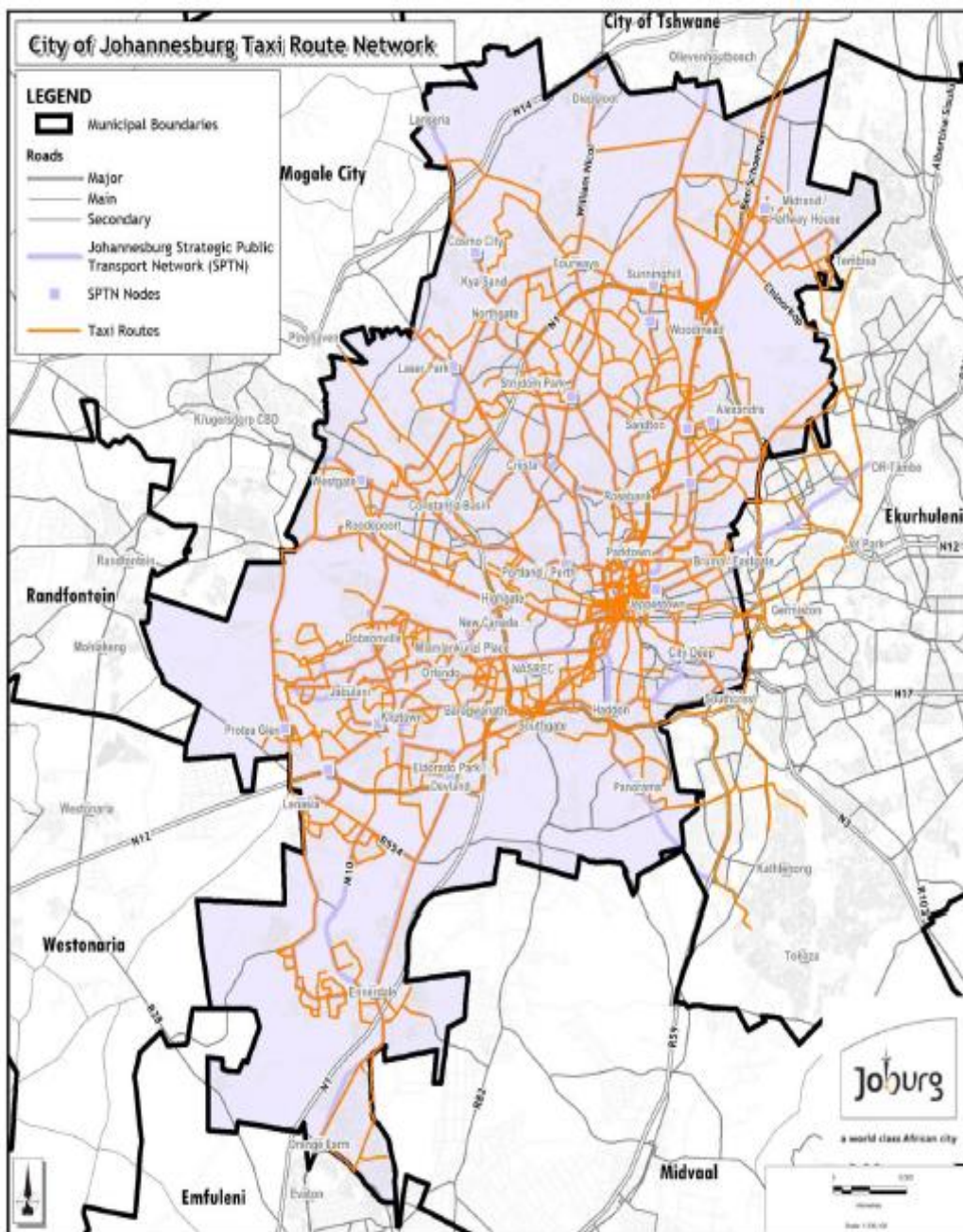


Figure 15: City of Johannesburg Taxi Route Network

Source: (City of Johannesburg, 2013)

Minibus taxis are the most used public transport mode in the City of Johannesburg with more than 1 013 different routes in the city (City of Johannesburg, 2013). These routes are shown in **Figure 15**.

3.5.4 Non-Motorised-Transport

Walking is Johannesburg's second main mode of transport after private vehicles even though most of Johannesburg's is not walkable because of a lack of adequate infrastructure like sidewalks (City of Johannesburg, 2013).

3.6. Travel Patterns

Table 3 shows the different trip purposes in Gauteng and the difference between Gauteng Travel Survey results in 2000 and the Gauteng Travel Survey results in 2014. The table shows that the main trips purposes are educational and work-related trips (Gauteng Department of Roads and Transport, 2016b).

Table 3: Trip Purposes in Gauteng

Trip purpose	GHTS2014 Number of trips	NHTS2013 Number of trips	GHTS2014 Percentage of trips	GTS2000 Percentage of trips
Education	1 821 193	2 207 189	47.7%	47.2%
Going to work at usual workplace	1 486 522	2 766 207	38.9%	31.2%
In the course of work, but not at usual workplace	9 717	-	0.3%	0.7%
Looking for work	40 861	-	1.1%	-
Medical/health purposes	27 294	-	0.7%	-
Other	47 704	-	1.2%	6.7%
Recreational	10 495	-	0.3%	-
Shopping	77 419	-	2.0%	0.2%
Dropping someone off/picking someone up	65 299	-	1.7%	-
Going home	96 720	-	2.5%	2.8%
Visiting friends/relatives	38 697	-	1.0%	-
Worship	51 294	-	1.3%	-
Visiting welfare office	8 991	-	0.2%	-
Not given	35 546	-	0.9%	-
Grand Total	3 817 751			100.0%
GTS2000	4 700 000			

Table 4 shows the preferred mode of transport in Gauteng during the morning peak. Non-Motorised transport is the most used model of transport, followed by minibus taxis and car (both as a driver and passenger), with train following as the fourth preferred mode of transport (Gauteng Department of Roads and Transport, 2016b).

Table 4: Mode of transport - Morning Peak

Mode of transport	GHTS2014 Number of trips	GHTS2014 %	GTS2000 %
Walk all the way	1 299 418	34.0%	37.7%
Bicycle	12 609	0.3%	0.6%
Motorcycle	9 104	0.2%	0.1%
School bus	189 906	5.0%	-
Bus (BRT/Rea Vaya)	9 611	0.3%	-
Bus (Other)	69 151	1.8%	4.3%
Car as a passenger	330 518	8.7%	9.8%
Car, as a driver	836 717	21.9%	19.0%
Company transport	37 298	1.0%	0.9%
Commuter taxi/minibus taxi	834 388	21.9%	22.4%
Train	77 658	2.0%	3.5%
Gautrain	1 808	0.0%	-
Gautrain bus	2 017	0.1%	-
Lift club driver	2 984	0.1%	-
Lift club passenger	59 624	1.6%	1.7%
Metered taxi	14 248	0.4%	-
Not given	1 075	0.0%	-
Other	29 615	0.8%	-
Grand Total	3 817 751	100.0%	100%

Table 5 illustrates the inter and intra-municipal trips that occur in the Gauteng Province between the different municipalities. The table shows that most of the trips were intra-municipal trips and the most trips were in the City of Johannesburg (Gauteng Department of Roads and Transport, 2016b).

Table 5: Inter and intra-municipal trips in Gauteng

Origin \ Destination	City of Johannesburg	City of Tshwane	Ekurhuleni	West Rand	Sedibeng
City of Johannesburg	3 985 785	48 892	131 845	30 047	22 651
City of Tshwane	33 203	1 911 613	9 325		1507
Ekurhuleni	153 842	24 198	2 543 914		9265
West Rand	23 310	1 537	1 686	505 221	422
Sedibeng	17 369	544	6 118	1 046	523 123
From outside Gauteng	38 428	18 284	10 050	2 011	2 011

3.7. City's Plans for Future Land Use Developments

There is a collection of strategies stipulated in the spatial framework for Johannesburg 2040, which aim to get the city where there are layers of mixed-use areas, corridors and nodes connected by a reliable and efficient transport infrastructure and system. The key elements of the spatial framework that address issues in this dissertation are summarised in his section. The main plans the city has for future land use developments that address spatial fragmentation are:

1. Unlocking Soweto as a true city district
2. Unlocking the mining belt.

3.7.1. Unlocking Soweto as a true city district

Obstacles standing in the way of realising Soweto as a true city district are very real and exist in present day. Despite Soweto being home to approximately 1.3 million people, a number that primes the township to be a socio-economically self-sustained city, the reality is as such that the people of Soweto remain heavily reliant on the Johannesburg inner city for access to economic and job opportunities (Gauteng Provincial Government, 2016).

To achieve the desired outcome of a strong economic center outside of the Johannesburg inner city and at the same time maintain strong links to the inner-city Soweto must amongst other things acknowledge by no fault of their own a lack of diversity in mixed-use activities, public spaces and socio-economic infrastructure.

There are several prevalent issues that must be addressed by the strategy to institute a meaningful transformation of Soweto. Namely (Gauteng Provincial Government, 2016):

- Spotting economic potential around public transport nodes and densifying the areas through mixed land use develop strong connections within Soweto's key nodes and strengthen the external connections to the Johannesburg inner city, the mining belt corridor and surrounding sub-cores.
- Upgrade the service and efficiency of rail transport.
- Bridge existing fragmentation through mixed land-use.
- Provide community facilities and general environment of a superior quality.

These envisioned strategies are depicted in **Figure 16**.

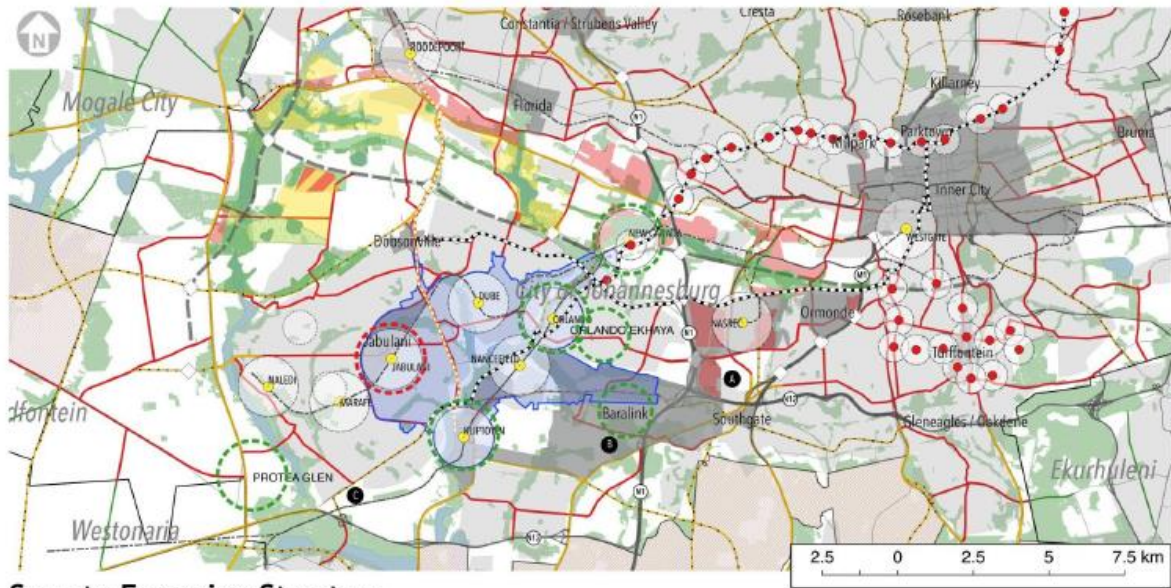


Figure 16: Soweto Emerging Structure
 Source: (Gauteng Provincial Government, 2016)

3.7.2. Unlocking the Mining Belt

As much as the effects of the spatial design imposed upon South Africa has resulted in disproportionate fragmentation and discontinuity, it is the very factor that presents us with an opportunity to bridge gaps along the mining belt. The mining belt is in fact amongst the most pivotal of the opportunities for appropriation and development of land (Gauteng Provincial Government, 2016).

The main aim being transforming what was used as a mining-belt buffer south of Johannesburg into an exuberant growth area through mixed-use activity.

The development strategy can be summarised into 3 top-line, broad-brush ideas (Gauteng Provincial Government, 2016):

- The connection of the mining belt both within and across. – The linking of sub-centre nodes to one another through new road connections and the integration of nodes with surrounding land use activities.
- Varying economic opportunity. – The optimisation of socio-economic potential of the mining belt through resuming lucrative mining activity and fortification of the commercial and

industrial sectors. Priority is given to industrial activities that can be consolidated and are in some way connected with Soweto.

- Create a motley collection of residential options. – Accommodate a range of income levels through a diversified and affordable housing offering along and in areas of the mining belt. Ideally compact, dense and with the feasibility to walk in within the areas without needing vehicular or alternative forms of mobilising within the area.

The planned developments for the mining belt are illustrated in **Figure 17**.

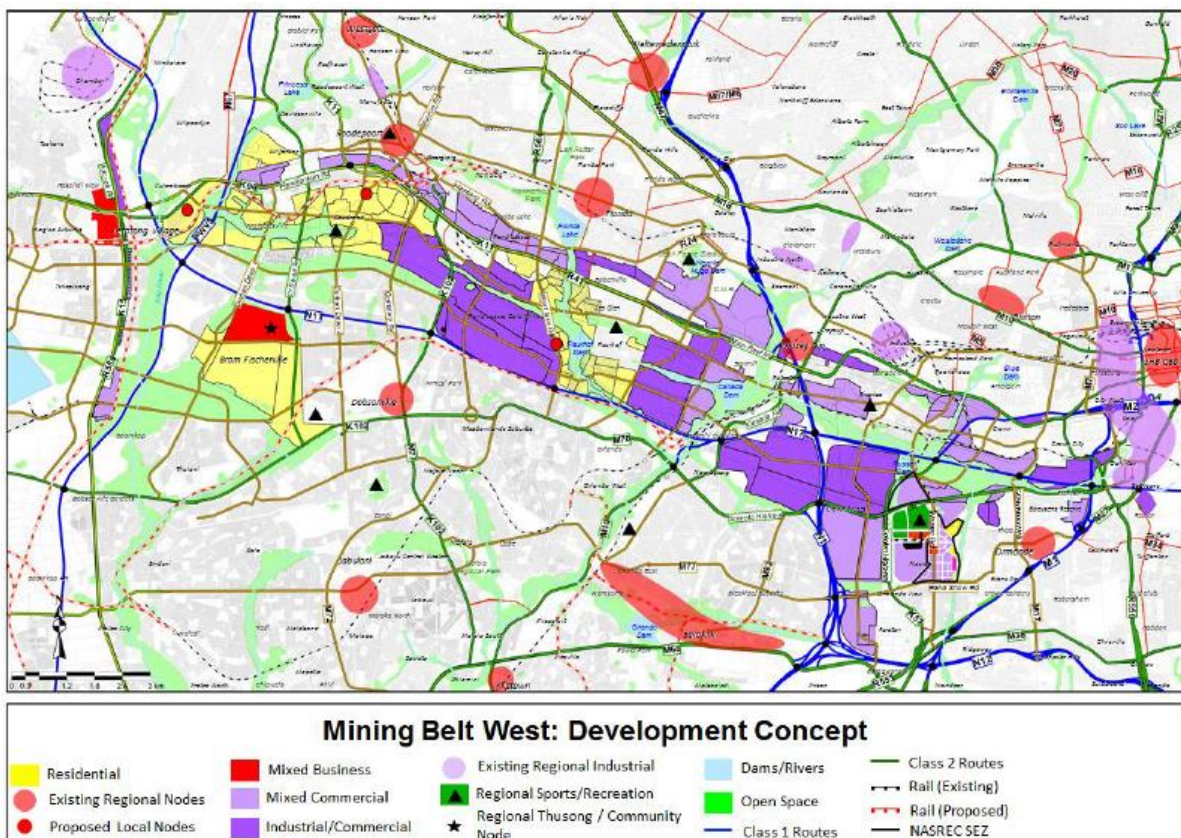


Figure 17: Mining Belt West: Development Concept
Source: (Gauteng Provincial Government, 2016)

4 MODELLING METHODOLOGY

Chapter 4 outlines the modelling assumptions as well as the modelling approach, that details the base scenario and future scenario. The model rationale for all decisions and choices is also explained, and the data sources used. The aim of modelling in this research paper is to compare the base model that models a monocentric city and future model that models a somewhat polycentric city.

4.1 Modelling Assumptions

- The model developed is a strategic model.
- Base Year – 2010.
- Forecast Future Year – 2040.
- All trips are assumed to be home-based work.
- Only one mode is modelled i.e. train.
- The existing residential land use in the City of Johannesburg is assumed to remain unchanged for the future scenario model i.e. only commercial land uses change for purposes of the outputs of this research.

4.2 Base Model Development

4.2.1 Network Development

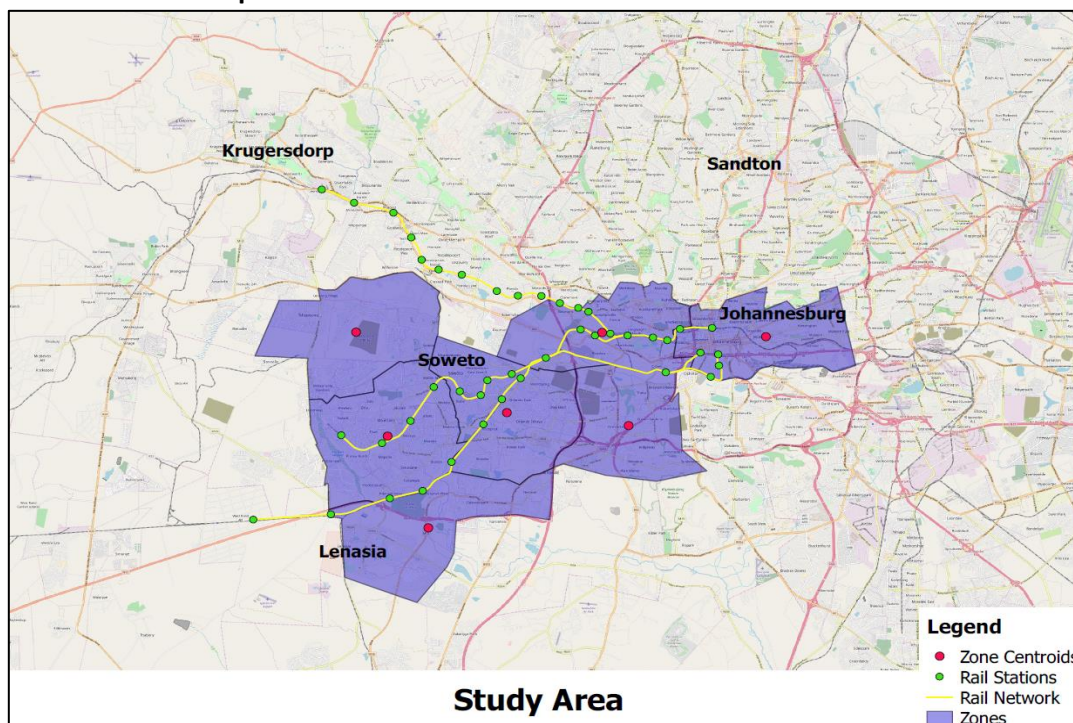


Figure 18: Base Model Network

The study area was divided into seven traffic analysis zones. These zones were informed by existing mesozones that already have economic data associated with the zones. These zones and rail network

were coded into QGIS and exported into PTV Visum for modelling. **Figure 18** shows the partitioning of the traffic analysis zones and the rail network that services these zones.

4.2.2 Trip Generation

As stated in Section 2.4, trip generation is the determination of the number of trips produced by and attracted to each zone. They are then assigned to different modes shares.

The demographic and socio-economic data for each zone were sourced from census data, and this data is depicted in **Table 6**.

Table 6: Population and Employment data

(Source: StatsSA)

TAZ	Population	Employment
6	179984	50031
7	110900	42663
8	304267	132765
11	451974	125842
12	616874	184448
13	80631	36208
17	153657	45496

The Committee of Transport Officials (COTO) South African Trip Data Manual is typically used in South Africa for transport studies, but it doesn't clearly provide how trip generation parameters can be calculated for public transport. A study was conducted by Onderwater (2015) in order to determine the trip generation public transport parameters and the outcomes of that study were used in this dissertation. These parameters are shown in **Table 7**.

Table 7: Public Transport Trip Generation Parameters

(Source: Onderwater, 2015)

Area	Per Resident	Per Worker
	PT Trips per workday	
Metro	0.65	0.8

The City of Johannesburg is a Metropolitan area and therefore the public transport trip generation rate used per resident is 0.65 and 0.8 per worker. To calculate the generated public transport trips in each zone, the population in each zone was multiplied by 0.65 to get productions per workday. An AM Peak Factor of 0.8 was used to calculate the total productions during the AM Peak in each zone for both the base and future development scenario. Since this study only focusses on one mode only i.e.

train, the productions were further split into the different public modes of transport i.e. Taxi, Train and Bus according to existing mode splits and these are shown in **Table 8**.

Table 8: Total trips generated per PT mode (Productions)

TAZ	Generated PT Daily Trips (Productions)	AM Peak Factor	Person Trips Modal Split (Source: StatsSA)		
			Public (Taxi, Train, Bus)		
		0.80	68.0%	12.0%	20.0%
6	116990	93591.68	63642.3424	11231.0016	18718.336
7	72085	57668	39214.24	6920.16	11533.6
8	197774	158218.84	107588.8112	18986.2608	31643.768
11	293783	235026.48	159818.0064	28203.1776	47005.296
12	400968	320774.48	218126.6464	38492.9376	64154.896
13	52410	41928.12	28511.1216	5031.3744	8385.624
17	99877	79901.64	54333.1152	9588.1968	15980.328

The resulting trips AM Peak train trips generated are as depicted in **Table 9**.

Table 9: Generated AM Peak Train Trips - Productions

TAZ	Generated AM Peak Train Trips
6	11231
7	6920
8	18986
11	28203
12	38492
13	5031
17	9588

The trip generation parameters were also used to calculate the generated attractions for each zone. The number of workers (**Table 10**) attracted to each zone was multiplied by 0.8 which is the PT trips per worker per workday. An AM Peak Factor of 0.8 was used to calculate the total attractions during the AM Peak in each zone. The results are shown in **Table 11**. Just like the productions, the attractions were further split into the different public modes of transport i.e. Taxi, Train and Bus to get the generated AM Peak train trips (attractions).

Table 10: Employees in each zone

(Source: CSIR, 2010)

TAZ	Agriculture, Forestry and Fishing	Mining and Quarrying	Manufacturing	Electricity, Gas and Water	Wholesale and Retail Trade, Catering and Accommodation	Transport, Storage and Communication	Finance, Insurance, Real Estate and Business Services	Community, Social and Personal Services	Total
6	370.126	1663.99135	872.79499	40.67512	1420.99795	253.05924	497.82643	2763.225	7883
7	319.957	0	19346.640	221.38209	6758.29394	7037.79557	67054.578	18027.262	118766
8	21.82	0	23869.803	797.57342	19520.70949	8801.52695	20833.998	39325.51	113171
11	112.810	0	4061.3462	214.65881	2715.22517	2078.21872	1765.18023	28317.363	39265
12	67.551	0	53.70984	347.38458	3407.56024	801.01536	2505.0568	31380.062	38562
13	227.843	0	5947.86233	129.76083	6518.86781	1975.02866	6991.308	9226.1110	31017
17	380.789	1214.66076	2649.77421	103.75629	2839.04611	1080.50574	826.50483	11308.401	20403

Table 11: Total trips generated per PT mode (Attractions)

TAZ	Generated Trips (Attractions)	AM Peak Factor	Person Trips Modal Split (Source: StatsSA)		
			Public (Taxi, Train, Bus)		
			0.80	68.0%	12.0%
6	6306	5045	3431	605	1009
7	95013	76010	51687	9121	15202
8	90537	72429	49252	8692	14486
11	31412	25129	17088	3016	5026
12	30850	24680	16782	2962	4936
13	24813	19851	13499	2382	3970
17	16323	13058	8880	1567	2612

The AM person trips for trains are now known and represent the base productions and attractions (**Table 12**) in this study.

Table 12: Total Productions and Attractions

TAZ	Population	Employment	Employees	Productions	Attractions
6	179984	50031	7883	11231.0016	605
7	110900	42663	118766	6920.16	9121
8	304267	132765	113171	18986.2608	8692
11	451974	125842	39265	28203.1776	3016
12	616874	184448	38562	38492.9376	2962
13	80631	36208	31017	5031.3744	2382
17	153657	45496	20403	9588.1968	1567

The productions and attractions in **Table 12** do not balance. This is because the productions and attractions are developed independently. The productions are based on household census data and are deemed to be more reliable; they are then the control totals. The attractions are therefore multiplied by the ratio of total productions over total attractions. This is done in order to reconcile the inconsistencies between the productions and attractions and conserves all trips in the model. The resulting adjusted attractions and productions are shown in **Table 13**:

Table 13: Productions and Adjusted Attractions

TAZ	Productions	Attractions
6	11231	2530
7	6920	38118
8	18986	36323
11	28203	12602
12	38493	12377
13	5031	9955
17	9588	6549
Total	118454	118454

4.2.3 Trip Distribution

The objective of the trip distribution step of the 4-step model is to convert productions and attractions from the trip generation step into Origin and Destination Matrices. The Gravity Model was used in this model for trip distribution. The main inputs into the gravity model were:

- Zonal trip productions and attractions from trip generation and;
- Shortest trip routes calculated from QGIS.

To calculate the intrazonal trips, the nearest neighbour index is used where the shortest trip routes of the sum of three neighbouring zones of the intrazonal zones were averaged and then multiplied by a factor of 0.9.

Table 14 shows the resulting Origin-Destination Trip Table.

Table 14: OD Trip Table - Base Model

Zones	6	7	8	11	12	13	17	Sum
6	23.2021	2285.2928	1718.9300	739.0674	5937.2831	341.3538	180.6526	11226
7	22.2537	3010.5384	2012.7485	906.5377	340.8301	414.6829	212.8673	6920
8	35.2245	4229.9587	7431.5487	1236.2131	601.4880	5087.7671	366.9640	18989
11	92.7463	11693.3412	7610.7614	1811.6404	1274.2516	1707.2112	4014.9128	28205
12	2330.0609	13688.3642	11566.6676	3960.9185	3791.6296	1962.7753	1191.8947	38492
13	5.4629	677.3977	3906.6864	236.8282	79.4843	75.9628	50.2095	5032
17	21.0242	2533.3735	2075.2058	3710.9479	351.7289	365.1741	531.0424	9588
Sum	2530	38118	36323	12602	12377	9955	6549	

The final O-D matrix was used in Visum to model the flow of traffic presented in the next section in **Figure 19** and **Figure 20**.

4.2.4 Trip Assignment Results

The resulting link flows of the model are shown in **Figure 19**. The peak flows towards the direction of the City Centre are thicker than the contra-flows in the opposite direction, which signifies the volume of trips in each direction. This proves that the spatial disparities experienced in the City of Johannesburg have an impact in the way people travel.

Link	FROM NODE NO	TO NODE NO	Base Model Volume of Passengers
7	7	8	9058
7	8	7	6019
8	8	9	9058
8	9	8	6019
9	9	10	9058
9	10	9	6019
10	10	11	31681
10	11	10	13041
11	11	12	31681
11	12	11	13041
13	54	55	8355
13	55	54	34471
14	53	54	8355
14	54	53	34471
15	52	53	8649
15	53	52	43466
16	51	52	8649
16	52	51	43466
17	50	51	8649
17	51	50	43466
18	49	50	8649
18	50	49	43466
19	12	49	8649
19	49	12	43466
20	12	13	35891
20	13	12	4693
21	13	14	35891
21	14	13	4693
27	20	21	13164
27	21	20	30500
28	21	22	13164
28	22	21	30500
30	22	24	13164
30	24	22	30500
55	12	24	36894
55	24	12	14634

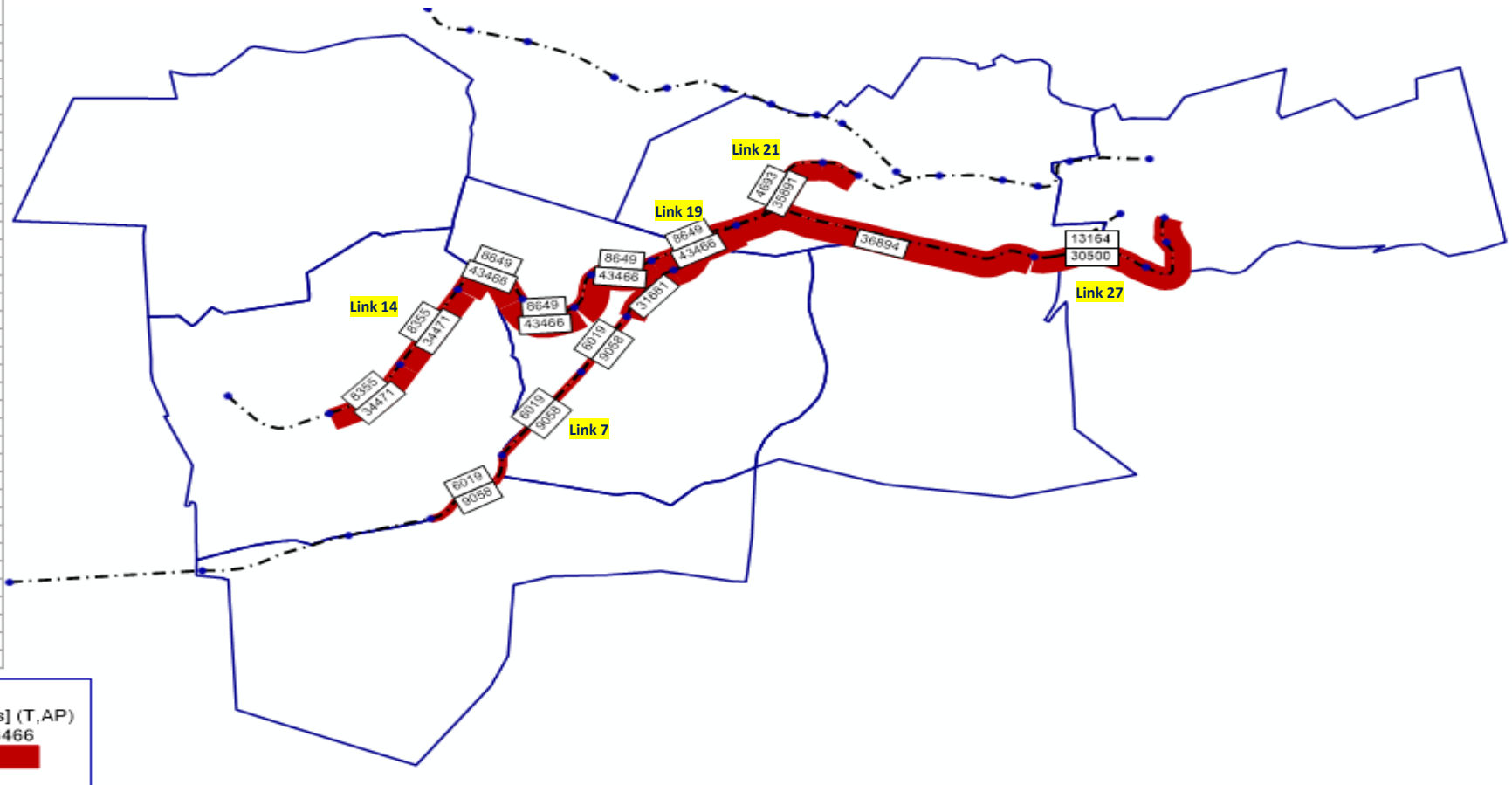


Figure 19: Base Model Results

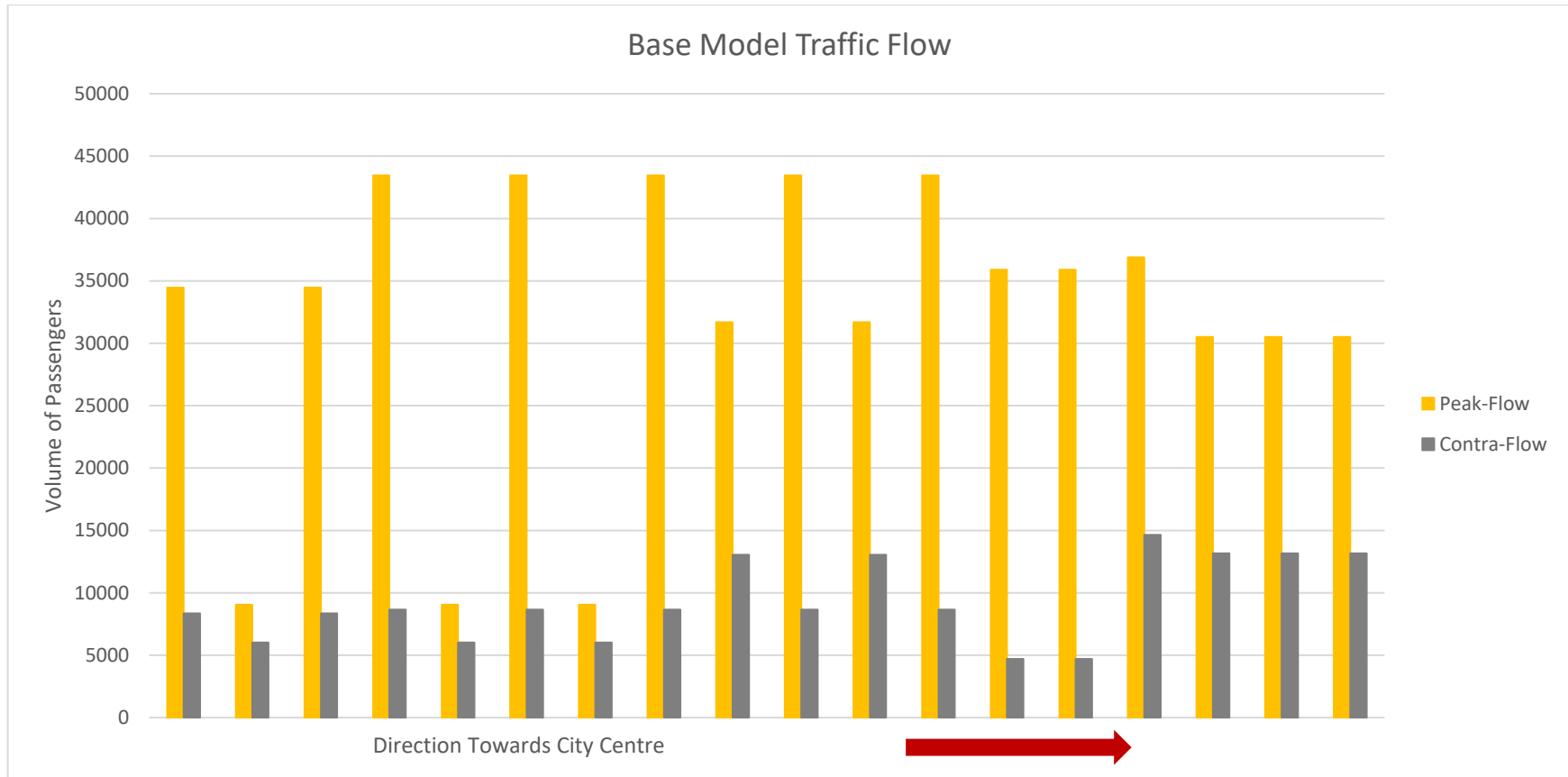


Figure 20: Base Model Traffic Flow

The base model traffic flow graph in **Figure 20** is a clearer representation of the link flow results as there is a clear distinction between peak-flow volumes and contra-flow volumes. As you move towards the city, there is still more peak traffic, however, the difference between contra and peak flow volumes isn't as huge as it is away from the city, which shows how traffic moves when economic opportunities are closer to residential areas i.e. traffic isn't unidirectional.

4.3 Model Calibration and Validation

Section 2.4.2.3 of this research paper outlines the necessity to ensure that the base model accurately represents reality. The data used for the model validation is passenger volumes data from PRASA for the study area in question. This data is shown in Appendix A.

A scatter plot showing the PRASA passenger volumes and modelled passenger volumes for the study area was used to show the validity of the model. The PRASA data isn't divided into contra-flows and peak flows, therefore the validity of the data can only be assessed for total volumes. The base model data is divided into contra-flows and peak-flows and the average between the two flows was then used.

The resulting scatter plot is shown **Figure 21**.

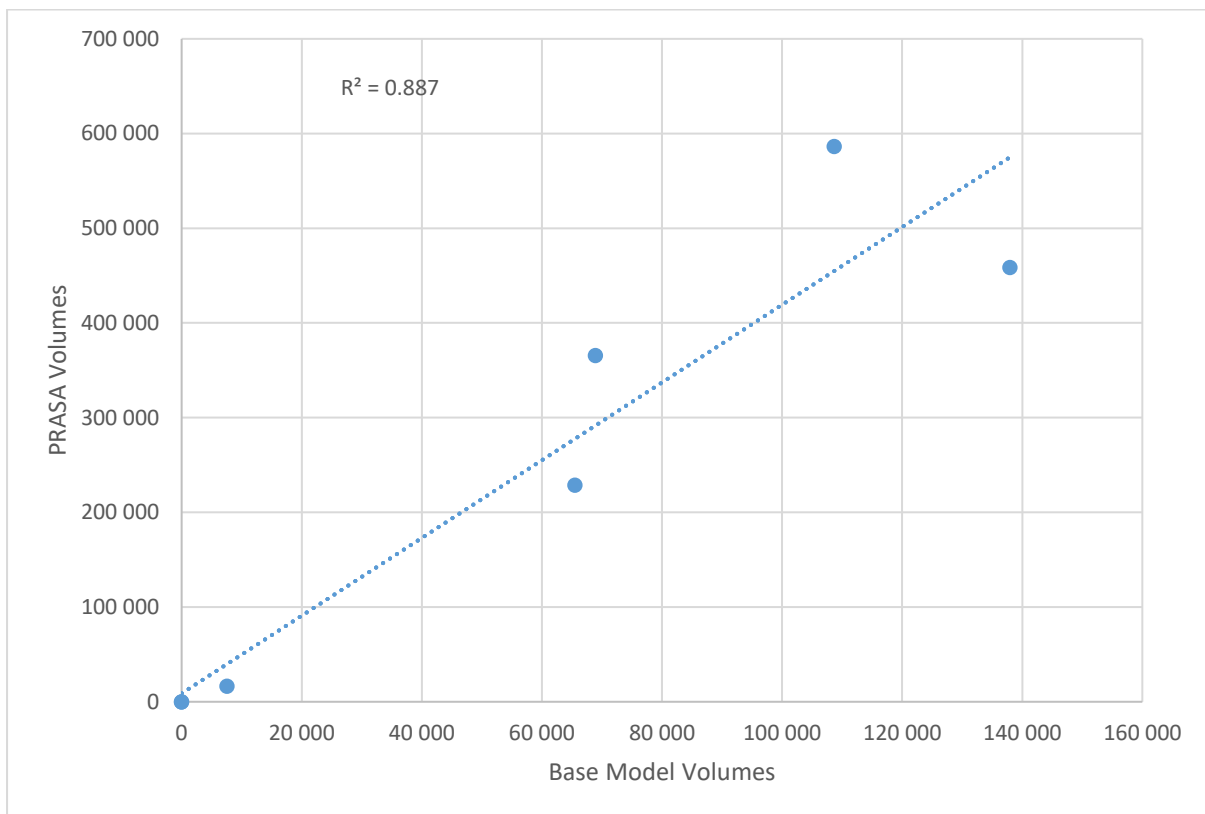


Figure 21: Scattered Plot of Model Passenger Volumes vs PRASA Passenger Volumes

The coefficient of determination, R^2 is 0.87. This means that 87% of the modelled data is predictable and there is a 13% variance from the PRASA data.

4.4 Future Scenario Model

4.4.1 Trip Generation

Growth rates were used to determine the increase in population and jobs in order to calculate the trips generated in each zone. The growth rates were applied to the already defined functions in the Base Model in order to calculate the change in trip generation.

An annual population growth rate of 2.6% as well as a 3.6% job growth rate up to 2037 (Gauteng Department of Roads and Transport, 2013). The same growth rate was applied from 2037 to 2040, because 2040 is the forecast year. **Table 15** shows the 2040 forecasted population and employment.

Table 15: 2040 Forecast Population and Employment

TAZ	Population	Employment
6	388736	144555
7	239526	123266
8	657167	383598
11	976190	363595
12	1332347	532926
13	174150	104616
17	331874	131452

The same trip generation public transport parameters used in the base scenario to calculate productions were used in the future scenario.

The public transport trip generation rate used per resident is 0.65. To calculate the generated public transport trips in each zone, the population in each zone was multiplied by 0.65 to get productions per workday. An AM Peak Factor of 0.8 was used to calculate the total productions during the AM Peak in each zone. Since this study only focusses on one mode only i.e. train, the productions were further split into the different public modes of transport i.e. Taxi, Train and Bus and these are shown in **Table 17**.

Table 16: Total trips generated per PT mode (Future Scenario)

TAZ	Generated PT Daily Trips (Productions)	AM Peak Factor	Person Trips Modal Split (Source: StatsSA)		
			Public (Taxi, Train, Bus)		
		0.80	68.0%	12.0%	20.0%
6	252678	202142.7019	137457.0373	24257.12423	40428.54038
7	155692	124553.4361	84696.33654	14946.41233	24910.68722
8	427158	341726.784	232374.2131	41007.21407	68345.35679
11	634523	507618.7081	345180.7215	60914.24497	101523.7416
12	866025	692820.3457	471117.8351	83138.44148	138564.0691
13	113197	90557.87291	61579.35358	10866.94475	18111.57458
17	215718	172574.4574	117350.6311	20708.93489	34514.89149

The resulting AM Peak train trips generated are depicted in **Table 9**.

Table 17: Generated AM Peak Train Trips – Future Scenario Productions

TAZ	Generated AM Peak Train Trips
6	24257
7	14946
8	41007
11	60914
12	83138
13	10867
17	20709

The 2040 forecast daily attractions are the crux of this research paper. The City of Johannesburg Metropolitan Municipality Spatial Development Framework (SDP) 2040 was used as the basis of the spatial transformations planned by the City of Johannesburg. The SDP intends on transforming the City of Johannesburg into a Compact Polycentric City that has industrial and commercial developments so that residents in the city live closer to where they work. The key elements of the Spatial Framework that are of importance for this study are (Department of Development Planning, 2016):

- Unlocking Soweto as a True City District
 - The aim is to transform Soweto into a city district where people have access and job opportunities within the area. And to create an economic centre linked to the Johannesburg Inner City.
- Unlocking the Mining Belt
 - One of the objectives of developing the mining belt is economic diversification and the potential of reclaiming land for economic development and job creation in close proximity to Soweto.

- Achieving a better spatial distribution of economic activity and job opportunities in the City of Johannesburg and retaining and consolidating existing business and economic nodes.

The spatial plans of the City of Johannesburg to address the issues listed above is illustrated in **Figure 22**. These include the Mining Belt Development, Industrial Development and Economic Nodes.

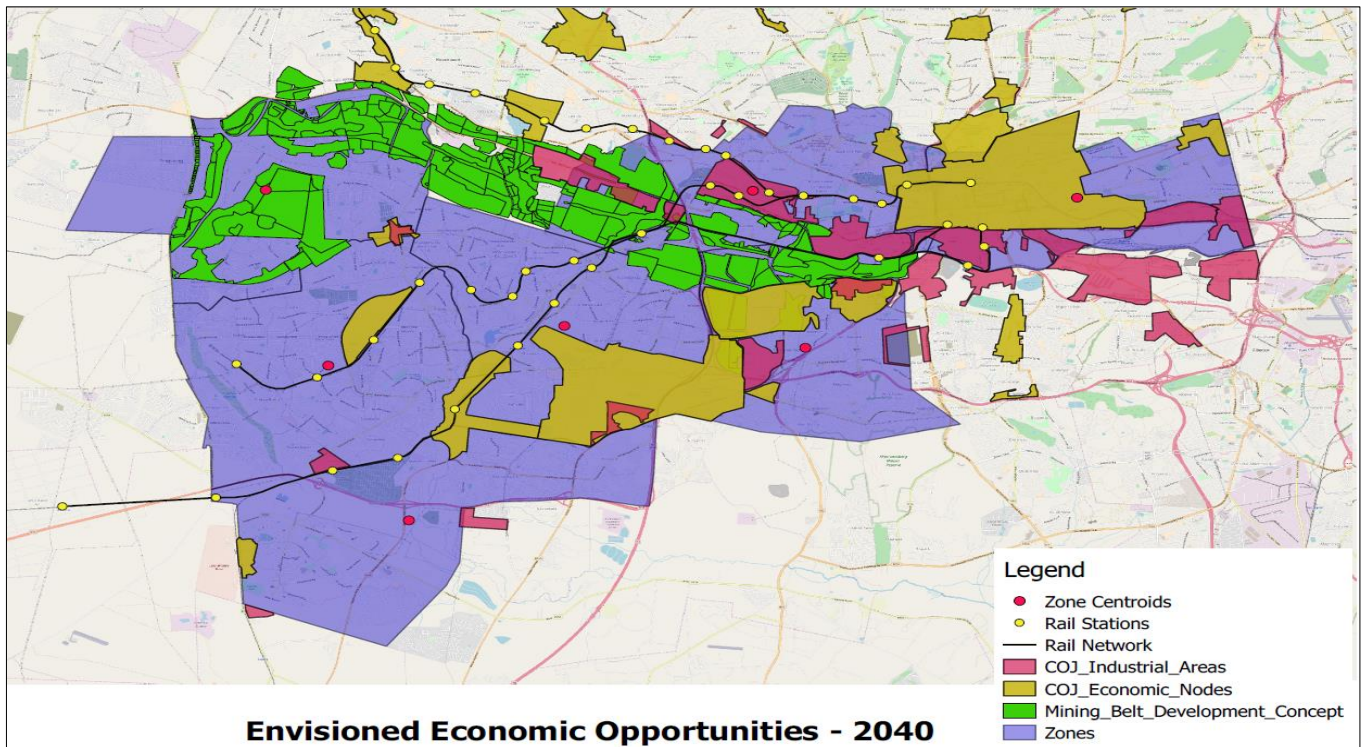


Figure 22: Future Economic Land Use Developments

(Department of Development Planning, 2016)

Development plans are typically represented in gross hectares, therefore need to be reduced for coverage so that infrastructure and empty land are excluded (Onderwater & McKune, 2016). A reduction factor of 50% was then used to determine the net density (ha) of the commercial and industrial development plans studied in this research. The net density estimates for each zone are detailed in **Table 18**. This was used to calculate the public transport trips for these activity areas.

Table 18: Net Density of Planned Economic Developments

Net Density (ha)	
Industrial	Commercial
816.3540292	1224.531044
1005.986189	1508.979284
633.6033185	950.4049778
699.1063119	1048.659468
378.203004	567.304506
887.7357163	1331.603574
46.60224	69.90336

The public transport trip generation parameters (Onderwater & McKune, 2016) used are shown in **Table 19**.

Table 19: PT trip generation for activity areas

Area	Net density people/ha	Type	PT Trips per person per day	PT Trips per ha per day
Working Areas	150	Industry	0.8	120
Working Areas	300	Office	0.8	250

To calculate the public transport trips per day, the net density people/ha was multiplied by the net density (ha) for both the industrial (150) and commercial (300) developments, and then multiplied by the PT trips per person per day (0.8). The resulting trips generated are shown in **Table 20**.

Table 20: Attractions Generated per Day

TAZ	Generated Trips (Industrial)	Generated Trips (Commercial)	Generated Trips (Total)
6	97962.48351	293887.4505	391849.934
7	120718.3427	362155.0281	482873.3708
8	76032.39823	228097.1947	304129.5929
11	83892.75742	251678.2723	335571.0297
12	45384.36048	136153.0814	181537.4419
13	106528.286	319584.8579	426113.1438
17	5592.2688	16776.8064	22369.0752

An AM Peak Factor of 0.8 was used to calculate the total attractions during the AM Peak in each zone. The results are shown in **Table 21**. Just like the productions, the attractions were further split into the different public modes of transport i.e. Taxi, Train and Bus to get the generated AM Peak train trips (attractions).

Table 21: Total trips generated per PT mode (Attractions) – Future Scenario

TAZ	AM Trips	Person Trips Modal Split (Source: StatsSA)		
		Public (Taxi, Train, Bus)		
		68.0%	12.0%	20.0%
6	313480	213166	37618	62696
7	386299	262683	46356	77260
8	243304	165446	29196	48661
11	268457	182551	32215	53691
12	145230	98756	17428	29046
13	340891	231806	40907	68178
17	17895	12169	2147	3579

The productions in **Table 17** and attractions in **Table 21** do not balance. This is because the productions and attractions are developed independently. The productions are based on household census data and are deemed to be more reliable; they are then the control totals. The attractions are therefore multiplied by the ratio of total productions over total attractions. This is done in order to reconcile the inconsistencies between the productions and attractions and conserves all trips in the model. The resulting adjusted attractions and productions are shown in **Table 22**.

Table 22: Productions and Attractions - Forecast Scenario Model

TAZ	Productions	Attractions
6	24257	40687
7	14946	61238
8	41007	42475
11	60914	38153
12	83138	22403
13	10867	46529
17	20709	4354
Total	255838	255838

4.4.2 Trip Distribution

The gravity model was used to calculate the OD Trip Table for the Forecast Scenario Model. The resulting Origin-Destination Trip Table is shown in **Table 23**. To calculate the intrazonal trips, the nearest neighbour index is used where the shortest trip routes of the sum of three neighbouring zones of the intrazones were averaged and then multiplied by a factor of 0.75.

Table 23: OD Trip Table - Forecast Scenario Model

Zones	6	7	8	11	12	13	17	Sum
6	874.1370	4485.9441	2315.6559	2671.5383	11599.6070	2160.8406	131.4945	24239
7	470.2001	6872.4378	2189.7649	2646.3992	537.7565	2119.9535	125.1309	14962
8	613.4297	5526.8690	9595.9658	2974.4162	782.1922	21437.6059	177.7943	41108
11	2414.7225	22841.9070	10202.9478	9384.1202	2477.3788	10754.4201	2908.1796	60984
12	35680.0585	15726.5274	9119.9690	8379.9714	6243.2852	7272.0670	507.7741	82930
13	183.5568	1707.7179	6759.0361	1099.4392	199.4331	889.2873	46.9364	10885
17	450.9434	4076.8458	2291.8705	10997.0266	563.3478	1895.0951	456.3186	20731
Sum	40687	61238	42475	38153	22403	46529	4354	

The final O-D matrix was used in Visum to model the flow of traffic presented in the next section in **Figure 23** and **Figure 24**.

4.4.3 Trip Assignment Results

Results			
Link	FROM NODE NO	TO NODE NO	Scenario Model Volume of Passengers
7	7	8	20357
7	8	7	4002
8	8	9	20357
8	9	8	4002
9	9	10	20357
9	10	9	4002
10	10	11	68062
10	11	10	28945
11	11	12	68062
11	12	11	28945
13	54	55	15123
13	55	54	75858
14	53	54	15123
14	54	53	75858
15	52	53	36606
15	53	52	80911
16	51	52	36606
16	52	51	80911
17	50	51	36606
17	51	50	80911
18	49	50	36606
18	50	49	80911
19	12	49	36606
19	49	12	80911
20	12	13	57660
20	13	12	11369
21	13	14	57660
21	14	13	11369
27	20	21	34199
27	21	20	35667
28	21	22	34199
28	22	21	35667
30	22	24	34199
30	24	22	35667
55	12	24	70957
55	24	12	33828

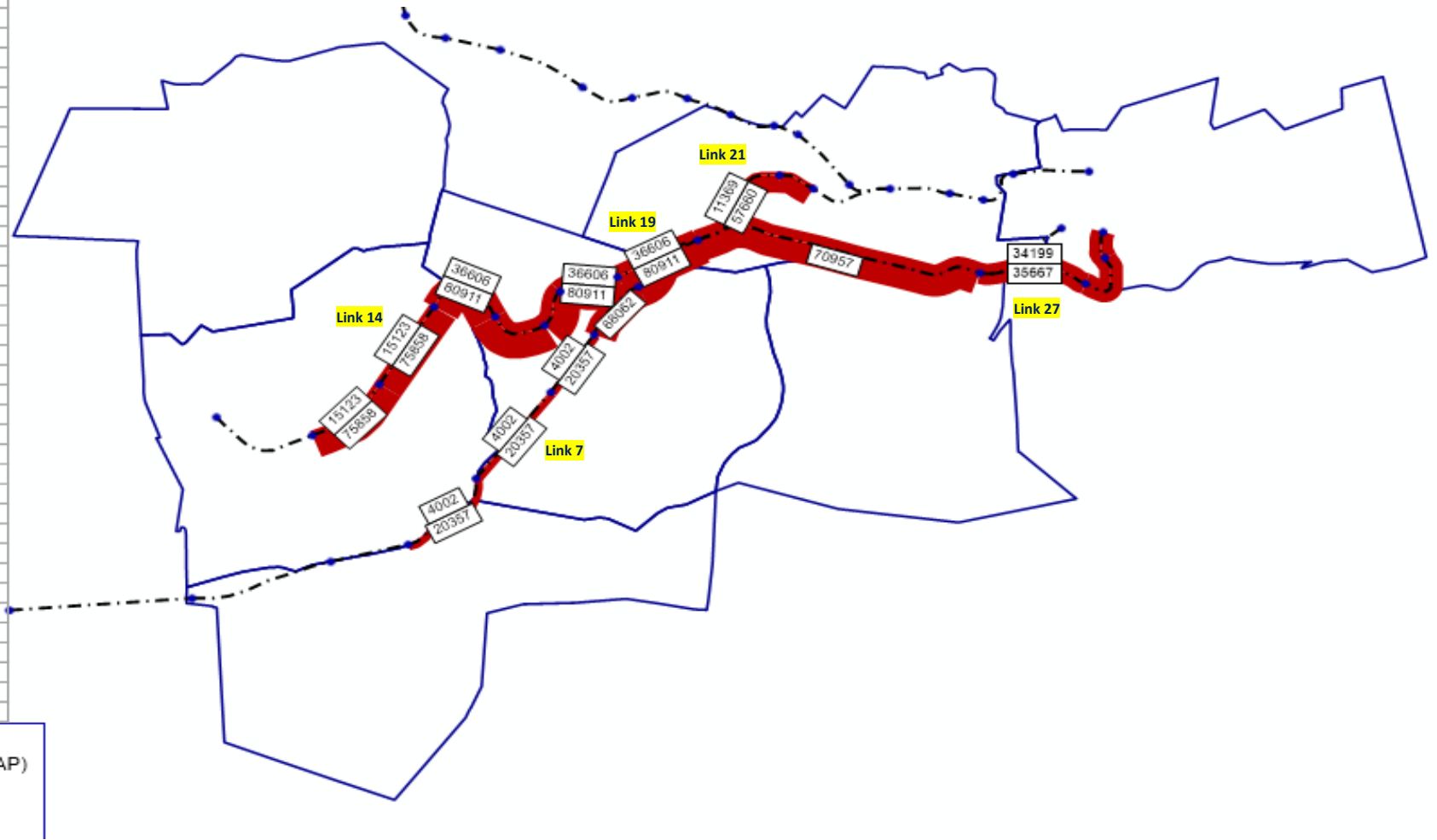


Figure 23: Forecast Scenario Model Assignment Results

The forecast scenario model also models a similar travel pattern to the base model i.e. there is little contra-flow traffic in places that are further from the City Centre; however, the future scenario shows that the peak-flow and contra-flow are almost the same as you move closer to the City Centre.

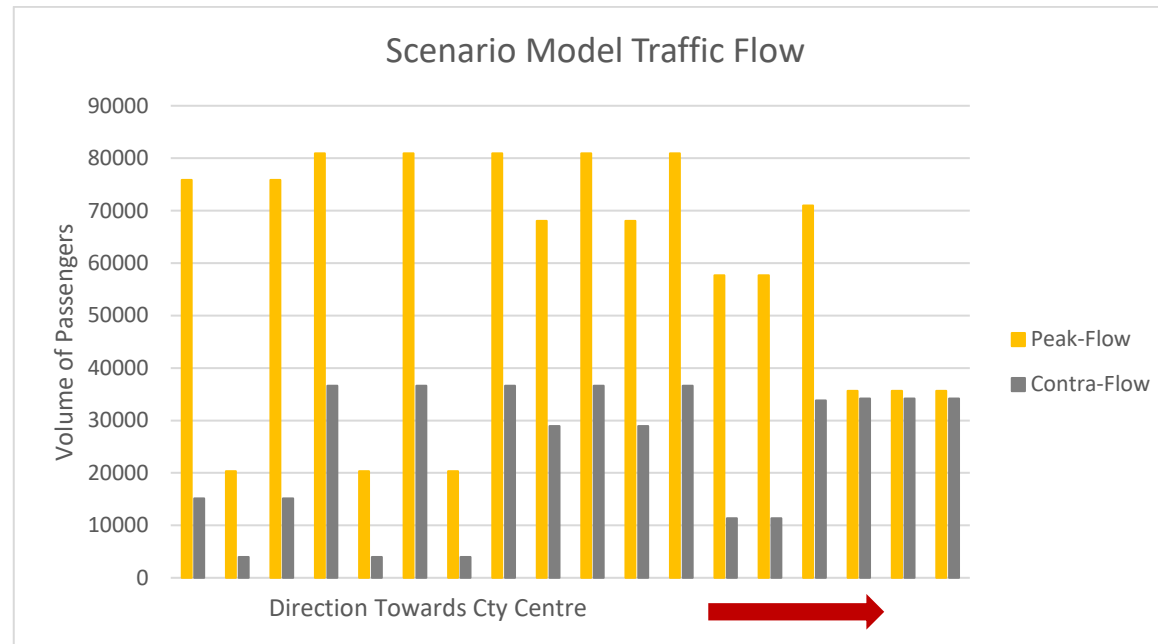


Figure 24: Scenario Model Traffic Flow

The scenario model traffic flow graph in **Figure 24** is a clearer representation of the link flow results as there is a clear distinction between peak-flow volumes and contra-flow volumes. As you move towards the city centre, there is still a small difference between contra and peak flow volumes, and a significant difference between contra and peak flows as you move away from the city centre, however, these results do not give us an indication whether there has been any change in the difference between contra and peak flows between the base model and the scenario model rail traffic flows.

A contra-flow simulation was then modelled in Visum to show the impact of the economic opportunities on the flow of both contra-flow and peak flow. This is shown by the link flows in **Figure 25**. The link flows show that contra-flow is indeed created by introducing economic opportunities in areas that are further from the city centre.

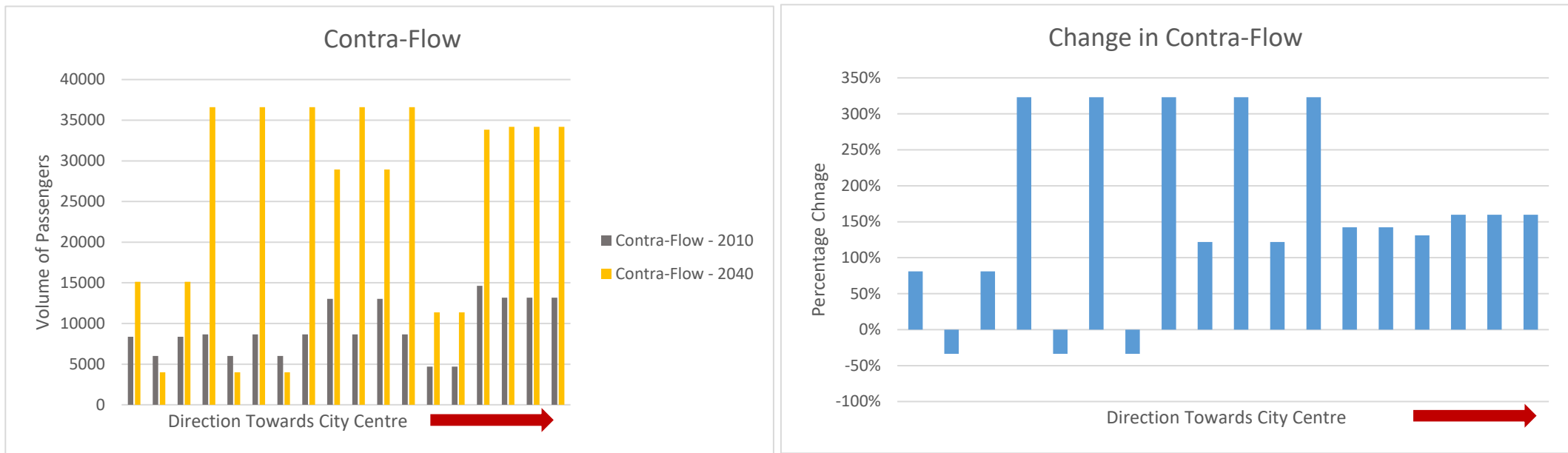


Figure 25: Contra-Flow

This shows a clearer and quantifiable representation of the contra-flow that is created as well as the percentage change of the contra-flow between the base scenario and the future scenario.

5 RESEARCH FINDINGS AND RECOMMENDATIONS

The following findings can be deduced from the study:

- The model was developed to test the effect of economic land uses to contra-flows for a 2040 forecast year.
 - The model shows that land use disparities have an effect on transport and the travel patterns of passengers as shown by the volumes of contra-flow and peak flow for the City Centre and areas far from the City Centre.
 - The development of strategic planning interventions does influence the flow of traffic by inducing contra-flow, this can be seen in the percentage change of contra-flow in the base scenario and future scenario.
 - There is an overall overage change in contra-flow of 156%. The areas furthest from the City Centre exhibit an increase of contra-flow of about 80%, with areas halfway to the City Centre exhibiting increases of about 350% in contra-flow. Areas near the City Centre also show that Contra-Flow increased more than 150%. There are, however, places that show a decrease of about 40% in contra-flow.
- Based on the results of the model, the following are recommended:
 - The desired outcomes of the study are met, but the areas furthest from the City Centre show the least contra-flow added, it is therefore recommended that the introduction of economic opportunities in areas far from economic opportunities are implemented along with residential interventions in areas that are mainly commercial.
 - The planned interventions are recommended to be introduced gradually and consistently over a period of decades.
 - Committee of Transport Officials (COTO) to undertake an urgent empirical study to determine trip generation parameters for all modes and publish a standard South African Public Transport Trip Generation Parameters Manual.

- Some of the areas which require further study for better results are:
 - Create sub-models that consist of disaggregate data so that various parameters can be calibrated.
 - Undertake a follow up study that would investigate individual and household level implications of the findings.
 - Develop a study in order to further refine the concept studied in this research by using the whole VISUM model of Gauteng, with 7 internal zones, and a number of macro-zones, with the recommended zones shown in Appendix B.
 - Consolidate all plans by the city in order to model all strategies at once and not in isolation; and in turn have an integrated implementation plan of all the strategies to yield the best results.

6 CONCLUSION

Chapter 6 of this thesis provides a conclusion of the study and its associated results.

The primary objective of this thesis was to create rail contra-flow by introducing economic opportunities in Soweto and immediate areas, because of their remoteness to the Johannesburg City Centre. In order to achieve the primary objective, the two secondary objectives below had to be investigated:

- a) Get a better understanding of the relationship between land use and rail transport.

Chapter 2 of this thesis provides a literature review of the relationship between land use and rail transport by outlining the symbiotic nature of the interaction between land use and rail transport and also highlights the importance of integrating the policies put in place to ensure that this reciprocal relationship is supported and encouraged. The literature review further explores the concept of contra-flow and how it can be a direct product of the land use and transport interactive relationship. This relationship was further explored and contextualised to a South African setting by getting a better understanding of the spatial form of Johannesburg and the status quo of rail transport as well as policies that have been put in place in order to provide a conducive and enabling environment for the land use and transport relationship to flourish and provide the desired spatial and transportation relief in Johannesburg.

The modelling of the base scenario and the future scenario results and comparison, therefore, shows that land use has an impact on how and where people travel as there is a significant difference between the contra-peak and flow-peak passenger volumes between the two scenarios that was observed. There is an overall overage change in contra-flow of 156%. The areas furthest from the City Centre exhibit an increase of contra-flow of about 80%, with areas halfway to the City Centre exhibiting increases of about 350% in contra-flow. Areas near the City Centre also show that Contra-Flow increased more than 150%. There are, however, places that show a decrease of about 40% in contra-flow.

- b) Developing a rail strategic transport model.

Chapter 4 of this thesis details the rail strategic model methodology. The methodology outlined in Chapter 2.4. was followed and the following was achieved as intended:

- Simulated rail base model of the status quo;
- Validated base model;
- Simulated future scenario model with an introduction of new developments that provide mixed land use diversity and;
- Simulated and analysed a contra-flow scenario

The main objective of this thesis was then achieved because the modelling results show that contra-flow can be created in Soweto and immediate areas.

In summary, the research shows that:

- a) The relationship between land use and rail transport in the context of a post-apartheid South African city was modelled by using a strategic model that follows the traditional 4-step model and using a macroscopic modelling software, PTV Visum.
- b) Land use does indeed affect how people travel and where they travel to.
- c) Strategic planning interventions like the Spatial Development Framework can be used in inducing contra-flow.
- d) Strategic models are helpful in modelling strategic planning interventions the research has shown that these strategic can be modelled and analysed for decision-making purposes.

In conclusion, the findings of the research provide positive results in showing that there are solutions that can be implemented that will actually produce the desired results by the government to eliminate the spatial legacy of apartheid.

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APPENDIX A: MODEL CALIBRATION AND VALIDATION

Table 24: Model Passenger Volumes vs PRASA Passenger Volumes

TAZ	Station	Source: PRASA, 2007									Total Passenger Volumes (2007)	Total Passenger Volumes (2008)	Total Passenger Volumes (2009)	Total Passenger Volumes (2010)	Average Flows (Source: Visum, 2019)
		Train Passenger Volumes			Transferring Passengers			Station Passenger Volumes							
		Board	Alight	Total	Board	Alight	Total								
		Board	Alight	Total	Board	Alight	Total	Board	Alight	Total					
Assumed annual passenger growth											2.60%	2.60%	2.60%		
12	Ikwezi	9 266	12 116	21 382	51	51	102	9 215	12 065	21 280	338 671	347 476	356 511	365 780	68 884
	Dube	9 450	11 064	20 514	1 422	1 422	2 845	8 028	9 642	17 669					
	Kliptown	6 839	7 283	14 122	5	5	10	6 834	7 278	14 112					
	Inhlazane	9 093	9 812	18 905	7	7	14	9 086	9 805	18 891					
	Merafe	10 037	12 030	22 067	0	0	0	10 037	12 030	22 067					
	Naledi	11 774	13 640	25 414	82	82	165	11 692	13 558	25 249					
	Midway	28 747	27 723	56 470	7 971	7 971	15 941	20 776	19 752	40 529					
17	Tshiawelo	6 913	7 475	14 388	0	0	0	6 913	7 475	14 388	15 281	15 678	16 086	16 504	7 539
	Waterworks	382	511	893	0	0	0	382	511	893					
11	Mlamlankunzi	3 803	5 186	8 989	0	0	0	3 803	5 186	8 989	424 747	435 790	447 121	458 746	137971.5
	Mzimhlope	6 289	7 844	14 133	1	1	2	6 288	7 843	14 131					
	Nancefield	5 490	6 291	11 781	0	0	0	5 490	6 291	11 781					
	Orlando	5 668	6 887	12 555	14	14	28	5 654	6 873	12 527					
	Phefeni	4 941	5 795	10 736	30	30	60	4 911	5 765	10 676					
	Phomolong	5 844	6 849	12 693	1	1	2	5 843	6 848	12 691					
7	Bosmont	1 699	1 311	3 010	0	0	0	1 699	1 311	3 010	542 919	557 035	571 518	586 377	108 676
	Croesus	7 731	8 326	16 057	0	0	0	7 731	8 326	16 057					

	Grosvenor	4 130	3 955	8 085	0	0	0	4 130	3 955	8 085					
	Langlaagte	12 036	12 876	24 912	2 232	2 232	4 465	9 804	10 644	20 447					
	Longdale	6 965	6 178	13 143	0	0	0	6 965	6 178	13 143					
	Mayfair	5 736	6 034	11 770	0	0	1	5 736	6 034	11 769					
	Industria	1 022	1 231	2 253	0	0	0	1 022	1 231	2 253					
	New Canada	31 117	32 037	63 154	13 463	13 463	26 926	17 654	18 574	36 228					
	Newclare	1 754	1 686	3 440	0	0	0	1 754	1 686	3 440					
	Westbury	1 910	1 830	3 740	0	0	0	1 910	1 830	3 740					
	Booyens	5 743	4 680	10 423	1	1	2	5 742	4 679	10 421					
	Braamfontein	9 465	8 147	17 612	20	20	39	9 445	8 127	17 573					
	Faraday	3 220	2 615	5 835	2	2	4	3 218	2 613	5 831					
8	Johannesburg (Park)	92 932	77 109	170 041	9 746	9 746	19 492	83 186	67 363	150 549	211 847	217 355	223 006	228 804	65 496
	Village Main	1 079	958	2 037	0	0	0	1 079	958	2 037					
	Westgate	2 673	3 226	5 899	46	46	92	2 627	3 180	5 807					
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0
13		0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX B: PROPOSED ZONES FOR THE GAUTENG VISUM MODEL

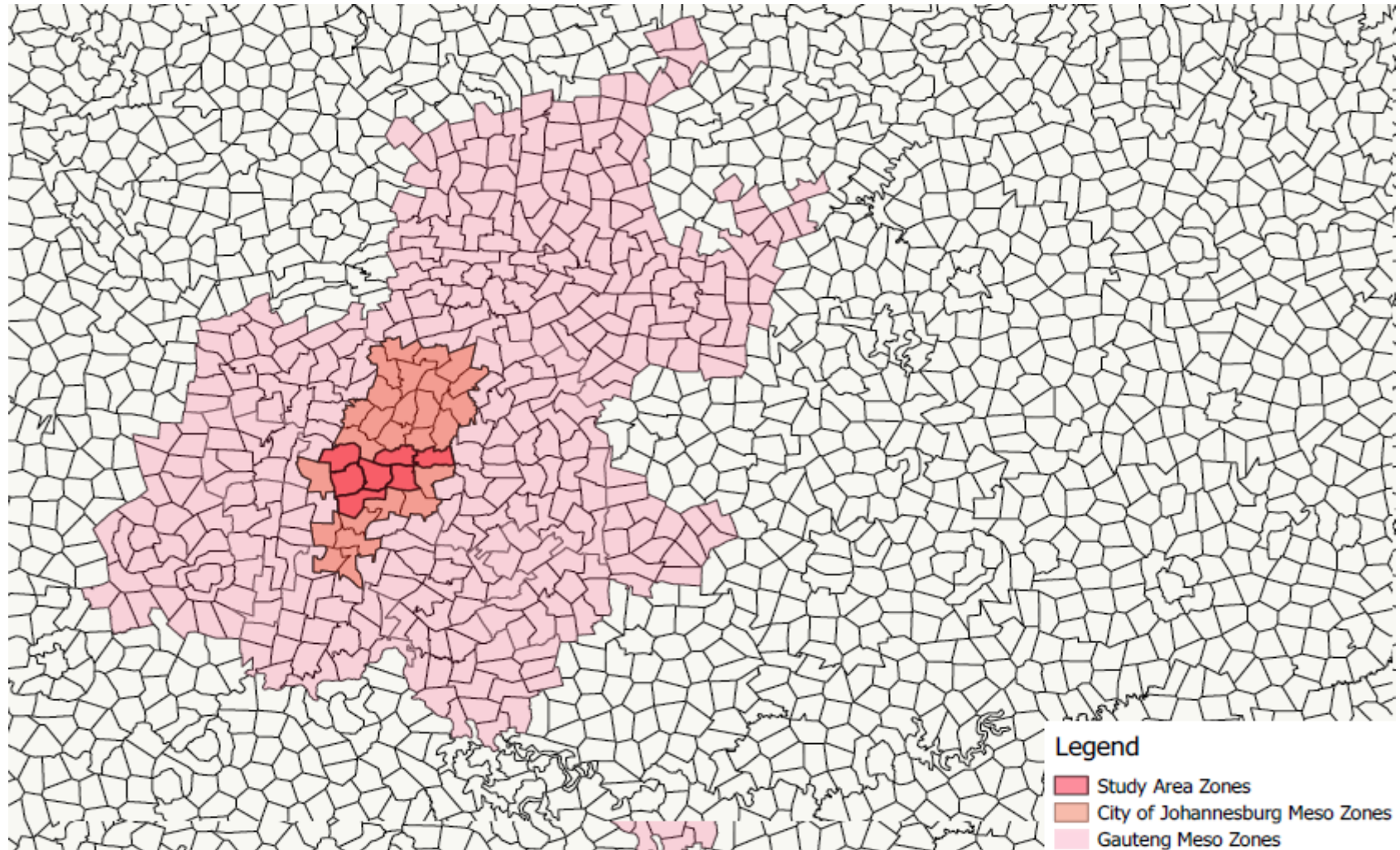


Figure 26: Proposed Zones for Gauteng VISUM Model