THE UNIVERSITY OF CAPE TOWN

MASTERS THESIS
[CIV5017Z]

Modelling Road Space Prioritisation for Public Transport using AIMSUN: A Case Study in Durban

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A thesis submitted in fulfilment of the requirements for the degree of Master of Engineering specialising in Transport Studies [EM017CIV06]

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November 2016

University of Cape Town

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Abstract / Summary

This study exhibits road space prioritisation of three types of public transport systems. The study first goes into a literature review of road space prioritisation and aspects of modelling this. These types of systems were then modelled using a case study of a single corridor in Durban, South Africa. Both a macroscopic modelling and microscopic modelling package were used to model a base year and various public transport scenarios. This was done to illustrate the effects of road space prioritisation along a corridor of the city.

The modelling was predominantly done in AIMSUN, a microscopic modelling package. The three public transport scenarios performed were: a quality bus scenario, a bus rapid transit system scenario and a mini-bus -taxi scenario. For a certain purpose, a relationship in road capacity could be formed between the macroscopic model and the microscopic model. An increase or decrease in capacity was used to illustrate the change in private car trips along the corridor to show the redistribution of traffic along the corridor. This was done in a macroscopic model and then transferred into a microscopic simulation model.

A costing analysis of these three scenarios was done at the end of the results chapter. It was concluded that the bus rapid transit system was the most feasible public transport system for the corridor based on the demand pattern used in this study for that specific corridor.

Acknowledgements

This study has proven to be one of the greatest challenges in my life thus far. A lot of focus and time was required, of which I put into each aspect when doing this research. I am thankful for all who supported me during this journey and for the guidance from God.

The person, who ensured that I worked constantly, that I gave my 100% throughout this study and for giving me her tremendous support is my wife Novashni (Sharleen) Moodley. I am forever grateful to you for always being my constant rock and for creating a place of home in my life. Thank you for being my other half and always pushing me forward. I love you.

A special thank you for the support and guidance from the day of applying for my studies, during each of the courses and dissertation goes out to none other than Mr Logan Moodley. I still remember the day you walked into my office and asked me “did you look at doing your postgrad studies in transportation?” To which I replied, no and you then passed me a course brochure of what UCT offers. I did my research and thereafter applied. This is what makes you an incredible and inspiring human being and I see you as a second father in my life.

I thank my manager, Manoj Rampersad, in aiding me to study and always supporting me during the entire duration of these studies. Your support during these studies is greatly appreciated.

I thank my parents for making sure I had a grounded upbringing and always making sure I had everything I needed and for supporting me throughout my life in all that I did and do. I thank my siblings for always showing their support and making sure I always make good decisions in my life and supporting me in all that I do.

My supervisor Mark Zuidgeest, thank you for your time and patience and for just being you throughout this dissertation and for helping me create a good research and making sure I did all that I needed to within the stipulated times. Your guidance throughout this study has been incredible. This gave me the direction whenever I felt lost. Thank you.

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1. Introduction

Transportation exists because it provides a means for the movement of people and the exchange of goods (Rodrigue *et al*, 2006). Developing transport systems to satisfy mobility needs has been a continuous challenge, noting that mobility supports economic development (Rodrigue *et al*, 2006). Transport accessibility is the main factor that contributes to the high economic activity in the Central Business District (CBD) but this accessibility is threatened by the increasing high usage of the private car. This is preventing mobility and increasing congestion (Gonzales, 2011).

The use of the private car as a means of daily commute has been increasing over the last few decades due to rising middle-income class. Growing incomes have led to growing car ownership and use across the developing world. These private cars have filled roads and streets to their capacities. Hence, worsening urban mobility and accessibility due to congestion and declining Public Transport (PT) levels of service (LOS) (Gackenheimer, 1999, cited Wilkinson *et al*., 2011). With these levels of congestion, the private car is no longer providing the levels of accessibility it intended to do. The predominant mode of PT in most parts of South Africa is the mini-bus taxi service. This service is a para-transit service as most of them do not operate on fixed routes at fixed schedules, and they do not have good headways or a timetable (Behrens, 2007). The private car and the para-transit mini-bus taxi service as a means of daily transport also has various negative impacts on traffic safety, congestion, air and noise pollution, quality of life and large land uptake due to their large highway requirements which make it unsustainable (Wallström, 2004; Behrens, 2007).

In order to move people more effectively and in a sustainable manner, an alternative system such a good formalised PT system is required to alleviate congestion on roads, to save time; cost and improve safety (Behrens, 2007). Where road space is restricted, providing adequate space for these alternative modes to the private car may require reallocation of highway capacity or road capacity for alternative modes (Wallström, 2004). Research on prioritising road space to provide for other modes of traffic such as PT and Non-Motorised Transport (NMT) is required so that sound decisions can be made when planning a city's road network (Currie *et al.*, 2007). Competing demands for the limited resources such as time and space i.e. road space, as well as cost (Rodrigue *et al*, 2006) are aspects to be considered. Prioritising road space for PT is said to better improve performance for the formalised PT system rather than bus and car share mixed use lanes. Research has shown a correlation between prioritised PT and less congestion for the private car. This also improves PT performance (Zheng and Gerolimins, 2013).

Doing the opposite, i.e. providing extra capacity with additional road space for private vehicle traffic, may only serve to temporarily ease congestion. This is because increasing the capacity only makes that road more attractive to cars. This leads to induced growth in vehicle traffic. Therefore, the method of suppressing demand is a more cost effective solution (Noland, 2001; Wallström, 2004). Providing more road capacity is not necessarily a viable solution to traffic congestion and rather a reallocation of road space for alternative modes such as PT is a possible solution (Currie *et al.*, 2003). This shows that the road space allocation problem is complex and therefore needs investigation.

The South African National Government is, therefore, moving away from the primary planning for the private car to transportation planning strategies which use road capacity for all modes of transport in a sustainable and integrated way. This is done by planning for transportation to move people instead of just private cars, hence allocating road space for the most appropriate modes of transport. This, for example, involves PT and NMT as well as Travel Demand Management (TDM) measures (National Department of Transport - NDoT, 2007a).

There are various cities globally, including cities of South Africa, where interventions are implemented that prioritise road space for PT rather than for private vehicle transport (Wallström, 2004; NDoT, 2007b). The mini-bus taxi services should be formalised and incorporated into scheduled PT systems (Write, 2004 cited in Behrens, 2007). The current PT system in most cities in South Africa mainly revolves around the informal para-transit mini-bus taxi services as these serve most of the captive PT users. This service is undesirable to the greater public as it lacks safety, security, comfort and reliability (Behrens, 2007). Major South African cities have taken the initiative to implement Integrated Rapid Public Transport Network (IRPTN) services with the combination of Bus Rapid Transit (BRT) services on dedicated lanes and rail services. These systems are being implemented to primarily provide a better service for the existing captive users (NDoT, 2007b).

This new service referred to in the previous paragraph, needs to be car competitive and attract existing car users. In support of road space prioritisation for a PT system, the policy aim from the NDoT (2007b) is recommending a 20% modal shift of private car work trips to the PT system. This proposal is assumed to be achieved with the use of

TDM measures (NDoT, 2007b). TDM measures aim to reduce the demand of single occupancy car ridership and create a shift towards PT, NMT and reduce the need to travel. This can be done with the use of various techniques and by changing travel behaviour. TDM measures reduce carbon emissions and are an alternative to increasing road capacity (Adjei and Behrens, 2012).

In addition, there is policy guidance to change the way we do the current planning and implementation to transport people (NDoT, 2007b). This change is from the 'predict and provide' approach for private vehicle transport to a prioritised road space for a PT initiative such as BRT. This change focuses on alleviating congestion in the long term because the current 'predict and provide' method of transport is not the solution to our transportation needs, and therefore needs to be abandoned (Cairns, 1998; Goodwin *et al*. 1991; and Owens, 1995; cited in Behrens and Del Mistro, 2010).

As cities across the world grow rapidly in population, different modes compete for limited urban road infrastructure to travel. Therefore, there is a need to understand how this road space is used and how it can be managed to improve accessibility for all modes (Zheng and Gerolimins, 2013). The evaluation and planning of urban transportation projects and policies, such as road space prioritisation, can be done with the use of computer models, which has become fundamental to the analysis (Siegel and Coeymans, 2005).

1.1. Problem Statement

High levels of congestion along routes towards Central Business Districts (CBD's), particularly during the morning peak hour, have led to questions about the possibility of reallocation of road space for private vehicles to favour more sustainable modes. Yet the impact of this reallocation of road space on traffic operations is unknown. Therefore, this research investigates how traffic volumes and travel times for the different modes along a specific corridor in the Durban CBD are affected by various road space reallocations, which favour PT.

1.2. Aim

This research aims to explore, model and test strategies of road space prioritisation for alternative modes, such as PT and NMT, to the private car with the intention to contribute to more sustainable transportation in a South African City.

1.3. **Objectives**

The objectives of this research are:

1. Knowledge inventory

    A. To explore literature and understand the principles of **road space allocation** with reference to road space allocation for PT.

    B. To explore literature on **transportation modelling** in terms of macroscopic and microscopic modelling in view of road space allocation.

2. Modelling and Testing

    A. To develop a modelling approach, including microscopic and macroscopic modelling techniques, for appropriate modelling of road space allocation in the context of Durban. This is done with the use of a microscopic modelling package namely Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks (AIMSUN) and a macroscopic model package namely Equilibre Multimodal Multimodal Equilibrium (EMME).

    B. To develop a modelling framework for constructing a microscopic model with parameters and an approach to deriving a demand matrix, in attempting to replicate actual traffic route operations.

    C. To choose an appropriate calibration and validation technique process.

    D. To define and use of appropriate Key Performance Indicators (KPI's).

3. Application

    A. To **develop a calibrated and validated AIMSUN 2015 base model** for the Dr Pixley KaSema Street (West Street), corridor within the CBD of Durban, KwaZulu-Natal.

        - This includes testing against the Design Manual for Roads and Bridges (DMRB) parameters in terms of volume of throughput traffic and travel time as used in the development of a base model, thereby ensuring that the model has integrity.

    B. To test the current base model against various scenarios of road space allocation.

        - Scenario 1: A rigid Quality Bus Service (QBS) in mixed traffic;

- Scenario 2: BRT with the associated dedicated infrastructure; and
- Scenario 3: Mini-bus Taxi Service (MTS) in mixed traffic.

4. Inferences / analysis

   A. To identify potential benefits of each type of PT system with its appropriate road space allocation by evaluating KPIs. The KPIs selected are travel time and performance LOS of each type of PT scenario. These KPIs are compared to the base year scenario.
   B. To do a high-level costing of each PT system (including the operational costs) in order to provide a complete and implementable road space allocation.

1.4. Limitations and Challenges

There were various limitations to this study, which are as follows:

- A limitation of time. A significant amount of time went into the building of the base year model and each of the scenarios. This research was done to the best of the researcher's ability given the limitations of time and access time to both modelling packages.
- The access to models was limited to AIMSUN and EMME in this study. Other microscopic simulation and macroscopic simulation packages could have been used, such as, PTV-VISUM and PTV-VISSIM.
- The EMME model was used as is, hence no option to do a mode choice modelling exercise was afforded. Therefore, the macroscopic modelling was focused on private vehicle trip distribution and the trip assignment stages only.
- The other corridors see increased problems when the capacity along the investigated corridor was reduced. This was outside the scope of this research and was not discussed.

1.5. Summary

There is the recognition that the private car and para-transit mini-bus taxi services as a means of daily transport is not sustainable and has various negative impacts on the environment. These negative impacts include land uptake due to their large highway requirements, congestion and air pollution. It is, therefore, the aim of cities to move towards decongesting their city. It is against this background that this research focuses on the reallocation of road space by prioritising it for PT and NMT and incorporating various demands with the use of an integrated macroscopic and microscopic transport model approach.

2. Literature Review

2.1. Introduction

This chapter reviews the literature on road prioritisation for PT and NMT. This includes the discussion of literature on road space prioritisation, TDM, induced and suppressed traffic and South African legislation. The chapter then goes on to describe transportation modelling aspects and how it could potentially be used in planning better use of road space.

2.2. Road space allocation, reallocation and prioritisation for PT and NMT

It is known that the private car is the most popular and most favoured mode of transport that remains an integral part of the economy and planning in most metropolitan cities (Wallström, 2004). Over the past few decades, the reaction to the increase in traffic demand by the private car has often been to increase the level of supply of additional road space. This traditional approach of providing further road supply to meet the traffic demand is no longer always appropriate. This has led to freeways becoming wider to meet the increasing demand of traffic (Wallström, 2004; Behrens and Kane, 2004). Studies now indicate that the benefits of creating additional road capacity are not as significant as previously believed. In some cases, the provision of new road links may have increased congestion problems. This occurs through a process that is known as traffic 'induction' (Wallström, 2004; Noland, 2001). In the aim to improve mobility and accessibility in planning urban transport networks, the primary challenge is traffic congestion. The improvement of PT may offer a possible alternative solution as the construction of new roads or the widening of existing roads for more private car capacity is not a viable option in most urban areas. The introduction of exclusive PT lanes is a sustainable and low-cost improvement, which needs further investigation (Mesbah *et al.*, 2009). The Victoria Transport Institute (2015) describes road reallocation as:

> *"Road Space Reallocation involves shifting road space currently devoted to automobile traffic or parking to serve other modes, such as sidewalks, bike lanes, High Occupancy Vehicle (HOV) and bus lanes, or rail lines"*
>
> (Victoria Transport Policy Institute, 2015).

A typical example of a cross section illustrating road space reallocation is shown in Figure 1, below (Robertson, 2013). Road space reallocation entails managing roadways to encourage more efficient and equitable transportation.

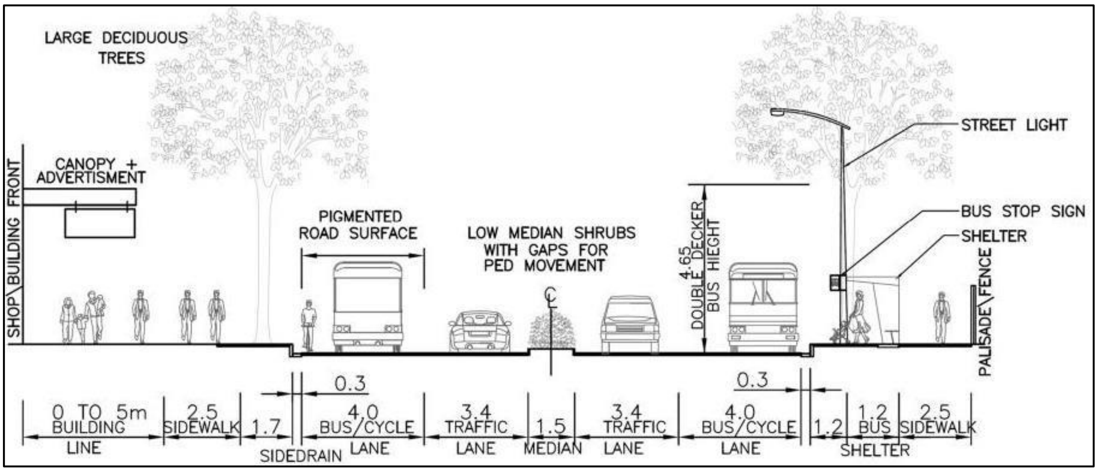
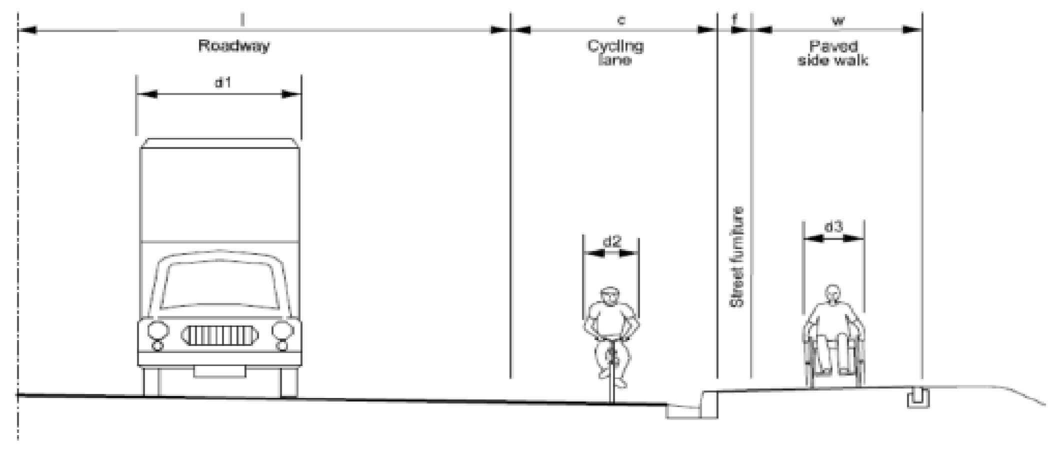


Figure 1: Road Space Reallocation - Typical road cross-section (Robertson, 2013).

The South African NMT guideline illustrates various cross-sections and guidance around the planning and design of NMT infrastructure along roads. For roads with a higher class, it is recommended that the NMT facility is fully separated from the motorised traffic with the use of a barrier such as a guardrail. NMT facilities for lower classes of roads can be separated by kerbs, street furniture or by marked lanes for cyclists in some instances. An example of roadway cross-section that illustrates a cycling lane, pedestrian and wheelchair lane and motorised vehicle traffic is illustrated in Figure 2 (NDoT, 2014). The reallocation of road space priority should be done in South African cities in the form of footways, cycle paths and dedicated bus lanes for exclusive use by pedestrians, cyclists and PT users, respectively (Behrens, 2014b).

Urban Distributors and Collectors (60 km/h)



Dimensions:

l = Min: 3,000 mm

c = 1,800 mm (Min: 1,500 mm)

f = 1,000 mm (COTO)

w = 1,800 mm (Min: 1,500 mm)

d1 = 2,500 mm (2,600 mm with mirrors)

d2 = 750 mm (900 mm with manoeuvring)

d3 = 700 mm (900 mm with manoeuvring)

b = 1,500 mm (min 1,200 mm)

Principles:

- Marked separation
- Traffic situation is less complex, so bicycles and motorised transport do not need a physical barrier.

Positive Aspects:

- Road reserve requirements are reduced.

Negative Aspects:

- Road safety risk increases if drivers are not disciplined.

Figure 2: NMT typical cross-section - Typical road cross-section (NDoT, 2014).

Reallocation of available road space to provide PT priority is increasing at a rapid rate worldwide (Currie *et al.*, 2003). The provision of PT priority schemes are mainly provided in relation to the volumes of PT vehicles and passengers. These are mainly sourced from experimental or other static modelling studies. Dynamic traffic simulation methods are rarely used to determine appropriate PT priority warrants. There are travel trade-offs between private car travel and PT when investigating literature on the allocating of road space. Some of these include PT travel time improvements as PT priority measures can clearly reduce travel time for PT vehicles.

However, research suggests that PT passengers' value on the reliability of PT services far outweighs that of an improved travel time within vehicles. Therefore, the use of prioritising or dedicating lanes for PT will improve the reliability. There is little consideration of reliability improvements (Currie *et al.*, 2003).

Improving travel times and the reliability of PT services has proven to have a direct relationship to increasing ridership (Currie *et al.*, 2003). This will, in turn, reduce road congestion, reduce vehicle-operating costs, reduce accident costs and lower environmental emissions and impacts (Currie *et al*., 2003; Targa and Rodriguez, 2004). Most PT priority schemes at a microscopic level recognise benefits of reduced PT vehicles and staff resources through faster running times but the actual costs of the entire system, essentially the full operating costs of implication are not considered (Currie *et al.*, 2003 Currie *et al.*, 2007). Noting, furthermore, that the project capital investments required for segregated right of ways are substantially high, quantification of the benefits and costs are needed (Currie *et al.*, 2003; Currie *et al.*, 2007). At a macroscopic level traffic route choice changes may also take place to move to less congested roads of the network. This may also take place due to drivers' perception that alternative routes may be quicker (Currie *et al.*, 2003). Road space to be prioritised for PT such as BRT instead of private vehicle transport is encouraged with the aim of planning a sustainable transportation system in terms of cost, physical space constraints and the environment. BRT systems provide a more equitable allocation of road space among road users rather than private vehicles on the road. Current road conditions show a rapid increase in private vehicles leading to traffic congestion with limited road reserve in CBD's, increasing urban sprawl and air pollution. Therefore, there is a need to improve transportation systems around urban cities in the world (Gautam *et al.*, 2012, cited in Gautam *et al.*, 2013).

PT in the form of BRT has grown from a single city in South America by providing a mass transit to a common element of an integrated system in 168 cities from 39 countries around the world (Global BRT Data, 2014; Hidalgo, 2011, cited in Lindau *et al*., 2014). This system provides a more efficient use of urban road space and provides affordable connectivity while being fast and reliable (Lindau *et al*., 2014). One of the first and best examples of a fully integrated rapid transit system in the world is the BRT system in *Curitiba, Brazil*. The relationship between the urban development and the PT system complemented each other. Similar to that of the rail transit, the BRT has its own right-of-way. This system is cheaper to construct, more flexible and faster to implement over the rail. In 1974 their system had a trunk and feeder services with a complimentary express bus service and a single ticketing system within their nine districts (Wilkinson *et al.*, 2011). The trunk routes have exclusive right-of-ways with feeders being in mixed traffic. In 1980 the city changed the payment structure from a passenger-based to a kilometer-based system (Wilkinson *et al.*, 2011). With enforced highly dense populated bus corridors came a high passenger demand. The current system in Curitiba is considered to be the first full-BRT system to be implemented in the world, and this system competes with the rail based system currently transporting approximately 560 000 passengers daily over the total network of 65 km (Pardo, 2009, as cited by Wilkinson *et al.*, 2011).

With the investigation of the worlds' best practised it can be found that in Curitiba-Brazil and in Bogotá-Colombia that the collector-distributor system works the best in the form of a trunk / haul line and feeder services also known as BRT (Duff-Riddell, 2013a). An illustration of this system is shown in Figure 3. A feasibility of new PT system such as a collector-distributor system needs to be further tested in local South African conditions. It is recommended to form the main trunk service for the large demand links and a feeder service for the smaller demand. The first or last part of this new system will form part of walk and cycle trips to the feeder pick up points. This is a crucial part of the system as sidewalks and NMT lanes must be planned and implemented to make the first, and last, part of the journey accessible. To reduce the walking distance, feeder services must be in proximity of 1 km for 85% of residents (NDoT, 2007a). To make the system more accessible the network must aim to find a balance between the distance walked and the travel distance of the PT service is required. This must be optimised to find the most cost-effective solution. The system must seek to minimise the total distance walked, to minimise the maximum distance walked, to minimise the total average distance walked and also to minimise the total cost of all users (Duff-Riddell, 2013a).

Figure 3: Bogota BRT (Dalton, 2009).

Literature suggests that instead of allowing cities to get further congested, restricting access to a city's congested areas can improve mobility for all travellers. Also dedicating road space to more sustainable modes like buses can improve accessibility for all modes, even if space is taken from cars (Gonzales, 2011). Most current planning and modelling exercises primarily focus on the private car. Car based mobility is proven to increase economic growth and hence remains an integral part of traffic management planning. There is now a shift from car planning towards person trip planning by finding ways to encourage the use of alternative modes of transport, such as PT and NMT (Wallström, 2004). Road space management involves balancing the needs of the competing demands for limited road space and time. PT priority requires careful balancing of the needs of a wide range of road users and an understanding of the costs and benefits of changing how a road functions (Currie *et al.*, 2007).

The most logical approach of road space priority is the provision of sufficient road space to permit non-private car modes of transport to be promoted in this spare space (Behrens, 2007). This must be done to not affect the mobility of the private cars, particularly during peak hours when a large amount of traffic congestion may exist. However, this is not possible, as it does not solve the challenge of finding ways of using existing road space capacity more efficiently. This can, however, be done by the promotion of more sustainable modes of transport in the form of PT and NMT (Wallström, 2004). These findings provide a basis for the development of a more balanced approach for PT priority and NMT provision. The desire to have a balanced approach to maintaining good levels of traffic flow between all modes and prevent congestion while maintaining economic growth by supporting mobility is the conundrum that is faced (Currie *et al.*, 2003).

2.3. <u>Transportation Systems Modelling and Analysis</u>

Conceptually the transport system can be seen to consist of three sub-systems. These are travel patterns, transport services and traffic services, as illustrated in Figure 4, and discussed by Schoemaker (2002). The first level is travel patterns, which are formed by travellers requiring to reach a destination. These include all types of travel for various reasons such as the movement of people, goods and services from point to point. Travel patterns are modelled using a macroscopic transportation planning model, or travel demand model. The second level is transport services which are catered for by selecting a mode of transport. These can be modelled using travel demand models or highly specialised mode choice models (Schoemaker, 2002). Travel demand models are mostly static by nature and represent vehicle flows. These models can display full and semi-operational aspects of traffic, but not the vehicle interactions (Burghout, 2004). The third level caters for traffic services with its appropriate traffic infrastructure. The planning and designing for traffic infrastructure are done at a microscopic level with the aid of microscopic models. These models represent individual vehicles and iterations. Individual driving is included in more detail. These models are dynamic (Schoemaker, 2002). Transport models help in planning transport and traffic. Macroscopic models investigate traffic flow and travel patterns. At a microscopic level, interactions between the modes and road infrastructure are modelled and assessed with the use of microscopic modelling (Burghout, 2004).

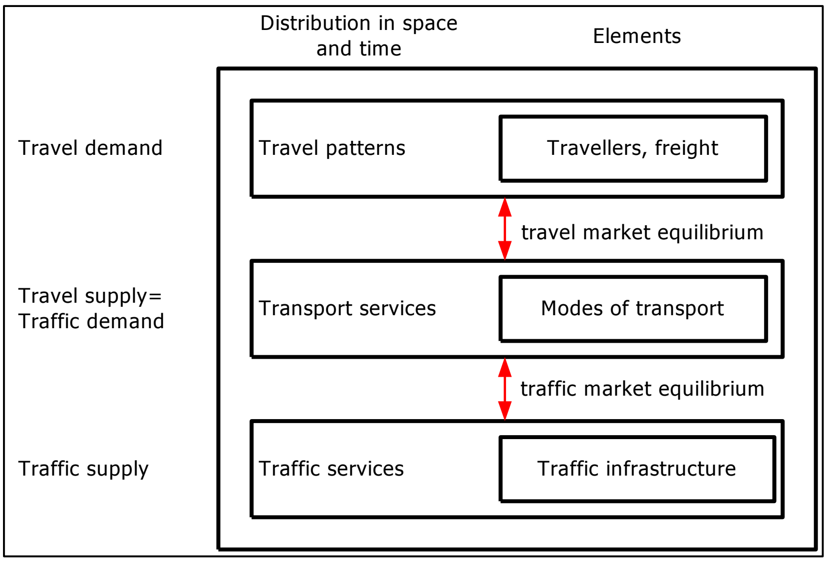


Figure 4: The theory of three markets: Travel, Transport and Traffic (Schoemaker, 2002).

Most transport authorities began using handbooks and manuals such as the Highway Capacity Manual (HCM) (2000) in transportation planning and engineering. This was improved with calculation utilities such as traffic flow models which became common. Simulation models are used to reproduce successive changes of the traffic system over time and space. The levels of traffic simulation models vary in detail and range from macroscopic, mesoscopic to microscopic models. Mesoscopic models fits in-between macroscopic and microscopic models which illustrate its analysis in platoons or groups of vehicles on links (Siegel and Coeymans, 2005). These models lack the capabilities of land-use macroscopic models and lacks the details of a microscopic models. Macroscopic models describe traffic at high levels of aggregation as traffic flow. This is where the number of vehicles per hour or peak period passes a certain point. This will not model individual vehicles and their behaviour but rather an aggregated traffic flow of vehicles. Microscopic models describe the behaviour of each vehicle entity that makes up the traffic stream as well as their interactions in detail (Burghout, 2004). These are discussed further in chapter 2.7.3, Hybrid Modelling.

Montero *et al* (1998) elucidate models slightly differently. According to Montero *et al* (1998), modelling traffic in real cities is complex with various types of modes sharing the roads. This is combined with congestion changing as demand patterns change over the course of a day. Transport models can be divided generally into city-scale (macroscopic) efforts and street-scale works (microscopic) (*Montero et al.*, 1998). City-scale investigation looked only at the behaviour of one mode of traffic thus far with the added effects of traffic congestion (Gonzales *et al*., 2010). Studies of multiple modes and the interaction thereof have only been modelled at the microscopic or street-level scale level for a time-independent scenario (Gonzales *et al*., 2010; Zheng and Gerolimins, 2013). Studies have looked at PT on a city scale with PT on idealised road networks (Zheng and Gerolimins, 2013). Therefore using a macroscopic model to make road space allocation decisions is difficult as it requires consideration of multiple modes. These considerations have been made at a much finer street-scale at a time-independent (unrealistic) environment. The existing body of work leaves a gap to be filled. A physically realistic time-dependent, city-scale model including multiple modes is much needed (Zheng and Gerolimins, 2013).

2.4. Travel Demand Management (TDM)

TDM can be in the form of physical measures, voluntary measures, regulatory measures and pricing measures. These measures aim to encourage or force a change in travel behaviour for the purpose of reducing the demand for single occupancy car travel and to redistribute these users to other modes. Regulatory measures can take the form of:

- imposition of new or changed regulations governing travel choices;
- physical measures through infrastructure retrofitting;
- pricing measures through new or changed user charges; and
- voluntary measures through enhanced personal scheduling flexibility, incentives and awareness campaigns (Behrens, 2014a).

This study has a physical TDM measure in the form of a PT prioritised lane. As an example, the replacement of mini-bus taxis with buses is expected to improve capacity. This free capacity could possibly be locked in by an NMT lane.

TDM measures aim to reduce congestion in the CBDs and to promote the use of PT and alternative modes instead of the private mode alone, thereby promoting economic growth. The National Land Transport Act (Act No 5 of 2009) reiterates this, defining TDM as:

"a system of actions to maximise the capacity of the transport system for the movement of people and goods rather than vehicles, among others, through increasing vehicle occupancy, developing priority measures for public transport, encouraging travel during off-peak periods, shifting demand between modes, restricting the space available for parking, adjusting the price of parking, and other appropriate measures"

(NDoT, 2009, pg.16).

If ridership is low on the PT system, TDM measures can be used to increase the ridership. In South Africa, the shifting of 20% of private vehicle users to PT by means of TDM measures sees the PT system being vastly improved (NDoT, 2007b). Congestion charging or road pricing is one of the strategies currently favoured as a means to bring about shifts into PT. This also is used to prevent some of the rebound effect of increasing overall travel in response to improved LOS on highways (Stopher, 2003). Congestion charging together with an efficient PT system can be used to increase PT ridership, if ridership levels are low.

The IRPTN is considered to be a car competitive mobility alternative and will enable the phasing in of stricter penalties and incentives to get the car users to switch to this network especially during the high congested peak times. By the year 2020 South Africa aims to implement a range of demand management measures which include: '*peak period road pricing, citywide parking levies and restrictions, possible tax incentives to employers and individuals to switch to the network, and local options with regard to staggering working and schools hours*.' (NDoT, 2007b, pg.21). Therefore, to further increase ridership and reduce congestion in the CBD more TDM measures, and incentivised PT are required. In this case, private car usage must be discouraged.

With TDM measures come the benefits of more capacity on the road network. This free capacity will need to be locked in. This can be done by converting existing lanes into dedicated PT infrastructure or NMT lanes, before single-occupancy vehicular traffic is induced along these routes. The European Conference of Ministers of Transport (ECMT) (2007, pp195) states that '*in light of induced and/or suppressed demand, capacity-producing measures should always be accompanied by measures that manage traffic levels in order to lock in the benefits derived from new capacity*.'

TDM measures aim to change travel behaviour. In travel behaviour modelling most research considered the traffic speed flow impacts of changes in road capacity. This was the main form of travel behaviour to be represented. Other travel behaviour changes include traffic re-routing as a result of reduced road capacity and have been considered in some models. Modal shifts from car to PT are also considered in some research, which could be used to increase the PT trip generation, but research does not show how this behaviour can be modelled (Currie *et al.*, 2007).

2.5. Induced and Suppressed traffic

When a congested road is widened with additional lanes to increase capacity (increased supply), this road will induce traffic to the roadway (Noland, 2001; SACTRA, 1994 cited in Behrens and Kane, 2004). Induced traffic is the shortcoming of new road capacity improvement on the Single Occupancy Vehicle (SOV) (SACTRA, 1994 cited in Behrens and Kane, 2004). This increased traffic on that roadway can occur due to various behavioural mechanisms that include modal shifts, route shifts, generation of new trips, redistribution of trips, and in the long term creates land use changes that create new trips as well as longer trips (Noland, 2001). Suppressed traffic (reduced supply) inversely mirrors behavioural responses to induced traffic. This is when road capacity is reduced and users move to alternative routes or alternative modes (Goodwin *et al.*, 1998 cited in Behrens, 2014b; and Behrens and Kane, 2004).

Induced traffic is caused by the notion that the new increased road capacity (supply of roads) will increase travel speeds as well as make the travel time shorter of the trip. Therefore, from an economic perspective, if the travel times are reduced the generalised cost of travel should also reduce making that route very attractive and thereby resulting in an overall increase in demand. Note that travel time is a major component of variable costs experienced by those using the private vehicle as a mode of travel, in this sense, this is a benefit for single car users (Noland, 2001). This increase in supply and reduced generalised cost leads to an increase in the volume of vehicles as can be seen in Figure 5. On the contrary, by suppressing the traffic and by reducing road capacity, travel times are increased thereby making this route unattractive and resulting in a decrease in demand along this route. This can also be referred to as traffic disappearing as a result of road closure (Behrens and Kane, 2004). Therefore, this has implications for the planning of transportation and the method of 'predict and provide' is not the solution to transportation needs. Therefore, this approach needs to be abandoned, especially in urban areas where there is an oversupply of latent demand (Cairns, 1998; Goodwin *et al*. 1991; Owens, 1995; cited in Behrens and Del Mistro, 2010). Transportation systems need to move away from the supply-side focus of providing more road capacity to a demand-side focus of managing the demand of traffic in South Africa and this is iterated in transport policy mentioned above (Behrens and Del Mistro, 2010).

In the short term induced traffic occurs when road capacity is increased, trips are re-routed from neighbouring streets and trips are also rescheduled to the peak times. In the long term passengers shift from PT or NMT modes to private vehicle traffic. This road capacity increase initiates greater trip frequencies and unbundling of trip chains, which also contribute to induced traffic. Choice of trip destinations spread further away. The mirrored effect occurs when traffic is suppressed with trips being re-routed to the neighbouring street, etc. (Goodwin *et al.*, 1998 cited in Behrens, 2014b).

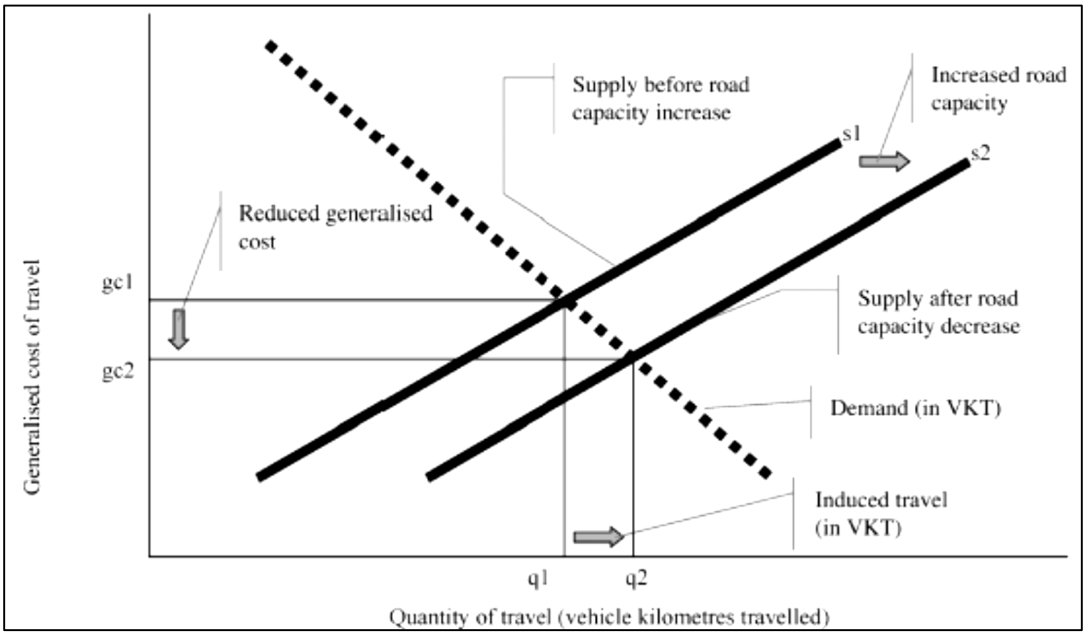


Figure 5: Induced traffic explained in terms of the micro-economic theory of supply and demand (Behrens and Kane, 2004).

Where VKT = vehicle kilometres travelled.

The traditional response to the problem of traffic congestion was to increase capacity by providing additional road space for private cars. Suppressing traffic by reducing capacity shows that traffic does not just use alternative routes but rather the theory of 'traffic evaporation' occurs (Wallström, 2004). Taking capacity away from the private car, which is the dominant mode of transport in most cities, is a brave decision for a road authority to take. Logic suggests that the removal of capacity could only make the situation worse in a network that is already congested. However, this theory suggests that reducing road capacity for cars in congested city centres can represent a sustainable solution to dealing with traffic congestion (Wallström, 2004; Behrens and Kane, 2004).

Understanding the phenomenon of induced and suppressed traffic will give light to the implementation of TDM measures including how these affect the traffic behaviour on the road and the surrounding roads. Increasing the capacity of the road to bring relief to congestion is proven to be ineffective as can be seen by the evidence of induced traffic (Behrens and Kane, 2004). This is because, in the long term, this leads to additional traffic on the road and the problems return once again with further increasing the car dependency. This presents a shortcoming of road capacity improvements (Noland, 2001). If the evidence of induced traffic illustrates the failed nature of supply-side policies as means to solving urban congestion problems, the evidence on suppressed traffic provides an appropriate policy alternative (Behrens and Kane, 2004).

Various TDM measures are used to control the transportation systems demand, in managing the demand-side and supply-side, in the promotion of more sustainable modes such as PT and NMT instead of continually supplying new road infrastructure. A balance between supply-side and demand-side strategies is required within an integrated policy framework (Bell, 1995; Goodwin, 1998, cited in Behrens and Kane, 2004). Although free flow conditions are ideal, a certain amount of congestion is acceptable as long as this congestion is managed so that the traffic continues to flow. This is key to the success of the transport system. Hence, it is important to manage the demand of the transport system and not only the supply (ECMT, 2007).

2.6. A South African Legislative Background on PT

Various aspects of PT are assigned to different spheres of government in South Africa namely the national, provincial and municipal or local spheres as these are prescribed in The National Land Transport (NLTA), Act 5 of 2009, chapter 2. 11. This Act reiterates policy from the 2007 Public Transport Action Agenda. This document states in chapter 2.15 that planning authorities at a municipal level must plan an integrated public transport network or a passenger rail service in its area and must establish an intermodal planning committee consisting of rail, bus and other modes of transport representatives involved (NLTA, 2009).

Most cities in South Africa had a good bus service but the system was undermined in the late 1980’s when the service was deregulated (International Union of Public Transport - UITP, 2008). During this time the growth of the mini-bus (Kombi) taxi began, which can carry up to 15 passengers (Barrett, 2003). The current PT systems mainly revolve around the informal mini-bus taxi services as these serve most of the PT users. This PT service operates as a para-transit service as most of them do not operate on fixed routes at fixed schedules, and neither do they have good headways or a timetable. This service is undesirable to the greater public as it lacks safety, security, comfort and reliability (Behrens, 2007). These para-transit services operate in mixed traffic and also do not gain the advantage of speed on congested roads.

All metropolitan municipalities across South Africa are in the process of implementing their IRPTNs as prescribed in the Public Transport Strategy (2007a). This service aims to transform from the current operator-oriented, low-quality service that mainly caters for captive users to a system that is user-friendly with a higher quality service for the current PT users and for the current car users. This new service aims to be affordable, minimise travel times, and provide security, comfort and convenience to the user (NDoT, 2007a).

The new and improved scheduled PT systems are expected to have high operational costs. This is due to the large distances it will cover hence creating high shortfalls requiring a subsidy. The current spatial layouts which exist in most South African cities feature PT users that travel large distances from townships for work opportunities. This is done largely with the use of the informal para-transit taxi service (Mtantato, 2012 & Behrens, 2007).

To have a PT system with possibly no subsidy the ridership of the system needs to be very high in both directions, as seen in cities such as Curitiba, Brazil (Wilkinson *et al*, 2011). The approach that was guided by the South African Public Transport Action Plan (2007) encourages priority infrastructure for road based networks with exclusive lanes and enhanced speeds through dedicated infrastructure (NDoT, 2007b). Therefore, as stated by Lindau *et al.* (2014) road space prioritisation for buses in the form of BRT or IRPTN services will have a significant advantage during the peak hours where traffic congestion occurs.

2.7. Modelling road space allocation

Modelling various road space reallocation configurations are the foundation of this research. Therefore, more in-depth discussion on modelling is discussed in this section. Macroscopic transport models, microscopic transport models, hybrid modelling and key performance indicators (KPI's) are discussed in this section.

2.7.1. Macroscopic transport modelling (Static)

The aim of travelling is to get from one destination to a destination. Travel is typically planned for in macroscopic models (Zuidgeest, 2014a). Macroscopic transport models, such as EMME, attempt to replicate the land use and transport interaction. The planning of transportation of cities the locations of human activities, such as living, working, shopping, education or leisure, determine the spatial interactions or trips in the transport system. This is the basic rationale of macroscopic traffic models (Wegener, 2011).

Transport planners use macroscopic transport models in determining where future road upgrades are required and where possible new links will help ease the congestion in the overall network (Montero *et al.*, 1998). Early attempts to model the two-way interaction between urban transport and land use began in the United States of America (USA) in the 1960s. Today a comprehensive range of integrated urban land-use transport models exist worldwide (Wegener, 2011).

Macroscopic models are static models and cannot model the dynamic nature of problems during the morning commute for cars and PT. These models identify equilibrium patterns and optimal pricing schemes (Tabuchi, 1993; Braid, 1996; Huang, 2000; Danielis & Marcucci, 2002; cited in Gonzales, 2011). The limitation of macroscopic models is that commuters are assumed to share an identical desired bottleneck departure time and only unrealistically simple cost functions have been considered for the PT mode (Gonzales, 2011). Existing macro models, for example, do not recognise that PT operations reduce the remaining capacity for cars, and the frequency of real PT service is adapted to the number of PT passengers (Gonzales, 2011).

Macroscopic transport models are based on the four-step modelling process. Information of the population, the economy and land use is inputted into the trip generation phase of the four-step modelling process. The four-step process begins with the *trip generation* in persons from zones. These trips are then distributed (*trip distribution*) onto the network links with the use of a trip length distribution function to other zones. These trips go through a *modal split* into private and PT modes taking into account vehicle occupancy. Thereafter these trips are assigned (*traffic assignment*) to the network. This is illustrated in Figure 6 (Beimborn *et al*, 2002).

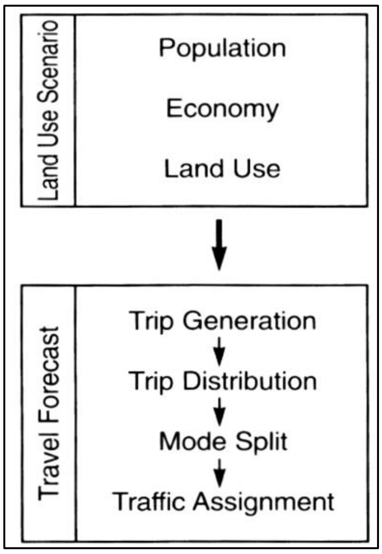


Figure 6: Macroscopic transport model forecasting process (Beimborn *et al*, 2002).

Macroscopic model networks, such as that in EMME, consist of nodes, links and modes (which constitute the base network). The network also contains turns, PT lines and PT segments (Montero *et al.*, 1998). The problem with existing macroscopic transport models is that PT operates on a separate assignment operating on a separate transit line, hence they do not recognize that the operations of PT services affect the capacity of the private car. Furthermore, it does not recognise that the frequency of real PT services is adapted to the number of transit riders (Gonzales, 2011). Hence, a mesoscopic or microscopic model is required to show the mix of traffic travelling on the same corridor.

2.7.2. Microscopic simulation modelling (Dynamic)

Microscopic models are used to model the operations of the road traffic conditions. These models are used to investigate existing traffic conditions and the performance of a corridor with and without a PT intervention. However, the analysis must consider different complex parameters such as driver behaviour. This includes lane change and lane discipline, traffic conditions, roadway conditions, mode choice and signal phasing. (Barcelo and Casas, 2002, cited in Gautam *et al.*, 2013). The mode choice shift is influenced by the demand matrix from the macroscopic model. These conditions involve taking many complex situations into account. A microscopic simulation model offers analysis of individual vehicle / driver behaviour and offers precise and realistic traffic conditions that other models lack (Barcelo and Casas, 2002, cited in Gautam *et al.*, 2013). The interactions between PT and car traffic are well illustrated in microscopic models. These must be modelled in scenarios particular to specific locations or time. Dynamic simulation modelling approaches can be used to show traffic flow impact of PT priority schemes. There is substantial variability in traffic flow in space and time, and trying to represent these is difficult using an analytical or stochastic approach. Dynamic or microscopic simulation models help represent these interactions in traffic flow. This includes factors such as signal timings, changes in traffic queue lengths and PT stop spacing (Currie *et al*, 2007).

Due to the dynamic nature of microscopic simulation models, random numbers in driver behaviour models are used. This refers to when a vehicle has to make a route choice, change lanes or accept a gap. Thus the results from these models will show random variability about mean values according to the random number (of seeds) used. Therefore, it is difficult to get an exact agreement between a microscopic simulation model's outputs and data collected from the real world. The model should aim to produce a similar average of values and spreads of values. Microscopic simulation models require three types of data, namely: *"network geometry data*, *calibration data* and *validation data*" (Helbing *et al.*, 2002). This data aims to replicate existing traffic and road conditions. These types of data are described in the proceeding three paragraphs.

- **Network geometry data**

Inputting network geometry data into a microscopic simulation model can be a very time-consuming task. Link information such as lengths and widths have to be measured, the number of lanes determined, intersection or junction layouts specified, locations of signals together with their timings entered, and PT stops and priority lanes identified (Helbing *et al.,* 2002). City centre pedestrian flows can be very high. These delays to pedestrian flows are often ignored when calculating traffic signal plans (Carsten, 1992, cited in Helbing *et al*., 2002). Some proposals to fix this oversight include pedestrian detectors to count the numbers waiting to cross the road and use these accurate numbers when setting signal timings. With the use of coordinated background maps, this is becoming an easier task as microscopic simulation models provide a graphical network builder (Helbing *et al*., 2002).

- **Calibration data**

The vehicle demand will need to be added to the model once the network geometry is done. The calibration data is used as an input into the microscopic simulation model. This is traditionally defined by specifying origin-destination (O-D) data. This is usually in the form of an O-D matrix. Some of the parameters that are calibrated in most microscopic simulation model are speed and acceleration data, driver behaviour characteristics, PT data, flow data, turning percentages and environmental data (Helbing *et al*., 2002). Traffic counts can also be used to update an O-D matrix by the use of a Furness balancing method to update the matrix to trip end totals or to blocks of cells in the matrix. The first procedure is done by repeatedly scaling rows and columns to meet trip end totals or boundary values until the matrix is obtained that satisfies the required trip distribution. The second procedure can be done by updating the O-D matrix by scaling groups of cells until they fit the traffic counts (Bliemer *et al.,* 2006). When transferring data from a macroscopic simulation model to a microscopic simulation model, as done by Siegel and Coeymans (2005), the O-D matrix could also be cordoned to the smaller scale of the microscopic simulation model from the larger scale macroscopic simulation model.

Most microscopic simulation models will usually use O-D data either based on route or based on turning volume percentages at each junction. This is done during the assignment stage of the model. The collection of O-D data for an input into a microscopic simulation model can be very time consuming as well as an expensive task. This is usually done by traffic counters at the entrances and exits of the network being studied to identify trip origins and destinations (Helbing *et al*., 2002).

- **Validation data**

Once the network geometry data and the model are calibrated, modelled runs are then performed to produce outputs which are checked against datasets that have not been used directly as inputs. This process is known as validation. Therefore, validation data is not a direct input into the model. Some of the typical datasets include travel time between points in the network, speed distributions at fixed points, average headways between vehicles, saturation flow, lane usage and roadside pollution levels. The use of new technology, such as Geographic Positioning System (GPS), allows easier and cheaper collection of validation datasets. This allows validation to be carried out against a larger number of types of data (Helbing *et al*., 2002).

When validating a model the standard method of comparison is to compare modelled values against observed values. There are two alternative analytic methods which are widely and frequently used to compare this. These model validation standards have been prescribed by the DMRB (1996). These two methods are outlined further which consists of the GEH (Geoffrey E. Havers) formula method and the other method is carry out a correlation analysis between the two sets of values to give a correlation coefficient (R). GEH is a form of the Chi-squared statistic that incorporates both relative and absolute errors (DMRB, 1996).

The GEH statistic formula:

$GEH = \sqrt{\frac{(M - C)^2}{(0.5(M + C)}}$; where GEH is the GEH statistic, M is the modelled flow, and C is the observed flow.

The GEH values can either be calculated for individual links or be calculated for groups of links, e.g. a screenline or a network-wide value (DMRB, 1996).The correlation analysis entails the comparison between modelled values against observed values in a scatter plot graph. The correlation coefficient (R) gives some measure of the goodness of fit. The slope of the best-fit regression line through the origin indicates a percentage of which the closer to 1 or 100% the better the fit. The regression line also helps illustrate the extent to which modelled values are over or underestimated. This is also known as a regression analysis (DMRB, 1996). Table 1 gives guidelines on acceptable values of validation measures for hourly flows.

Some of the shortfalls in most microscopic simulation models are trying to replicate the exact realistic on street situation. These shortcomings include searching for parking spaces, pedestrians, bicycles/motorbikes, induced and suppressed traffic, weather conditions and parked vehicles, which are not modelled. When a model's objective is traffic efficiency they provide indicators to measure speed, travel time, congestion, travel time variability and queue lengths. Indicators about PT regularity and modal split are often not provided. The environmental objective can be measured by the simulators by exhaust emissions. Roadside pollution levels and noise levels can be evaluated in some models (Algers, *et al*., 1998; Siegel and Coeymans, 2005).

Table 1: Assignment Validation: acceptable guidelines

Criteria and Measures Acceptability Guidelines	Criteria and Measures Acceptability Guidelines
Assigned Hourly flows compared with observed flows Individual flows within 15% for flows 700-2,700 vph Individual flows within 100 vph for flows< 700 vph Individual flows within 400 vph for flows > 2700 vph Total Screen line flows (normally > 5 links) to be within 5%	) > 85% of the cases) All or nearly all screen lines
GEH statistic: Individual flows: GEH < 5 Screen line totals: GEH < 4	 > 85% of cases All or nearly all screen lines
Modelled journey times compared with observed times Times within 15% (or 1 minute, if higher)	 > 85% of the routes.
Correlation analysis, modelled vs. observed values Correlation coefficient , R Slope of the best-fit regression line	 0.95 (R-squared > 0.903) between 0.9 and 1.10

Table from DMRB, 2006

2.7.3. Hybrid modelling

As discussed earlier, models used for urban transportation analysis can be classified into three groups as being macroscopic, mesoscopic or microscopic which are translated from travel, transport and traffic system levels (Zuidgeest, 2014b; Schoemaker, 2002; Barceló *et al*, 2005). These are related to how each model represents vehicle movements in the network. Models range from a macroscopic view, as an average hourly person trips converted to vehicular flows on links, where the demand is derived from origin and destination pairing of trips based on a gravity model. This is done in the attempt to replicate the land use and transport interaction (Siegel and Coeymans, 2005). The interaction of human activities, such as living, working, shopping, education or leisure in the transport system is the basic rationale of macroscopic traffic models (Wegener, 2011). The mesoscopic view illustrates the analysis of platoons or groups of vehicles on links. The microscopic view considers each vehicle as a single entity that makes its own decisions and is, therefore, good for operational investigations. For long term planning and analysis, which have a high impact on the system, macroscopic modelling programmes are used. Most macroscopic models illustrate demand modelling, changes in trip distribution and modal choice shifts. Whereas, microscopic models are used mainly in detailed design, operational analysis and in projects involving dynamic changes in the system. This is where the traffic assignment is considered, for example, the testing of operational changes such as signals and lane changes (Siegel and Coeymans, 2005). For the purposes of this study, macroscopic and microscopic modelling are focused on.

Macroscopic assignment models based on the user equilibrium approach are widely used in most transportation planning analyses. Wardrop's (1952) equilibrium principle, as a behavioural principle modelling of the route choice process, has led to the creation of a great mathematical model which uses algorithms that provide solutions of traffic flows on links of the network. This traffic flow output is a static average peak period flow sufficient enough to be used in planning decisions. Static flow models do not show driver behaviour and interactions between different modes. The time-varying traffic flows at peak periods combined with network geometry can produce undesired congestion that cannot be analysed with static models. Therefore, there is a clear case to change the analytical methodology to combine a macroscopic model and a microscopic model. This can be done with the use of the macroscopic model like EMME and a microscopic model like AIMSUN amongst others (Montero *et al.*, 1998).

Most modelling applications from a macroscopic model to a microscopic model and vice versa are usually done through a mesoscopic model or some sort of graphic interface which facilitates communication between both models. As illustrated in the study done by Montero *et al.* (1998) a graphic user interface named Generic Environment for Traffic Analysis and Modelling (GETRAM) is used to make the communication between models easier and error free (Montero *et al.,* 1998). In most projects, the combination of macroscopic and microscopic models is required. Macroscopic models are used to model large-scale projects such as the whole city or municipality. This is used in initial planning stages where the data is aggregated. Thereafter the detail design issues need to be addressed, and this is where the macroscopic model falls short. In this case, a microscopic model can be used to test different design and operational alternatives (Siegel and Coeymans, 2005).

Sigel and Coeymans (2005) agree with the methodology to use both macroscopic and microscopic models. This is where the demand generated by the macroscopic model helps test modal and route choice shifts and the microscopic model is used to test operational aspects that affect the traffic (Siegel and Coeymans, 2005). With an absence of a mesoscopic model, the methodology used and recommended by Siegel and Coeymans (2005) is shown in Figure 7.

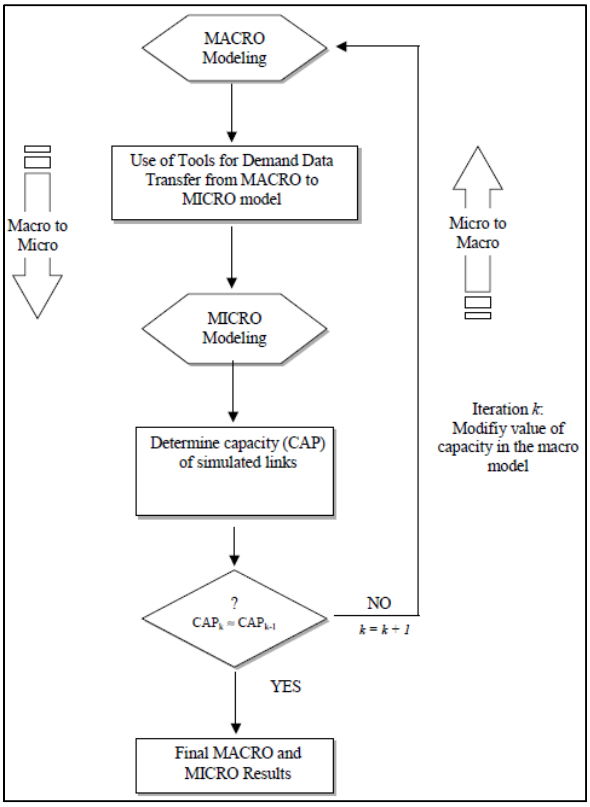


Figure 7: Combining macroscopic and microscopic models (Siegel and Coeymans, 2005).

Therefore, capacity from the macroscopic model can be taken into the microscopic simulation. In turn, certain operational constraints and testing, such as detailed link capacity saturation, can be taken from the microscopic simulation model to adjust the macroscopic model.

2.7.4. Key Performance Indicators

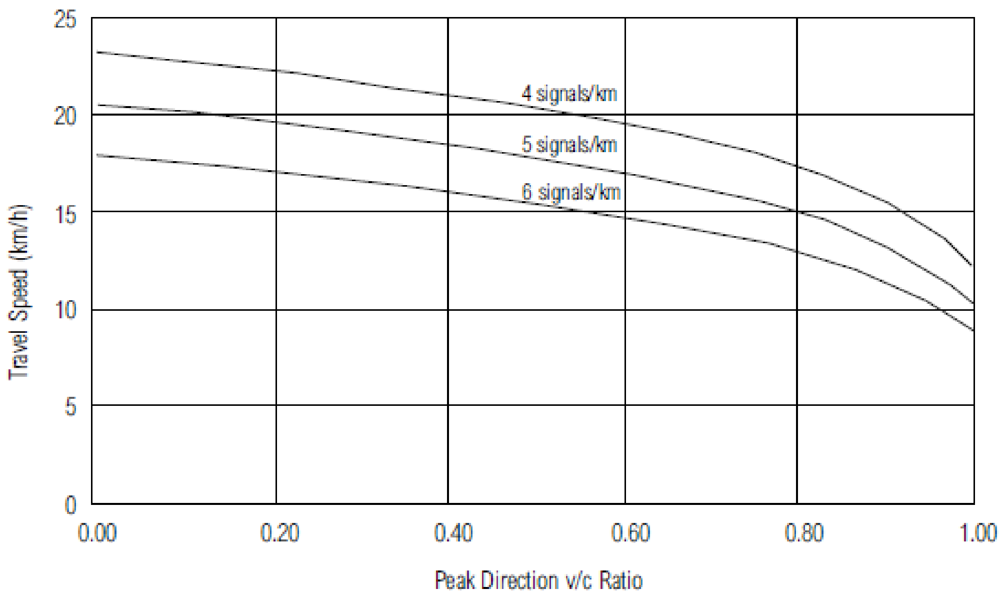
An important element, when planning and implementing various PT priority scenarios, is the evaluation criteria between the various schemes. In the past, the evaluation criteria used in most modelling research approaches in PT priority schemes were focused on travel time impacts and speed flow capacity analysis (Currie *et al.*, 2007). Travel speed on a particular class of road can be interpreted into performance LOS. Table 2 illustrates urban street LOS based on the average travel speed and its associated urban street class (HCM, 2000). The HCM (2000) prescribes that if demand volume exceeds capacity at any point on the facility, the average travel speed for urban streets might not be a good measure of the LOS.

Table 2 Urban Street LOS by Class

Urban Street Class	I	II	III	IV
Range of free-flow speeds (FFS)	90 to 70 km/h	70 to 55 km/h	55 to 50 km/h	55 to 40 km/h
Typical FFS	80 km/h	65 km/h	55 km/h	45 km/h
LOS	Average Travel Speed (km/h)			
A	> 72	> 59	> 50	> 41
B	> 56–72	> 46–59	> 39–50	> 32–41
C	> 40–56	> 33–46	> 28–39	> 23–32
D	> 32–40	> 26–33	> 22–28	> 18–23
E	> 26–32	> 21–26	> 17–22	> 14–18
F	≤ 26	≤ 21	≤ 17	≤ 14

Table from HCM, 2000

When there are multiple signalised intersections, the average speed along the road segment will decrease due to the friction of the peak traffic volumes at these intersections. Therefore, HCM developed speed-flow curves to measure LOS in terms of volume over capacity (V/C) ratio. An example of speed-flow curves for a class four urban street with four to six signals per kilometre is shown in Figure 8.



Note:
Assumptions: 50-km/h midblock FFS, 10-km length, 120-s cycle length, 0.45 g/C, Arrival Type 4, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation.

Figure 8: Speed-Flow Curves for Class IV Urban Streets (HCM, 2000).

2.8. Summary of the Literature Review

As discussed in this chapter the reallocation of road space can be done in South African cities in the form of footways, cycle paths and dedicated bus lanes for exclusive use by pedestrians, cyclists and PT users respectively (Behrens, 2014b). As shown in current trends, car use in the country is expanding and congestion will worsen and extend onto large freeways. Hence, a shift to facilitate a different direction is required. This should be based on an improved balance and integration between public and private transport through the use of TDM measures (Van Ryneveld, 2010).

In the evaluation of urban transportation projects and policies, the use of computer models has become fundamental to analysis. Currently, there exists an abundant variety of models available. However, a unique model which is capable of solving the variety of problems that a transportation planner or traffic engineer is required to address, is yet to be developed. Therefore, a combination of a macroscopic model and a microscopic model may be required to model the complexities of trip distribution and operational aspects of a corridor. The different scenarios developed will need to be evaluated using some KPI's. Some of these KPI's are travel time, performance LOS, traffic flow and travel speed.

3. Methodology

The methodology for this research is broken up into three sections, namely (a) modelling and testing, (b) a case study and (c) post processing.

3.1. <u>Modelling and Testing</u>

A good example of a modelling approach between a macroscopic to microscopic simulation modelling was discussed earlier which was used by Siegel and Coeymans (2005), and illustrated in Figure 7. The use of both a macroscopic model and a microscopic model is required due to the shortcomings of using only one of them. Where the former is too broad and unrealistic or non-responsive to sensitivities of operational aspects of the traffic and the latter not being able to calculate the effects of route choice. To calculate the change in demand over the corridor due to capacity changes, an iterative process between both models was used, similar to that used by Siegel and Coeymans (2005). Therefore, to best simulate road space prioritisation or allocation for PT the development of a relationship between a macroscopic model such as EMME and microscopic model such as AIMSUN was used, based on the change of capacity. A microscopic traffic simulation model is the main tool used to assess general traffic operations and operational impacts of various PT priority schemes (Zuidgeest 2014a; Currie *et al*, 2003).

The approach to the modelling process used was similar to that used by Siegel and Coeymans (2005). This entailed using the demand trip matrix for the cordoned or cropped area from the macroscopic model EMME into the microscopic model AIMSUN. This was then modelled in AIMSUN. A base model scenario for both models was created and tested. The capacity for the base year scenario was determined and modelled in the microscopic model and the new exact capacity was transferred to the macroscopic model for a rerun. This created a new demand in the macroscopic model which was outputted and re-tested in the microscopic model. The iterative process with the use of the capacity in both models gave a common connection between them.

The EMME sub matrix was demand adjusted to the latest classified vehicle intersection counts for 2015. This was extracted from EMME and inputted into the AIMSUN simulation model. This is illustrated in a flowchart in Figure 13 and is further discussed in Chapter 4 – Modelling and Results. The demand matrix and shifts thereof were mainly focused on trips made by the private car which directly and indirectly affect the PT. AIMSUN was used to evaluate the scenarios and for post-processing. The calibration process of the 2015 base year entailed outputting a 2015 base year cordoned matrix from EMME.

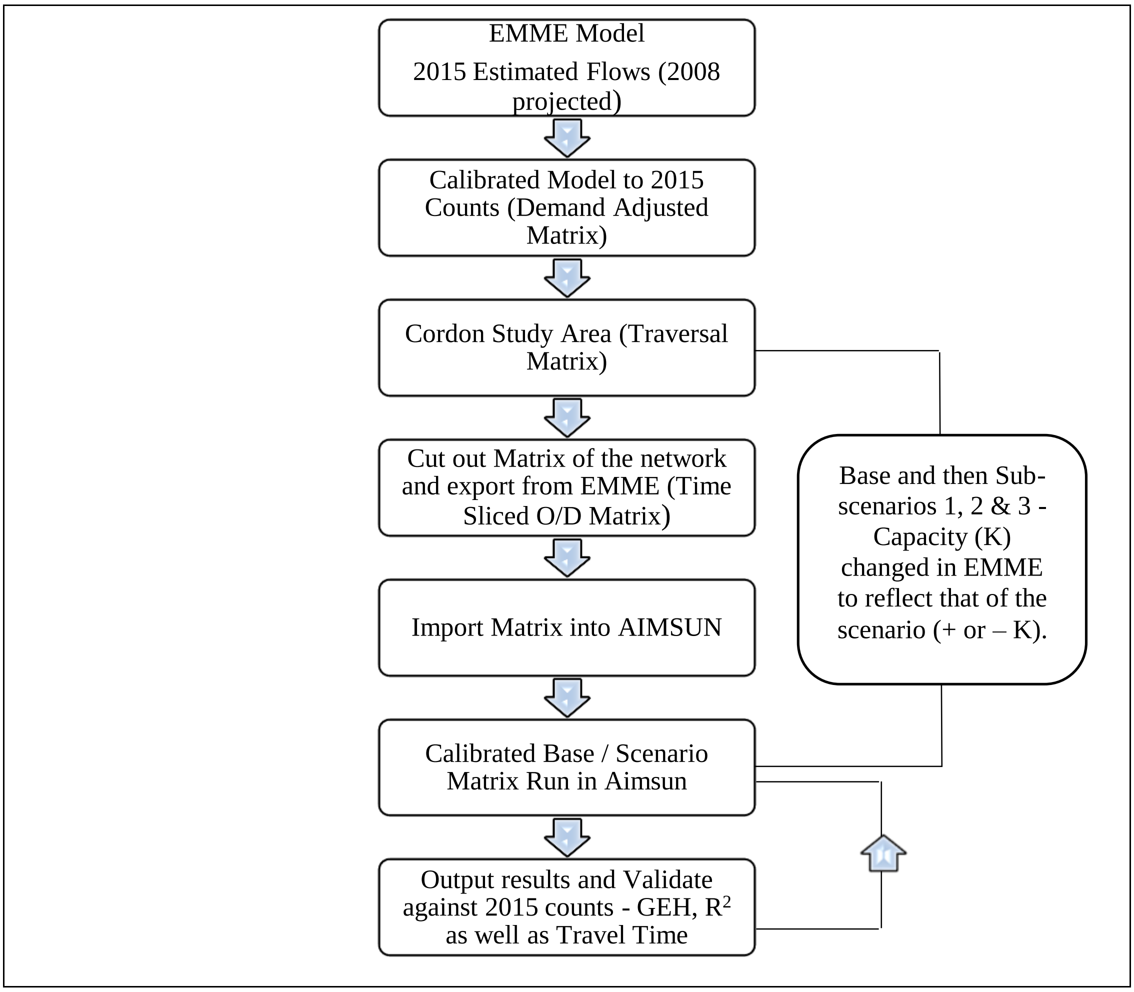


Figure 9: Flowchart of modelling approach and testing for the base year and scenarios

There was a cyclic analysis from a macroscopic static model (EMME) to a microscopic dynamic model (AIMSUN). Reference to literature and a static model was constantly used to analyse and understand results in the macroscopic modelling network as well. The most appropriate performance indicators for the modelling process were used. The most commonly used applications in the transport industry in modelling is the validation, calibration and tested against GEH parameters in terms of volume of throughput traffic. The GEH formula is illustrated on page 24. Traffic throughput and travel time were used in the calibration and validation of the base model. This ensured that the model had integrity that was set to a 2015 year time slice.

3.2. Case study

A case study of a corridor, Dr Pixley KaSema Street, within the CBD of the city of Durban in eThekwini Municipality, within KwaZulu-Natal, South Africa was investigated with a focus on the use of the road space. The current issues along the corridor are the high pedestrian activity and high volume of mini-bus taxis. These modes of travel have various conflicts with each other together with the private vehicle traffic along the corridor. The volume of traffic along the corridor is very high. This corridor has a large number of signals, which reduces the flow of traffic through it. An AIMSUN microscopic transport modelling software was used to create a dynamic traffic model of the corridor with its various modes of traffic. The model was calibrated to a 2015 base year morning peak hour. Primary data in the form of latest traffic flow counts and signal timings for the CBD were used in the model. These counts were collected from various stakeholders such as the eThekwini municipality and consultancy companies. The average realistic travel time was captured from the GPS system in Google Maps. This was validated by a drive along the corridor during the morning peak hour and a recorded video, which also confirmed the base travel time along the corridor, with a mean of 10 minutes. This average travel time on a typical weekday morning was tested in November 2015 is illustrated in Figure 10.

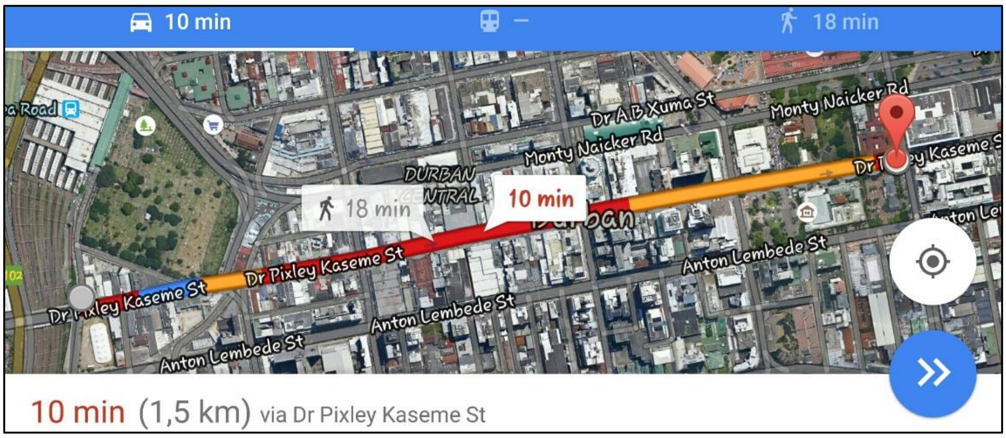


Figure 10: Google Maps live travel time along Dr Pixley KaSema Street

The initial travel demand for the corridor was taken from EMME for the PT, private car and the freight matrix. The municipality's macroscopic model, that used a four-step modelling process was calibrated to a 2008 base year and a 2015 projected base year. The latter of which was validated to 2015 counts. The eThekwini Municipality macroscopic transport zones are made up of 338 Zones. Zones 1, 2, 3, 4 and 36 feed into this corridor of Dr Pixley KaSema Street (West Street) as illustrated in the Map as shown in Figure 11. The data for these zones were carried over to the microscopic simulation model.

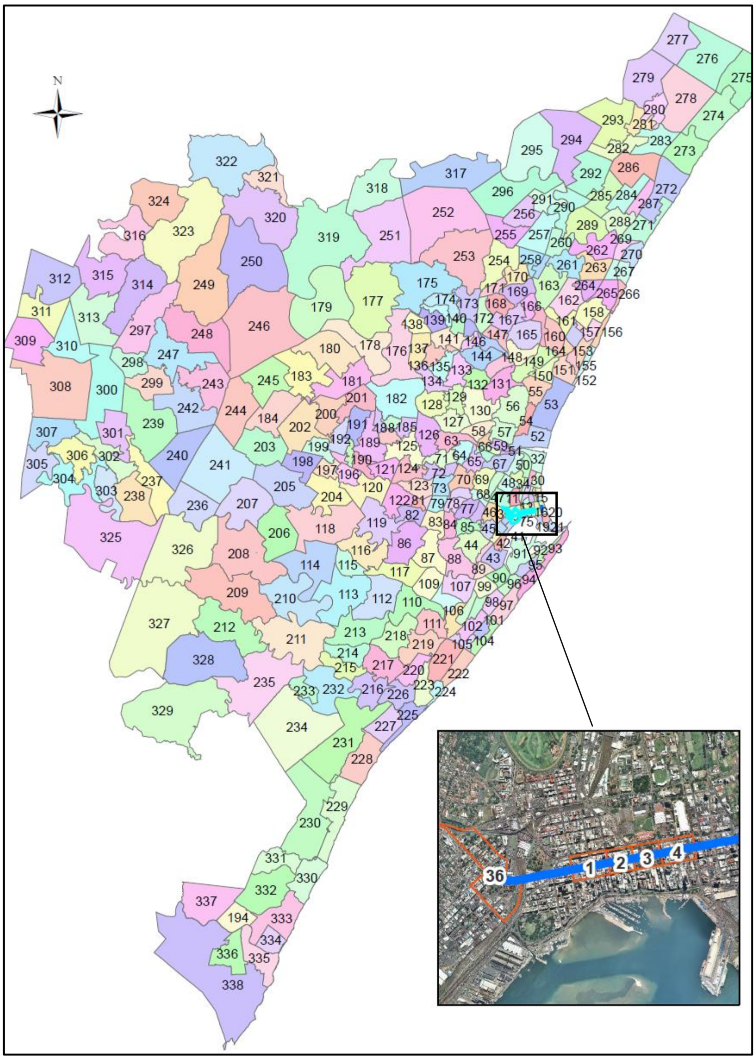


Figure 11: eThekwini macroscopic transport zonal system.

Scenarios with different PT interventions and road space prioritisation initiatives, such as reduction of lanes and conversion of lanes, were tested along a specific corridor. The study area was the Dr Pixley KaSema Street (West Street) corridor as illustrated in Figure 12 .

Figure 12: The Study Area - Dr Pixley KaSema Street (West Street).

3.3. Background to the eThekwini EMME model:

Information gathered for the EMME macroscopic model were population by traffic zone, employed residence, car ownership and employment. These were all categorised by low, medium and high-income groups. A demographic forecast study was also done by eThekwini Transport Authority (ETA) which was completed in 2010 with a 2008 base year that incorporated census data to project the household information. This data was forecasted in five-year time intervals from the 2008 base year (2015, 2020, 2025, 2030 and 2035 forecasted years).

The model was based on a four-step modelling process with the trip generation that used equations for home-base work trips, non-work trips and truck trips taking productions and attractions from and to each zone for each of these trips. The modal split between private and public transport was done at the origin zone which used a car ownership model and at the destination zone that used modal split factors. These were derived from the household travel survey (HTS). The modal split between different public transport modes was done with the use of EMME's built-in transit assignment based upon optimal strategies. The trip distribution stage, which uses a gravity model based on entropy maximisation was applied to combine income group, trip purpose and mode (Oberholzer, 2013).

The gravity model was defined as follows:

$$T_{ij} = A_i O_i B_j D_j e^{-\beta Cij}$$

where:

Tij	= Trips from zone i to zone j
Ai	= Row factors to match row totals to productions by zone
Oi	= Trip productions in origin zone i
Bi	= Column factors to match column totals to attractions by zone
Dj	= Trip attractions in destination zone j
Cij	= Cost of travel from zone i to zone j
e	= Exponent
β	= Calibration value to be determined empirically.

A Furness procedure was used in the development of the trip distribution matrix. This is an iterative process whereby each cell with zone origin production is multiplied by the destination zone attraction, and multiplied by the negative exponent of the travel cost between the origin and destination zone. The EMME's two-dimensional matrix balancing against the trip productions and attractions was used. In the model development stage, the best results obtained were with $\beta = 0$. Therefore, this implies that the travel costs do not play a role in trip distribution in the ETA model, only the relative weights of the zone productions and attractions. The traffic assignment from a fixed matrix was based on a user equilibrium assignment technique with volume delay used from the road links and expanded to a multiclass assignment to include a separate heavy matrix. The PT assignment was based on optimal strategies from a fixed PT person trip matrix and was assigned to an integrated PT network comprising of taxi, bus routes and rail. This secondary split between PT modes was a component of the assignment hence allowing transfers between the PT modes. The PT travel time functions included fare-related distance based time penalties and an equivalent boarding penalty. These were stored in user-defined fields. The fare functions and associated time penalties are illustrated in Table 3 (Oberholzer, 2013).

Table 3 Public Transport Fare Functions and time penalties.

Mode	Boarding R	Distance R/Km	Time Value of Fare min/R	Boarding Penalty min	Distance Penalty min/km
Rail	1.81	0.034	4.8	8.69	0.16
Taxi	5.00	0.333	1.7	8.50	0.57
Bus	4.80	0.117	2.68	12.86	0.31

Table from the eThekwini EMME model, Oberholzer, 2013

The EMME model was calibrated with this information with 2008 counts and 2004 current public transport records (CPTR). This model was then validated with 2008 screen line counts. A transport master planning exercise was completed in 2014. A 2015-forecasted base year was validated to the most recent link counts and screen line is the new forecasted base year in the current EMME model. The EMME model is calibrated to a 2008 HTS data that was completed by the ETA. This study was based on household data of a 2% sample size within the eThekwini municipality.

3.4. Base year and the scenarios modelled

For this study a 2015 base year microscopic simulation model was developed with the use of AIMSUN. In developing this model, the following characteristics were used: the network configuration was taken from a previous model that was done for the inner CBD by Development Engineering Logistics Consulting Africa (DELCA) Systems for the ETA in 2007. The network from this model was cordoned to the study corridor. The development of the model entailed calibration of the data for the model such as signals phasing timing, O-D demand, the speed of vehicles on the links, acceleration and deceleration rates of vehicles for different types of modes, vehicle driver behaviour in the form of following distance or gap acceptance characteristics and queue lengths at intersection. This was validated to the 2015 base year classified vehicle flow counts and travel times. The base year model was calibrated and validated with the use of GEH and the goodness of fit analysis (R-squared). Thereafter various scenarios were modelled and tested. A set of indicators were selected to evaluate each scenario once the scenario was modelled in both the macroscopic and microscopic model.

In the aim of prioritisation of road space for PT within the CBD, various types of PT interventions along the corridor were tested. These scenarios are:

- Base year scenario,
- Scenario 1: A rigid Quality Bus Service (QBS) in mixed traffic,
- Scenario 2: A Bus Rapid Transit (BRT) service with the associated dedicated infrastructure,
- Scenario 3: A Mini-bus Taxi Service (MTS) in mixed traffic.

It must be noted that in the bus scenarios, the mini-bus taxis were removed from the system and the total PT passenger demand transferred into the bus scenarios. The PT passenger demand remains unchanged in each of the scenarios for the various PT modes tested. The evaluation along the corridor was based on traffic on the road links and at intersections. For the QBS scenario and BRT scenarios, with spare capacity gained with each system, an NMT lane was inputted and results discussed. The various scenarios that were modelled are shown in the flowchart in Figure 13. Note that a sub-scenario is a derivative of the previous scenario with a rerun-changed capacity in the macroscopic model. This was done with an aim to show the possible rerouting along the corridor. Hence, testing induced and suppressed demand along a corridor for a particular PT scenario.

The link capacity was changed in the macroscopic model and a re-assignment done in the macroscopic transport model for each of the sub-scenarios done in AIMSUN. Changes in link capacity changed impedance in the macroscopic model hence, having an effect on the traffic redistribution at the traffic assignment stage. This caused the private traffic to reroute. A new traffic matrix for the corridor was generated and outputted for each scenario from EMME. The output was inputted into the microscopic as a sub-scenario.

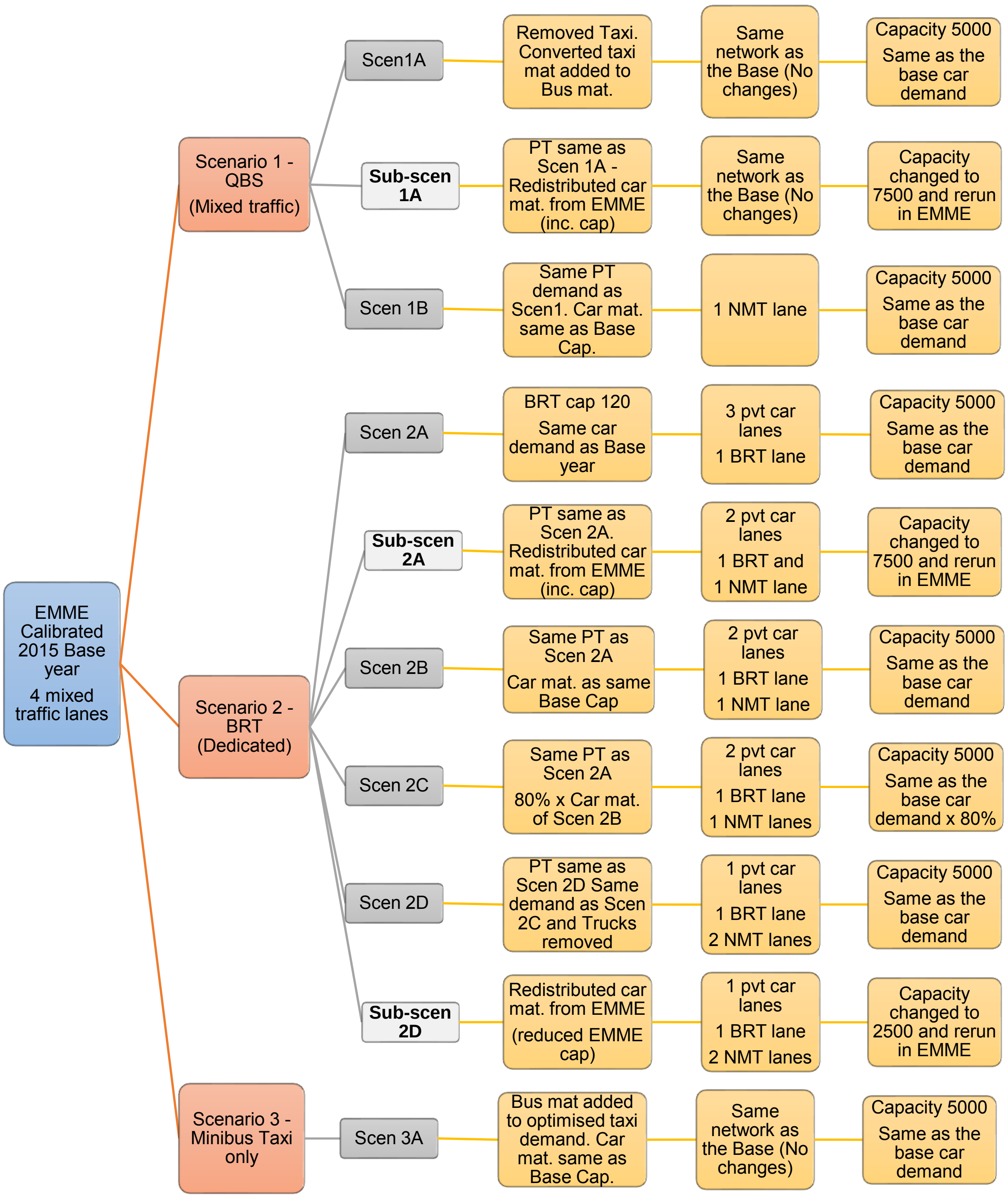


Figure 13: Flowchart of the scenarios modelled and tested.

The modal choice could not be tested in this study, because the macroscopic model modal choice was done at the trip generation stage and not the assignment stage. The macroscopic model assumed that the PT users would remain captive users and would only use alternative PT modes.

3.5. Post processing

The various outcomes which were achieved in this study include potential benefits for the private car traffic and for each type of PT system. The most appropriate performance indicators and evaluation criteria were used to measure each of the scenarios potentials. These were based on the review of the literature. These indicators were based on travel time, performance LOS, traffic flow, travel speed and travel cost (Currie *et al*., 2007).

A travel cost was also formulated based on the operational speed of each of the PT system. Quantitative methods of assessments on the road network were used. The various shifts in traffic are measured and discussed herein (Currie *et al*., 2007).

AIMSUN, EMME, Microsoft Access and Microsoft Excel were used to link the scenarios and also for post-processing of the results. As discussed by Currie *et al.* (2007), there are direct impacts and secondary impacts to evaluating PT alternatives. These are illustrated in Figure 14. The ultimate evaluation for this research was based on a cost evaluation in selecting the most appropriate PT system in prioritising road space for PT.

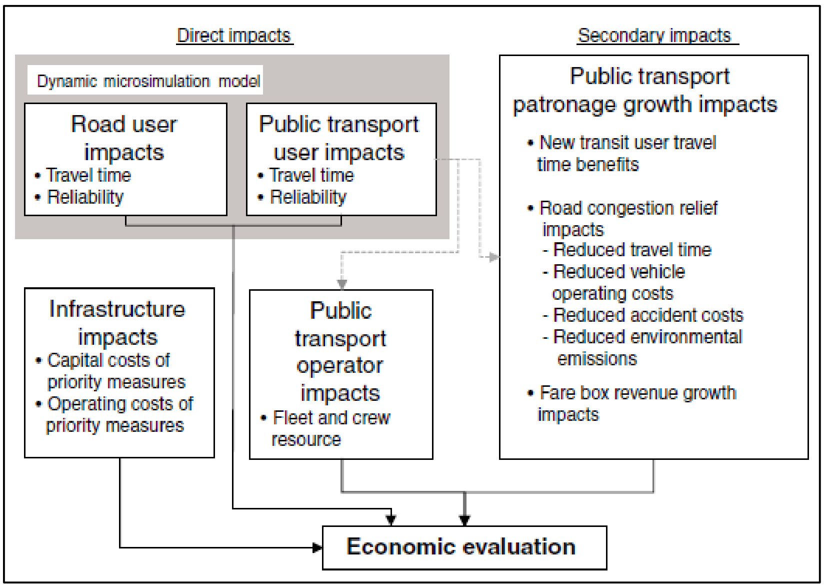


Figure 14: Evaluation Framework and Criteria (Currie *et al*., 2007).

Permission to use this study area and EMME outputs was obtained from Mr L Moodley, the Deputy Head of the Strategic Transport Planning Department of the ETA within the eThekwini Municipality (January 2015).

3.6. <u>Limitations of the Modelling</u>

- The GEH did not pass the DMRB standards by some of the modes. This is due to the fact that the high accessibility of the CBD network cannot be balanced (because the traffic that enters one end would not balance and exit the other).
- The trucks have not been calibrated to its appropriate travel time. The truck trips were featured in all scenarios modelled but its results are not discussed in this research.
- To have all traffic counts of the base year for the same day in 2015 or 2013 was not possible to ascertain for this project. Therefore, traffic counts ranging from 2013 to 2015 were used with a 1.5% growth rate increase per year to a 2015 base year. These counts were supplied by the eThekwini municipality.
- A fully hybrid model was envisaged but the eThekwini EMME model cannot show a change in the modal split between private car and PT. Therefore, the PT was not extracted from the macroscopic model as the results remained the same after each assignment. Therefore, each individual PT scenario was not modelled in the macroscopic model. This lead to a relationship in capacity between the microscopic simulation model and macroscopic simulation for the private vehicle traffic.
- For the BRT scenarios, feeder services are required to transport passengers to locations outside the corridor. These were not modelled in these BRT scenarios.
- Although NMT lanes were in the scenarios. The NMT trips were not modelled in each of the scenarios. This NMT lane remained unused and the effect of this offset lane on the motorised traffic was modelled.
- The exact PT passenger volumes that use the corridor was based on a calculative assumption. This is because the exact numbers were not recorded for this study. Visual observations were done and the passenger numbers used in this study was very conservative.
- Other corridors outside the study area were affected by the changes done in the various scenarios modelled. These were not discussed in this research.

4. Modelling and Results

4.1. Base year development

As discussed previously, the idea of road prioritisation for PT is the goal and thus needs to be modelled. It was decided that an integration between two modelling packages would be used, namely AIMSUN and EMME, a microscopic package and a macroscopic package respectively. A network of a corridor was created surrounding Dr Pixley KaSema on AIMSUN. This can be seen in Figure 15 and Figure 16. The network comprises of links, intersections, centroids and boundary centroids known as gated centroids. Each link has a capacity, speed and volume-delay function (VDF).

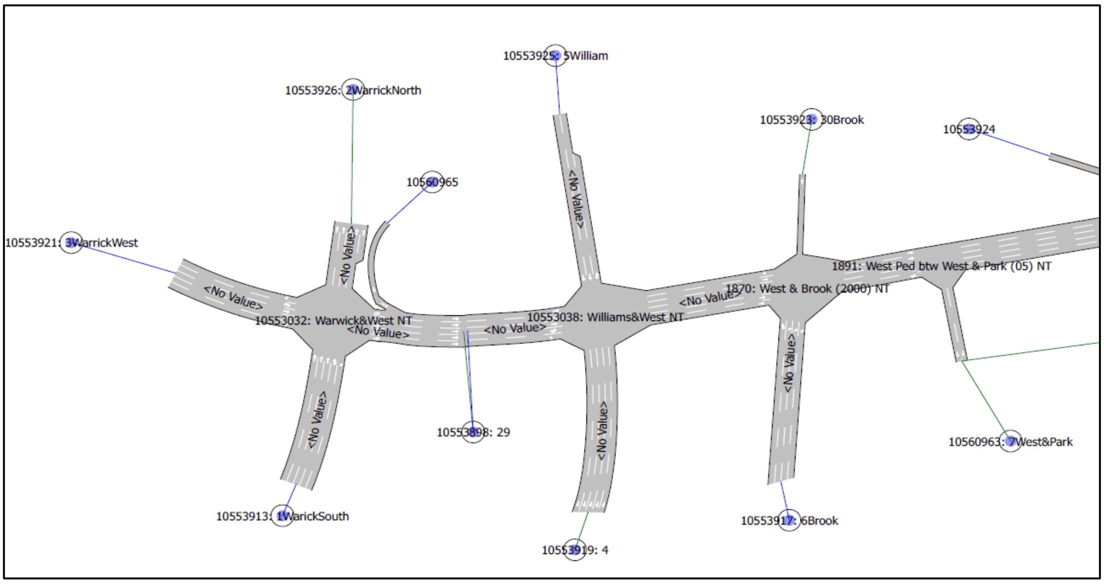


Figure 15: Network image of the west of Dr Pixley KaSema.

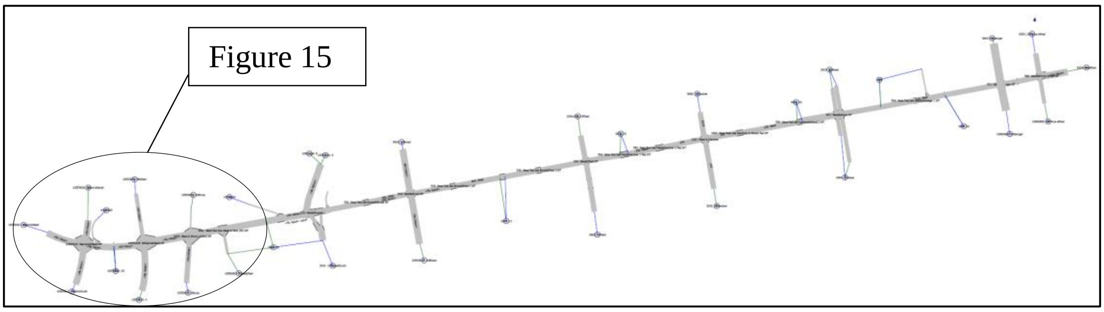


Figure 16: Network image of the full network of Dr Pixley KaSema.

As mentioned earlier, a previous microscopic AIMSUN study was done in 2007 and the various information and modelling criteria were used from this model. The intersections were checked and re-coded with the latest traffic signal design timings that were obtained from Urban Traffic Control (UTC) branch in the ETA. An example of this is illustrated in Figure 17.

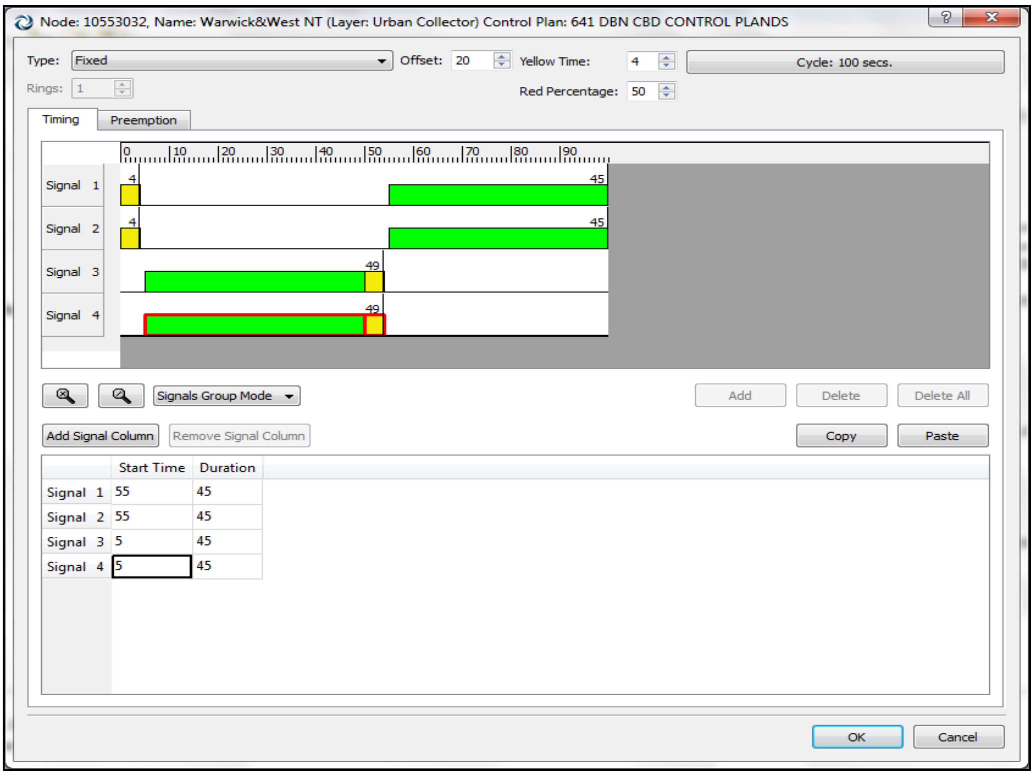


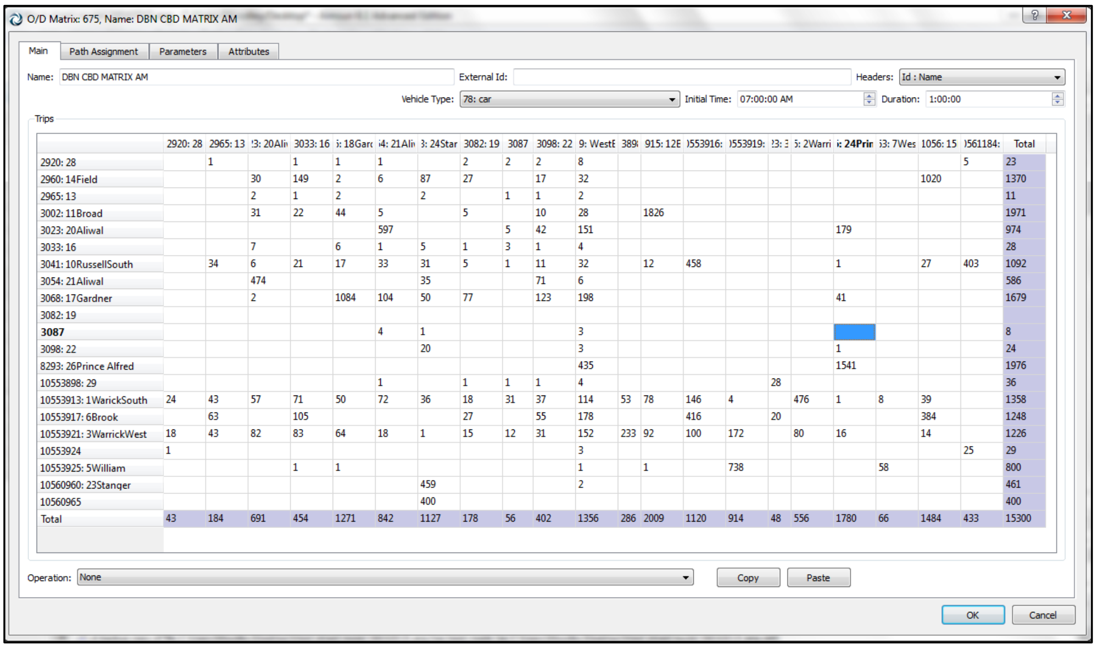
Figure 17: Traffic signal design timings for intersection 1 – Warwick and Dr Pixley KaSema.

A 2015 base matrix was needed to start the modelling process. There were many options considered, such as the Furness method by building a matrix from existing traffic counts as discussed in Chapter 2. But then the matrix would not be able to be translated back into EMME. Therefore, it was decided that an EMME matrix would be used as a base matrix into AIMSUN. A cordon was created in EMME known as *gates* so that a sub-matrix could be outputted. A car matrix, freight matrix and PT matrix were outputted. This matrix was then converted into a matrix with the correct centroid names that was compatible with the AIMSUN model.

This matrix was then inputted into AIMSUN as seen in Figure 18. The process done was similar to that as mentioned by Siegel and Coeymans (2005) when transferring data from a macroscopic simulation model to a microscopic simulation model. The O-D matrix was cordoned to the smaller scale of the microscopic simulation model from the larger scale macroscopic simulation model. The matrix columns and rows needed to be matched with the macroscopic model to that in the microscopic model prior to transferring the data. This required that the data be sorted by columns and rows with the use of the zone names.

The capacity was changed for the base. This new capacity was inputted into the model in an iterative process and it was found that the capacity per lane was equivalent to

1250 vehicles/lane in the macroscopic model. During the iterative process, it was observed that the change in link capacity needed to be a minimum of 2500 vehicles/corridor along the corridor to see a change in the outputted matrix when taken into AIMSUN. For the base year scenario, the link capacity was set to 5000 vehicles/corridor in EMME. This gave the best relationship (R^2) when comparing this outputted volume to that of the traffic counts along the corridor.



	2920: 28	2965: 13	:3: 20Ali	3033: 16	;: 18Gar	i4: 21Ali	3: 24Star	3082: 19	3087	3098: 22	9: WestE	389	915: 12E	)553916:	)553919:	23: 3	5: 2Warri	i: 24Prin	53: 7Wes	1056: 15	)561184:	Total
2920: 28		1		1	1	1		2	2	2	8										5	23
2960: 14Field			30	149	2	6	87	27		17	32									1020		1370
2965: 13			2	1	2		2		1	1	2											11
3002: 11Broad			31	22	44	5		5		10	28		1826									1971
3023: 20Aliwal						597			5	42	151							179				974
3033: 16			7		6	1	5	1	3	1	4											28
3041: 10RussellSouth		34	6	21	17	33	31	5	1	11	32		12	458				1		27	403	1092
3054: 21Aliwal			474				35			71	6											586
3068: 17Gardner			2		1084	104	50	77		123	198							41				1679
3082: 19																						
3087						4	1				3											8
3098: 22							20				3							1				24
8293: 26Prince Alfred											435							1541				1976
10553898: 29						1		1	1	1	4					28						36
10553913: 1WarickSouth	24	43	57	71	50	72	36	18	31	37	114	53	78	146	4		476	1	8	39		1358
10553917: 6Brook		63		105				27		55	178			416		20				384		1248
10553921: 3WarrickWest	18	43	82	83	64	18	1	15	12	31	152	233	92	100	172		80	16		14		1226
10553924	1										3										25	29
10553925: 5William				1	1						1		1		738				58			800
10560960: 23Stanger							459				2											461
10560965							400															400
Total	43	184	691	454	1271	842	1127	178	56	402	1356	286	2009	1120	914	48	556	1780	66	1484	433	15300

Figure 18: Initial origin-destination (OD) matrix from EMME plugged into AIMSUN.

The latest counts for all the intersection in the study area along Dr Pixley KaSema was collected from the Road Safety Branch within ETA and Arup Consulting who did a study in 2013 within the CBD. For the calibration process, an output method from AIMSUN was developed using the statistical streams as seen in Figure 19. This created a file from AIMSUN, which was outputted into a Microsoft Access file after each assignment.

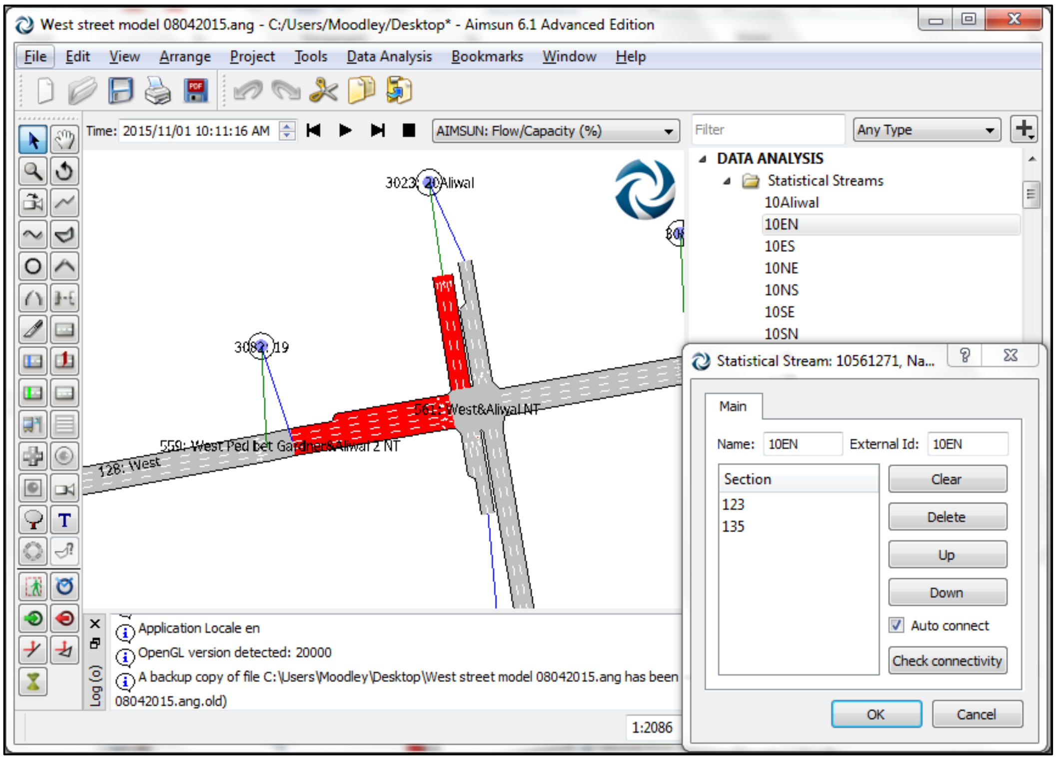
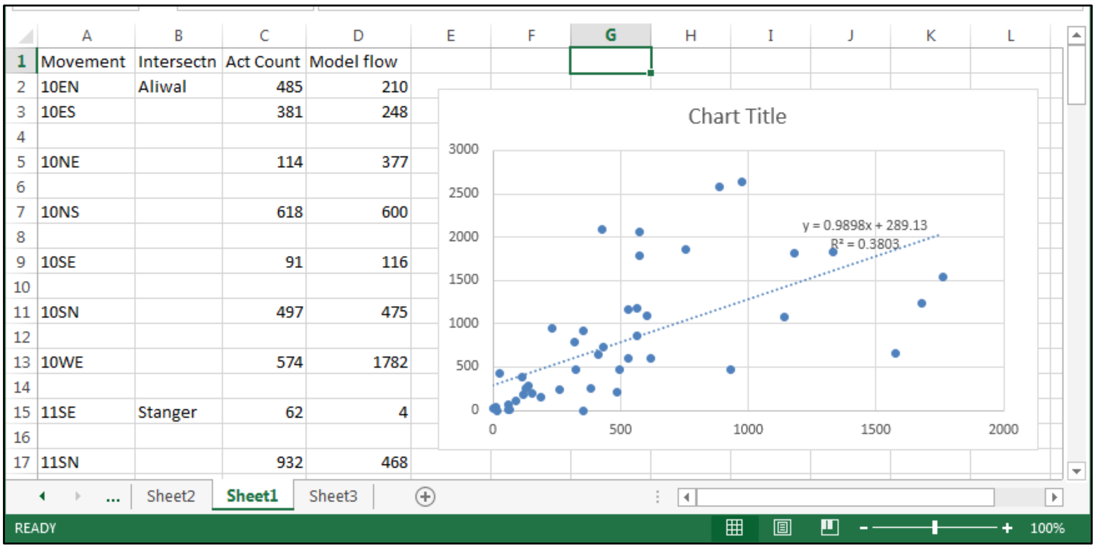


Figure 19: Traffic movements from AIMSUN into statistical streams.

Thereafter a calibration spreadsheet was set up on Microsoft Excel in terms of the DMRB (2006) standards of which the output from AIMSUN could be compared to the actual intersection counts as shown in Figure 20. Intersection counts were done at different times of the year. For intersections with no traffic count information for 2015, past year intersection counts were used with a 1.5% growth rate for each year to 2015. Note that these intersection counts were not older than that collected in the year 2013. Some of the counts used and illustration of comparisons are shown in the appendix.



Movement	Intersectn	Act Count	Model flow
10EN	Aliwal	485	210
10ES		381	248
10NE		114	377
10NS		618	600
10SE		91	116
10SN		497	475
10WE		574	1782
11SE	Stanger	62	4
11SN		932	468

Figure 20: AIMSUN modelled output tested in excel against actual counts.

The first output from AIMSUN used the cordoned morning peak hour private car matrix from the 2015 EMME scenario. This showed a relationship of 38% between the model and the counts (R-squared) as shown in Figure 21. This was too low and did not provide a good relationship between the model and counts. Note that the eThekwini EMME model is a large macroscopic model. This lacks the detail required for a single corridor as the distribution was not calibrated to that required for this research.

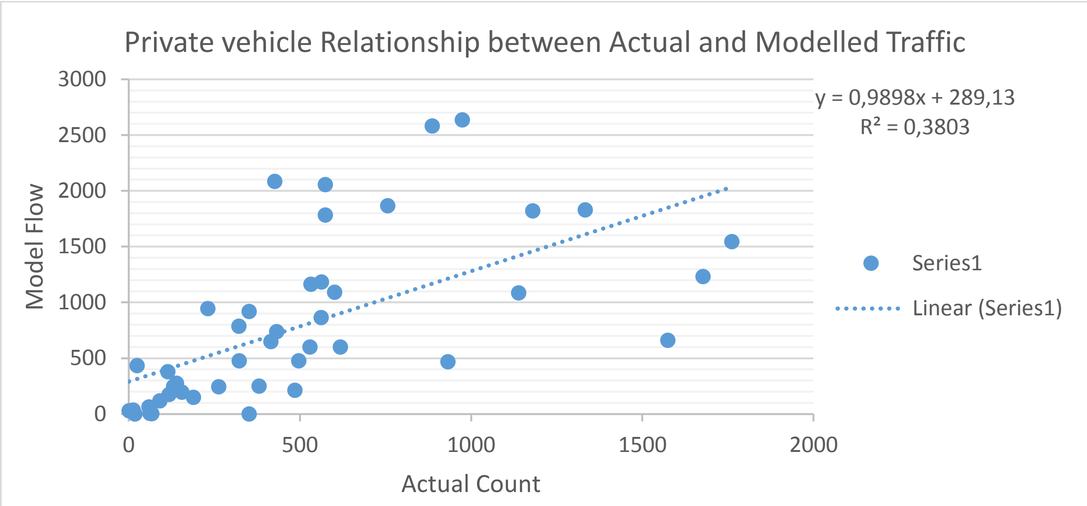


Figure 21: Relationship between private vehicle traffic counts and modelled traffic.

Therefore, a cordon method of calibrating the EMME 2015 matrix cordon around the study area was done using a demand adjustment method in EMME with the latest intersection traffic counts as shown in Figure 22 and Figure 23. This adjusted the EMME distribution along the corridor significantly. This new cordoned demand adjusted matrix was used as the new 2015 base matrix going forward.

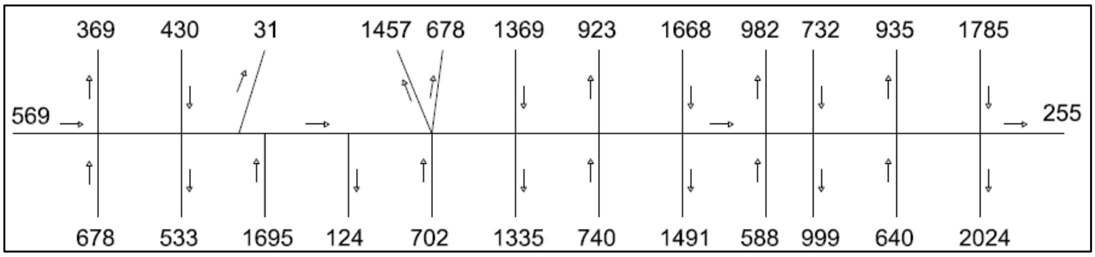


Figure 22: Actual counts changed into gated flows taken into EMME to be adjusted to.

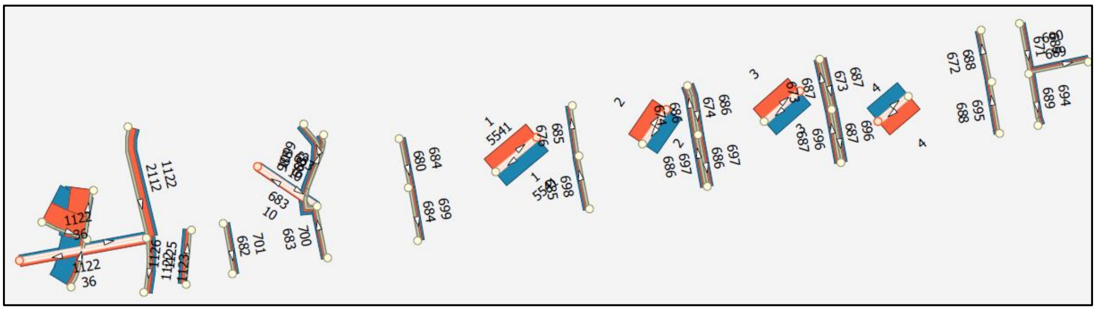


Figure 23: EMME links cordoned as gates of the study area.

Figure 24 to Figure 26 illustrate the demand adjusted EMME matrix of private car counts to the modelled flows which illustrated a 0.917 R-squared or goodness of fit in EMME at step five (5 iterations). The matrix was then adjusted for 15 iterations and this gave an R-squared of 0.963 at step 14 as illustrated in Figure 26. The original EMME origin-destination matrix did not change greatly. Instead, the traffic distribution re-routed along or away from the corridor where required.

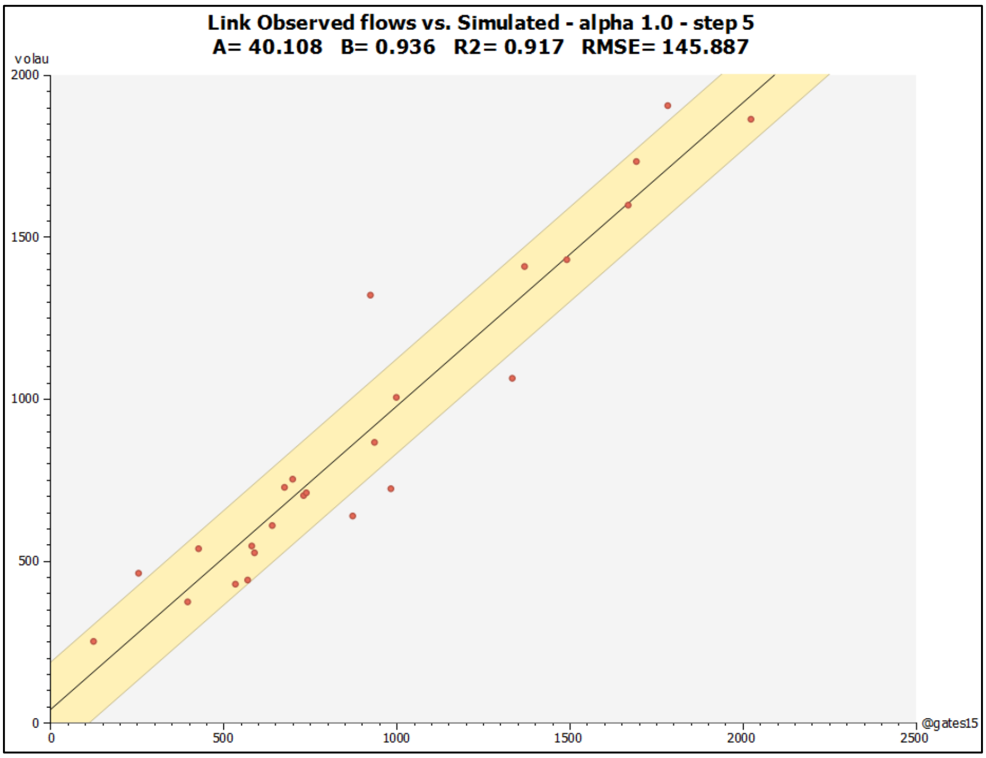


Figure 24: Demand adjusted EMME matrix of private car counts to modelled flows.

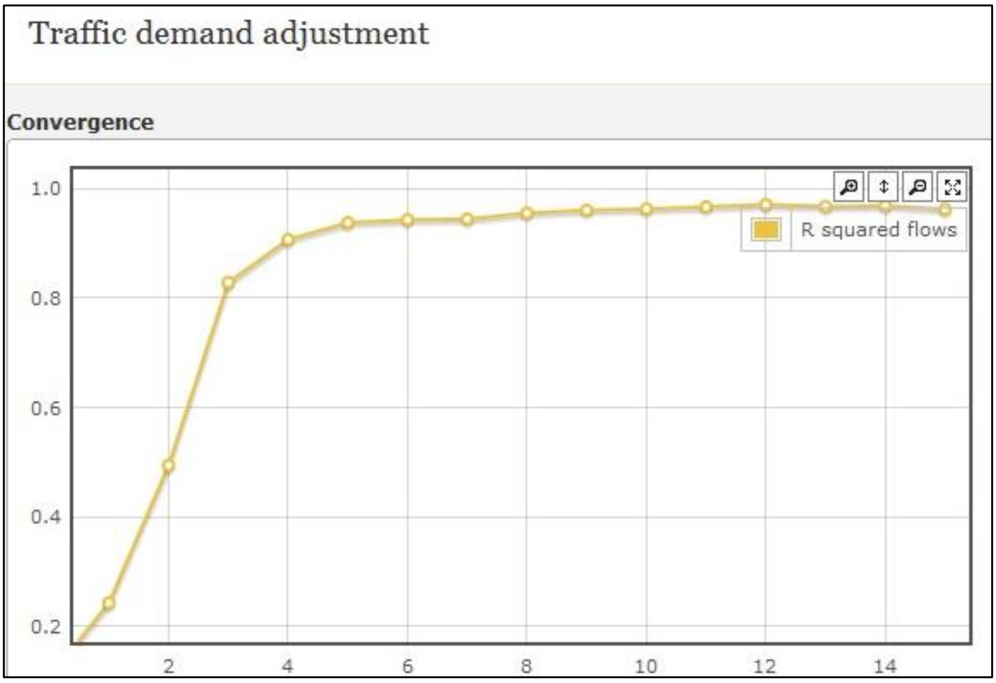


Figure 25: Demand adjusted EMME matrix of private car counts to modelled flows.

Iteration	R squared flows	RMSE flows	R squared demand	RMSE demand	O. F. Link flows term	O. F. Turn flows term	O. F. Demand term	O. F. Total
...								
1	0.2420	458.93	0.9764	0.21	6386977.09	0.00	0.00	6386977.09
2	0.4941	361.17	0.9490	0.31	3736424.25	0.00	0.00	3736424.25
3	0.8288	217.89	0.9047	0.43	1220480.03	0.00	0.00	1220480.03
4	0.9072	158.52	0.8810	0.49	599354.49	0.00	0.00	599354.49
5	0.9382	125.58	0.8500	0.56	382190.59	0.00	0.00	382190.59
6	0.9436	121.79	0.8343	0.59	350965.46	0.00	0.00	350965.46
7	0.9449	120.20	0.8151	0.63	344027.72	0.00	0.00	344027.72
8	0.9558	104.95	0.8034	0.66	275682.52	0.00	0.00	275682.52
9	0.9611	101.17	0.7929	0.68	242855.15	0.00	0.00	242855.15
10	0.9634	97.25	0.7917	0.68	227690.73	0.00	0.00	227690.73
11	0.9671	93.95	0.7817	0.70	206425.29	0.00	0.00	206425.29
12	0.9714	85.73	0.7835	0.70	177367.80	0.00	0.00	177367.80
13	0.9680	91.65	0.7830	0.70	197964.71	0.00	0.00	197964.71
14	0.9693	88.58	0.7825	0.70	190410.58	0.00	0.00	190410.58
15	0.9628	99.75	0.7756	0.72	232674.63	0.00	0.00	232674.63

Figure 26: Demand adjusted EMME matrix of private car counts to modelled flows.

A new traversal car matrix was outputted from EMME and inputted into AIMSUN as illustrated in Figure 27. Changes to the model's conditions such as vehicle speed and lane speeds were adjusted to match the existing travel time, averaged to 10 minutes along the corridor. The final base scenario was outputted and compared to intersection counts that gave a calibrated and validated relationship of 77% as shown in Figure 28. The matrix in AIMSUN could have been further edited to give a higher R-squared but then the matrix would lose its connection to the EMME demand adjusted matrix when going back and forth in testing various scenarios. Therefore, the new private vehicle base matrix used is the final demand adjusted matrix as seen in Figure 27. The GEH for individual flow that is less than 5 is 33% and 64% is less than 10. This is a limitation of the study because the high accessibility of the CBD network cannot be balanced, as the traffic that enters one end would not balance and exit the other end. Therefore, the GEH in a CBD environment will not pass the DMRB standards as required.

Name: demand_adj3_Orig External Id: demand_adj3_Orig Headers: Id : External Id

Vehicle Type: 78: car Initial Time: 07:00:00 AM Duration: 1:00:00

Trips

	2920	2965	3023	3033	3036	3054	3063	3082	3087	3098	8319	1055389…	1055391…	1055391…	1055391…	1055392…	1055392…	1056095…	1056096…	1056105…	1056118…	Total
2920		0.420	0.410	0.670	0.770	0.410	1.320	0.170		0.360	0.570		1.110	5.570						5.450	25.950	43.180
2960			196.530	47.590		0.010	11.340	11.320		11.420	3.790									942.130		1224.1...
2965			0.230	1.680	2.200	1.100	3.210	0.430		0.890	3.720									0.120		13.580
3002		38.880		78.170	56.560	18.390		8.530		16.230	24.930		1216.4...							8.950		1467.0...
3023						797.570				77.610	17.790											892.970
3033					5.190	2.110	0.020	0.830		1.710	0.690											10.550
3041	48.030	87.470	27.930	28.200	45.770	30.330	140.050	7.020		14.390	50.310		23.970	211.890						72.030	532.130	1319.5...
3054			732.040				84.430			13.170	102.220											931.860
3068					1342.8...	237.870		99.840		99.920	38.530											1818.9...
3082						0.340				0.150	0.040											0.530
3087																						
3098							115.520				42.200							0.800				158.520
8293											174.750							2383.7...				2558.4...
10553898	0.010	0.070	0.030	0.110	0.140	0.090	0.610	0.030		0.060	0.420		0.210	0.960	6.020				0.030	0.980		9.770
10553913	15.200	64.820	0.670	57.050	46.700	27.250	10.110	12.190		22.600	75.350		149.820	151.220			372.960		0.050	179.600		1185.5...
10553917	27.640	170.210	1.170	89.140	25.460	36.170	2.060	22.990		47.100	11.490		14.210	610.200						112.390		1170.2...
10553921	20.680	68.870		55.590	59.240	61.180		14.180		29.050	11.160		33.840	71.290	440.020				22.220	1.400		888.720
10553924																						
10553925	0.160	0.020		0.030	0.050	0.020	0.010	0.010		0.020	0.030	11.010	0.040	0.030	551.240				1.470			564.140
10560960							562.910				22.160											585.070
10560965																						
Total	111.720	430.760	959.010	358.230	1584.9...	1212.8...	931.590	177.540		334.680	580.150	11.010	1439.6...	1051.1...	997.280		372.960	2384.5...	23.770	1323.0...	558.080	14842....

Figure 27: Demand adjusted matrix in AIMSUN.

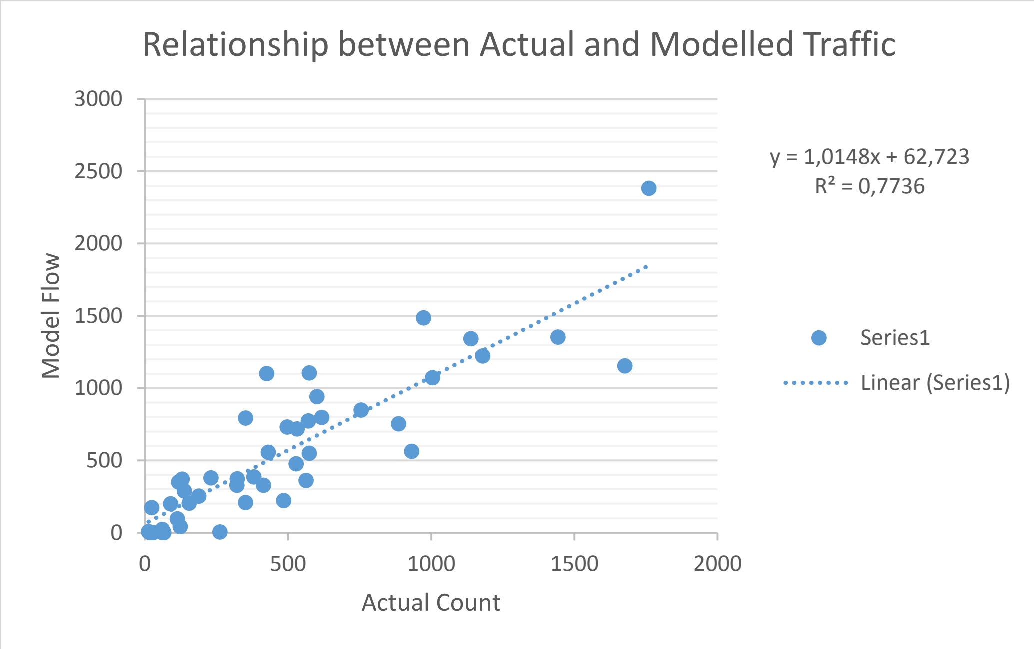


Figure 28: Demand adjusted matrix relationship between private vehicle traffic counts vs. modelled traffic.

The total PT matrix was also outputted from EMME but these were in persons and not in passenger car units (PCU), hence a calibration process began to get a good fit between the counts and the modelled flow. With an iterative calibration process, it was discovered that a number of taxi vehicles were too high. This was because the number of person trips were taken directly from EMME into AIMSUN. Therefore, with a goodness of fit method, it was calculated that the original taxi matrix needed to be reduced by 55% in trips. This in conjunction with vehicle speed changes and some cellular modification to the taxi matrix improved the relationship between the counts and modelled flow from 25% to 75.6% as illustrated in Figure 29 and Figure 30 respectively. There were only 59.1% of the GEH for individual flows all less than 5 and 81.8% less than 10.

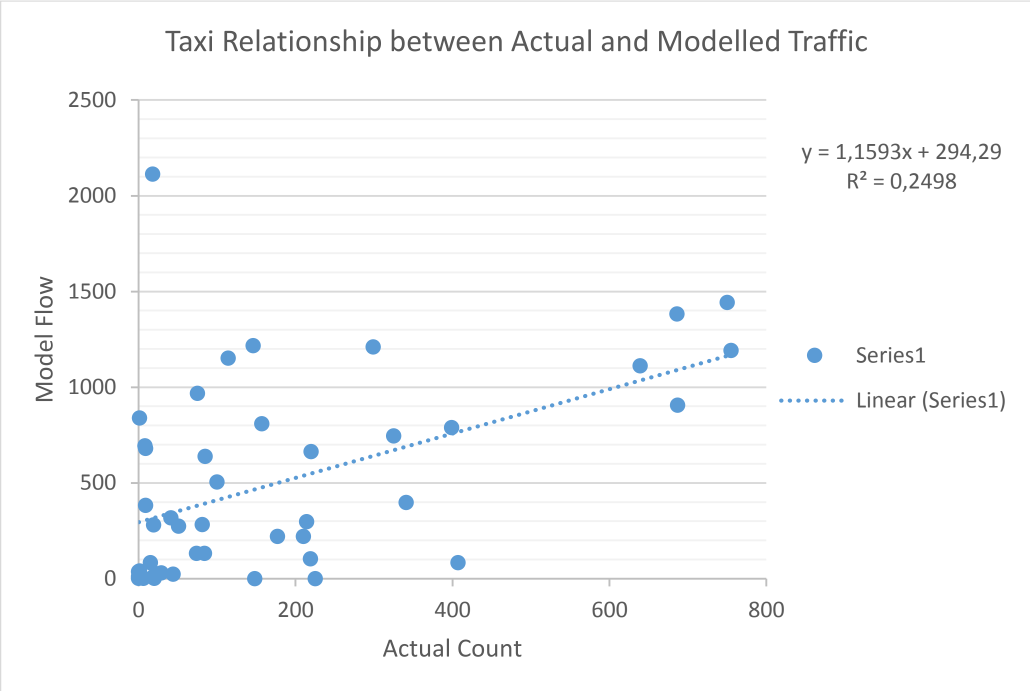


Figure 29: Initial Taxi relationship between traffic counts and modelled traffic.

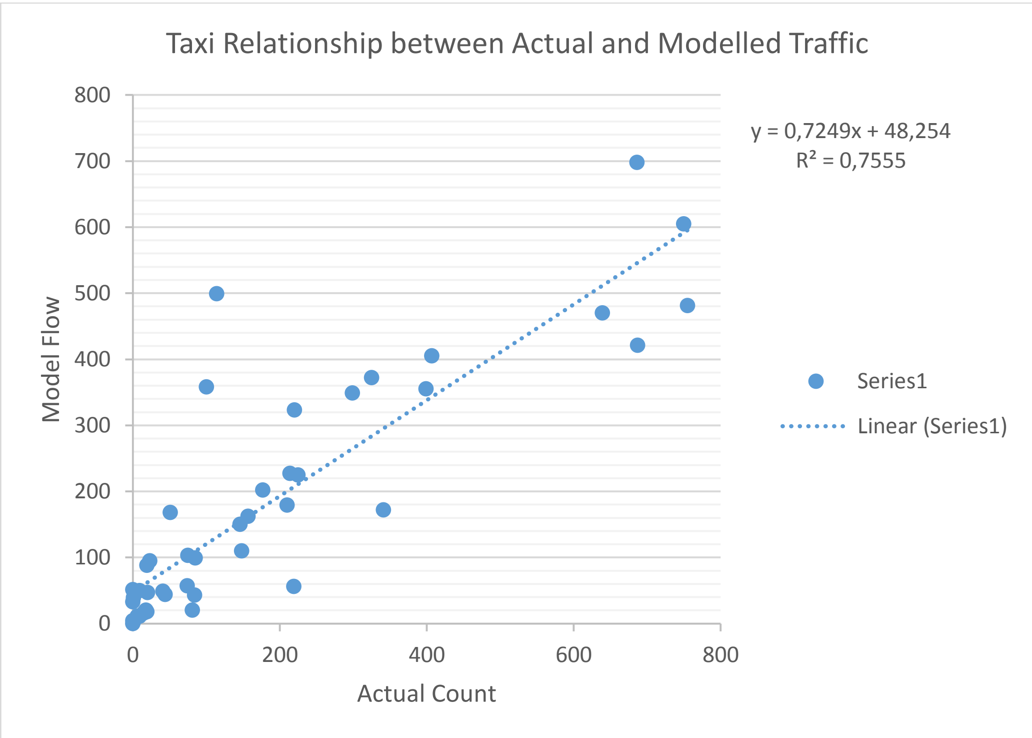


Figure 30: Final Taxi relationship between traffic counts and modelled traffic.

A bus matrix was created using a reduced taxi matrix. The initial matrix that was used to start the process had a relationship of 38.6% between the bus counts and the modelled flow. A calibration process began to get a good fit between the counts and the modelled flow. The matrix was improved to suit the intersection counts and produced an improved relationship between the counts and modelled flow from 38.6% to 85% as illustrated in Figure 31 and Figure 32 respectively. The GEH for individual flows were all less than four (100 % < 4).

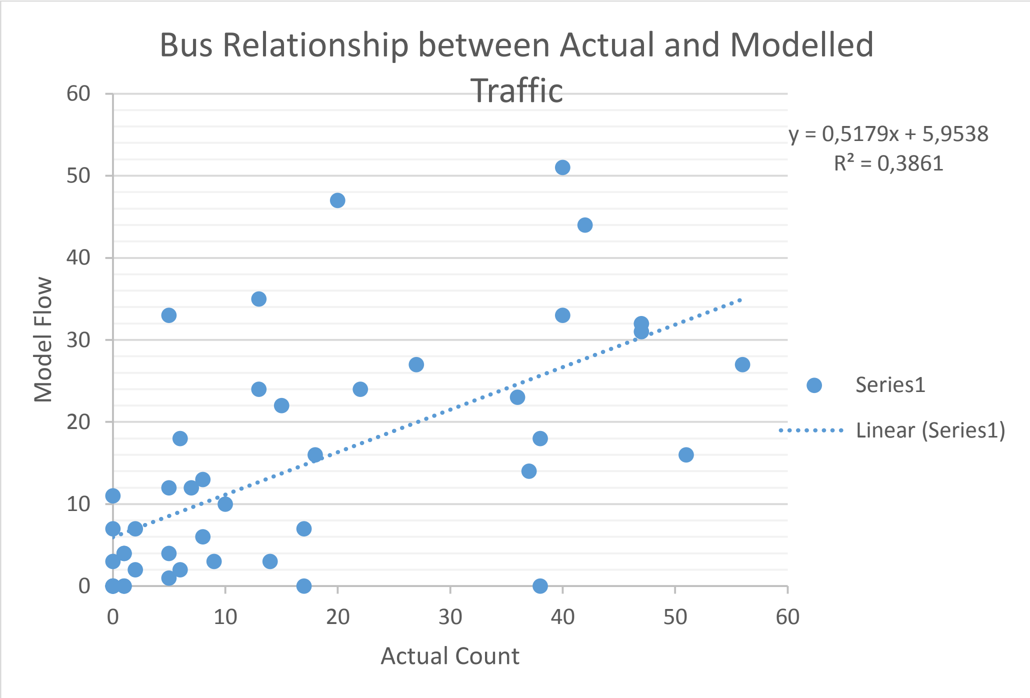


Figure 31: Initial Bus relationship between traffic counts and modelled traffic.

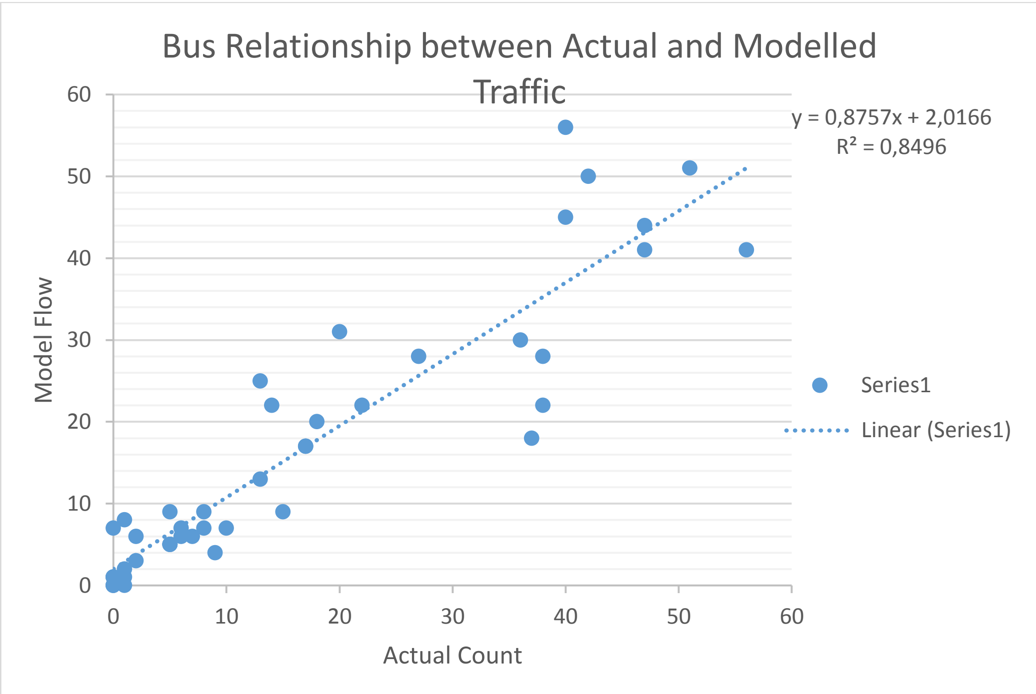


Figure 32: Final Bus adjusted matrix relationship between traffic counts and modelled traffic.

A road freight (truck) matrix was outputted from EMME for the research but illustrated a relationship below 30%. The output of the final bus matrix showed a better fit of

62% to that of the freight intersection counts. Therefore, the calibration process began with the final bus matrix to get a good fit between the counts and the modelled flow. The relationship was improved between the counts and modelled flow from 62% to 77.4% as illustrated in Figure 33 and Figure 34 respectively. The GEH for individual flows were all less than four.

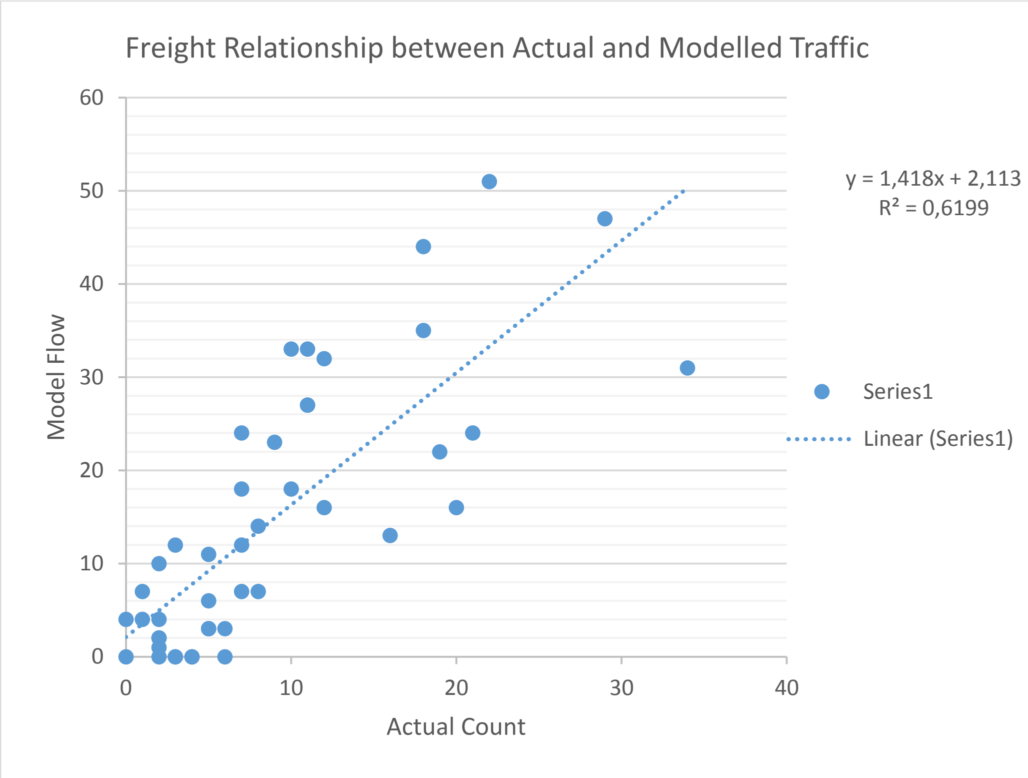


Figure 33: Initial Freight-adjusted matrix relationship between traffic counts and modelled traffic.

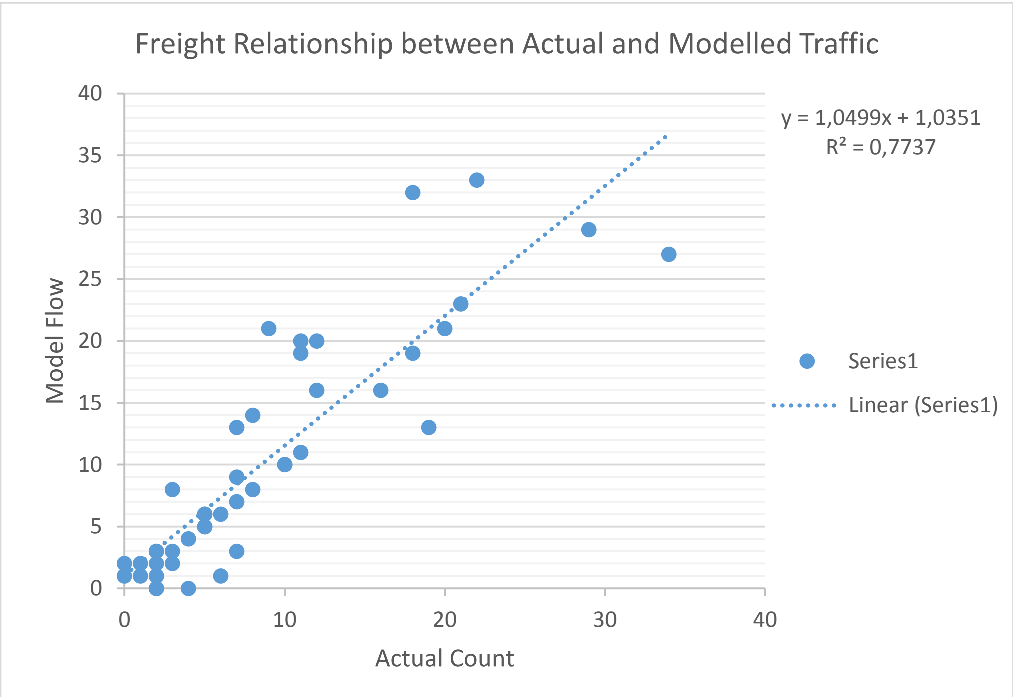


Figure 34: Final Freight-adjusted matrix relationship between traffic counts and modelled traffic.

The four modes were combined to give an ultimate relationship between the intersection traffic counts and modelled flow of 88.8% as illustrated in Figure 35. There were 44.4% of the GEH for individual flows all less than 5 and 77.8% less than 10.

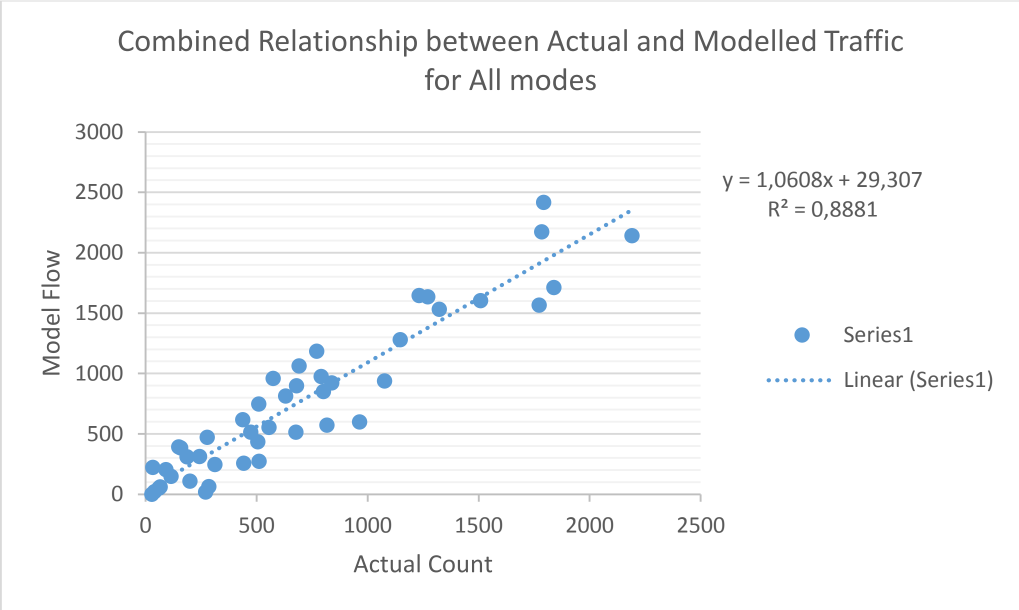


Figure 35: All modes combined relationship between traffic counts and modelled traffic.

4.2. Scenario testing

4.2.1. Base Year Scenario (2015)

The demand adjusted final matrix was used in developing each of the various scenarios. For these scenarios, the final car matrix from EMME was used also known as full matrix (MF) 1640 with the result saved in MF1630. The sub-scenarios demands were re-run in EMME. This was done to illustrate a possible suppressed and induced traffic demand along the corridor. The base year scenario that was done in AIMSUN showed that the current conditions on Dr Pixley KaSema Street are congested during the morning peak hour. This is very noticeable towards the west or beginning of the street as illustrated in Figure 36. There were various modes such as the private car, trucks, buses and mini-bus taxi all competing for the same road space. This road space also includes high volumes of pedestrian activity. A comparative analysis based on traffic flow, travel time and performance LOS was done between the base year scenario and each of the scenarios tested.

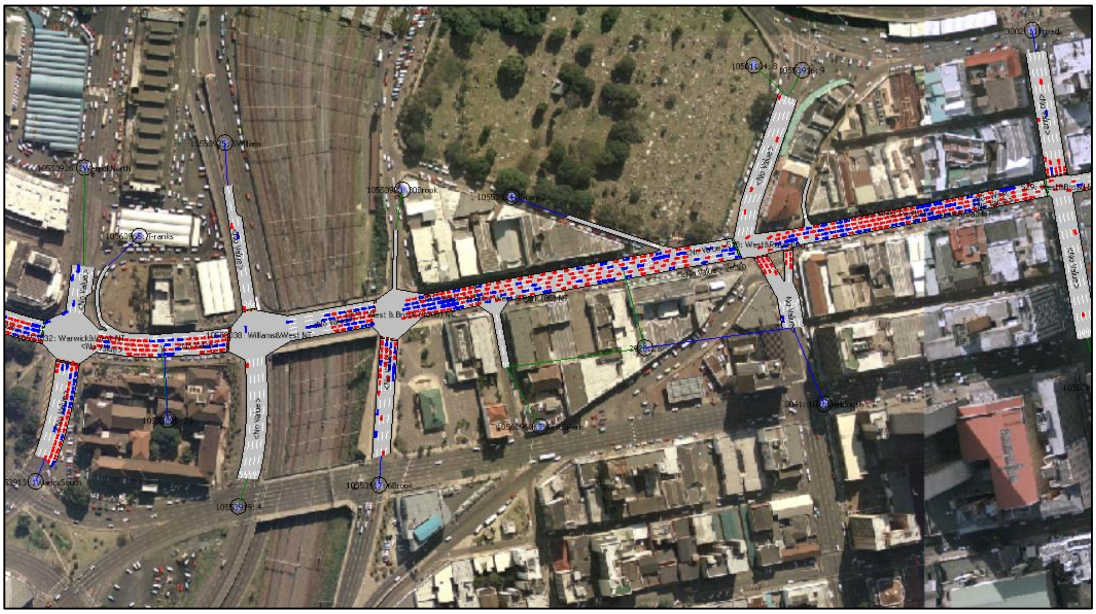


Figure 36: Calibrated 2015 Base situation on the current network.

AIMSUN has a feature of outputting data with the use of a function called statistical streams. This was used to output the traffic flow, speed and travel time for each scenario. This data was used in the evaluation process. This was done with the aim of finding the most appropriate reallocation of existing road space. Three statistical streams for the corridor were captured in AIMSUN as illustrated in Figure 37. These were outputted into a Microsoft Access file and the relevant information copied into Microsoft Excel as illustrated in Table 4. This information was analysed and it was decided that the statistical stream labelled as 13 west to east (13WE) would be used for the evaluation of the base year scenario and the various scenarios.

Figure 37: Distances of the statistical streams that outputs were based on

Table 4: Output of the criteria for the 2015 Base year scenario for each mode.

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	0	Combined	365	10.54	2.80043	9.861	2.57836	10.55	2.63435	7.47185	2.558156	6.61181	2.62387	9.811	10.551	3852.044
14WE	0	Combined	137	12.37	3.01859	11.67	2.84839	11.58	2.78541	7.66873	2.578914	6.6969	2.83919	10.248	5.1417	1585.814
15WE	0	Combined	796	11.15	3.30733	10.36	2.86984	6.80	1.73341	4.69621	1.622862	4.10118	1.7318	6.2965	15.565	5409.535

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	1	Car	201	10.93	2.88784	10.24	2.65533	10.16	2.50468	7.44524	2.532527	6.40597	2.50057	9.6915	5.8082	2042.547
14WE	1	Car	74	12.84	3.05947	12.18	2.83599	11.09	2.483	7.59238	2.527283	6.44324	2.43349	10.068	2.778	821.0245
15WE	1	Car	440	11.59	3.3392	10.81	2.89359	6.51	1.58738	4.69059	1.583205	3.92599	1.59082	6.1886	8.5992	2863.333

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	2	Bus	25	10.61	2.83176	9.936	2.58672	10.46	2.6545	8.30903	2.640426	6.7325	2.60694	9.08	0.722	261.5641
14WE	2	Bus	12	13.00	3.50863	12.13	3.23942	11.12	3.02989	8.41609	3.037636	6.46146	2.92647	9.9167	0.4496	133.3903
15WE	2	Bus	34	11.59	3.82574	10.7	3.08201	6.57	1.64543	5.1455	1.659509	4.02426	1.58309	5.6176	0.664	223.4377

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	3	Trucks	5	10.76	0.59053	10.73	0.52185	9.71	0.51755	7.59518	0.517725	6.085	0.58766	9.6	0.1447	48.5391
14WE	3	Trucks	2	12.85	1.18776	12.79	0.83808	10.56	0.96429	7.90034	0.965353	6.08125	1.26395	9.5	0.0751	21.11978
15WE	3	Trucks	15	10.50	2.07731	10.07	2.07348	6.99	1.57643	5.57674	1.57492	4.51083	1.82195	6.5333	0.2933	104.8683

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	4	Taxi	134	9.93	2.61911	9.307	2.40259	11.19	2.759	7.35097	2.617527	6.91772	2.83394	10.134	3.8764	1499.394
14WE	4	Taxi	49	11.48	2.7326	10.85	2.61267	12.45	3.04006	7.59154	2.615185	7.16276	3.38925	10.633	1.839	610.2797
15WE	4	Taxi	307	10.52	3.15148	9.755	2.73331	7.22	1.86399	4.61148	1.66381	4.34076	1.90485	6.5147	6.0088	2217.896

Table 4 is an output from AIMSUN for the base year with various columns. Each row represents a statistical stream, where 0 represents the combination of all modes, 1 represents the car, 2 represents the Bus, 3 represents the trucks and 4 represents the taxi for this scenario. These rows have column data for all modes modelled for the morning peak hour. The data in some of these columns illustrate the flow (volume) of vehicles, the average speed (km/h), the speed standard deviation (speed_D), the travel time in minutes (*ttime* (min)), the travel time standard deviation (ttime_D) and various other time measurements of the streams are shown in seconds as well as the number of average stops taken (nstops). Note that the statistical stream distances are shown in Figure 37.

The column *ttime (min)*, in Figure 38, illustrates the data for the base years combined travel time for all modes is 10.55 minutes. The mini-bus taxi service shows the highest travel time of 11.19 minutes amongst the various modes. The trucks showed the fastest travel time with the private vehicle very close to the trucks travel-time of approximately 10 minutes. Trucks will be present and remain the same in all scenarios unless otherwise stated but not discussed for the remainder of the research as they have very similar travel times to that of the private car. Note that the trucks have not been calibrated to its appropriate travel time. The study area has 24 signalised intersections along the corridor. This is much greater than six signals per kilometre. The use of the travel speed and the urban streets by class as shown in Table 2 to calculate LOS would not be appropriate (HCM, 2000). This corridor favours pedestrians with various midblock pedestrian signalised crossings.

The more appropriate measure would be to use the speed-flow curves to determine V/C ratio that corresponds to the appropriate LOS as shown in Figure 8. The 2015 Base year combined travel speed is 10.54 km/h which is of an approximate 0.94 [-] V/C ratio. This illustrates that this corridor is currently operating at a LOS E and is close to a LOS F.

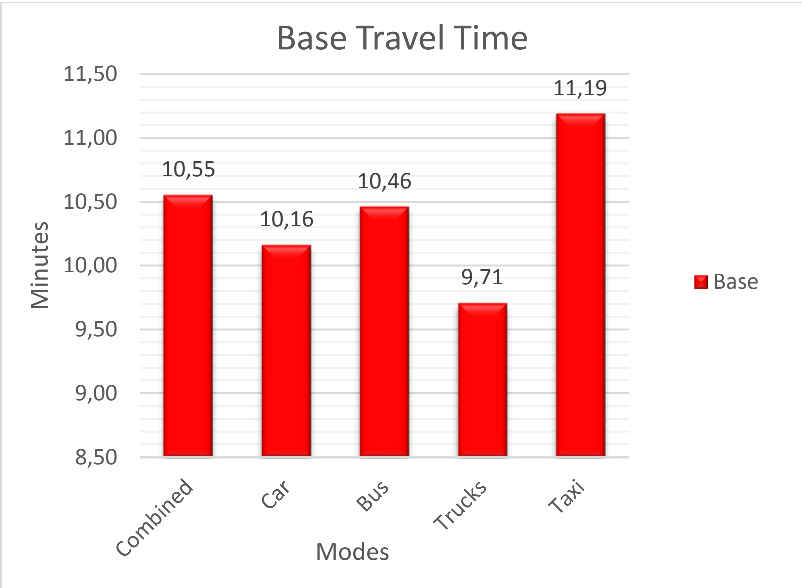


Figure 38: Base year travel time

4.2.2. QBS Scenario 1A

The QBS Scenario 1A is a 9m quality bus service operating in mixed traffic. The passenger demand for the buses was calculated by converting the current demand of taxis into buses and this passenger demand required new buses and was added to the existing buses in the network. The onsite observation of the occupancy of the mini-bus taxi service was lower than the maximum capacity of 15 for each taxi during the morning peak hour. Therefore, the passenger occupancy was assumed to be a conservative number of passengers per taxi of 10. The total amount of taxis in the matrix for the base year were 3363 taxis and the total amount of buses in the base year matric were 306 buses. The bus capacity along the links of the corridor was observed to be below half the capacity assumed to have a conservative 30 passengers per bus in the morning peak hour along the corridor. Therefore, each cell in the taxi matrix was multiplied by 10 passengers and each cell in the bus matrix multiplied was by 30 passengers. These added up to the total PT passenger matrix demand in the study area.

The total PT passenger demand during the morning peak hour was calculated to be 42811 person trips in the morning peak hour moving through the study area. This PT passenger matrix required a matrix of 714 (42811/60) buses. The car demand remained the same as the base in this scenario initially. The only slight network change from the base was the inclusion of bus stops. These were positioned on the extreme right lane with the use of given the bus priority over a small section of roadway for the bus stop. A segment of the network is shown in Figure 39 from AIMSUN.

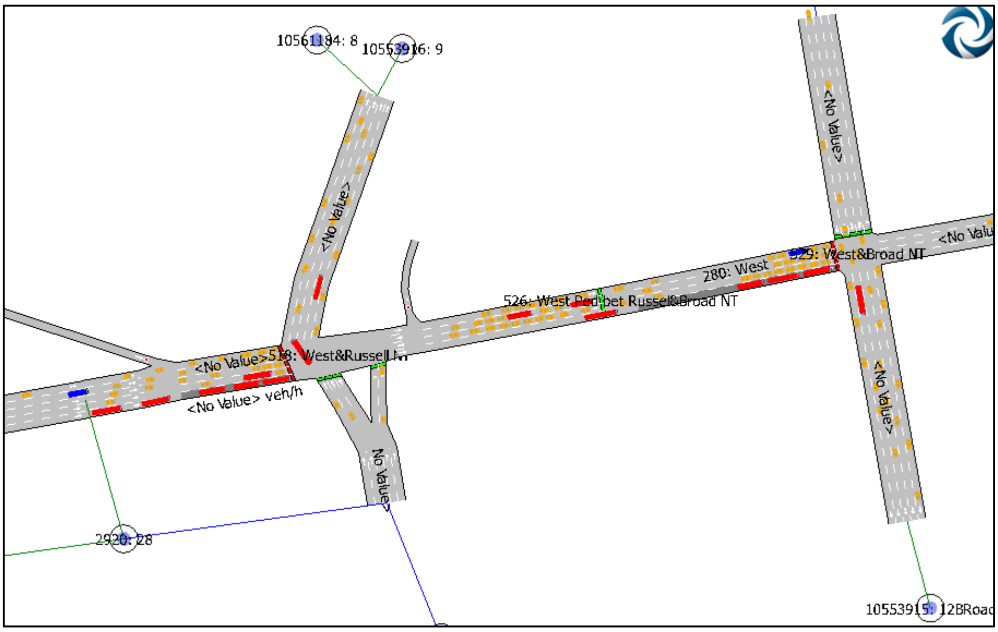


Figure 39: QBS Scenario 1A snapshot from AIMSUN

By transferring the mini-bus taxi passenger demand into that of the buses, the network showed significant additional spare capacity as the mini-bus taxis were removed from the system and hence showed an overall improvement when compared to the base year. As illustrated in Table 5 for the column ttime (min) and in Figure 40 , scenario1A in blue, showed an improvement in travel time across all modes when compared to that of the base year scenario, in red. The combined travel time improved by 4.78 minutes over 1.7 kilometres. The travel time for the PT improved by 2.64 minutes. The private vehicle travel time has the best travel time with an improvement of 4.82 minutes in this scenario, hence, this scenario works in favour of the private vehicle.

Table 5: Output of the criteria for QBS Scenario 1A for each mode.

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	0	Combined	324	18.944	3.95175	18.02	4.07879	5.77	85.3134	191.266	91.67155	158.94	71.9033	4.4475	562.03	112265.8
14WE	0	Combined	80	20.056	4.13019	19.1	4.26718	7.07	102.042	229.109	117.9039	181.894	84.5856	5.1375	180.06	33928.92
15WE	0	Combined	474	23.756	7.55004	21.43	7.06167	3.28	68.5705	93.8789	75.62253	66.9763	53.6491	2.0063	556.05	93407.51

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	1	Car	275	19.979	3.14205	19.5	3.04659	5.34	50.3154	159.706	42.96037	137.223	40.2797	4.2109	477.12	88072.3
14WE	1	Car	59	21.906	2.6454	21.6	2.56597	6.25	44.5466	166.724	30.84103	141.419	28.2461	4.678	132.86	22142.46
15WE	1	Car	354	26.37	6.14364	25.36	5.04838	2.78	28.616	57.2206	23.4976	44.6186	20.5508	1.6667	415.43	58962

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	2	Bus	44	12.413	1.82468	12.16	1.76155	8.55	74.3829	387.692	73.18852	295.585	79.0724	5.9318	76.235	22575.28
14WE	2	Bus	19	14.099	1.56068	13.92	1.56587	9.69	70.3973	424.366	68.58797	310.224	76.6482	6.5789	42.7	11041.42
15WE	2	Bus	105	14.326	2.77258	13.83	2.6094	5.08	56.5447	220.004	56.32954	145.35	58.9317	3.2	123.06	32028.04

Speed-flow curves were used to determine the V/C ratio as shown in Figure 8. This QBS scenario for the combined travel speed is 18.94 km/h which corresponds to a LOS A. This is a big improvement over the base years LOS E.

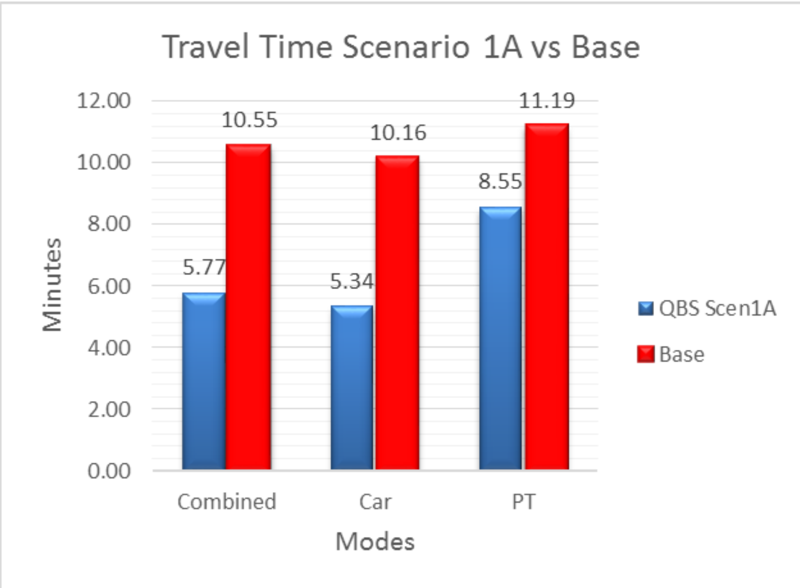


Figure 40: QBS Scenario 1A (blue) and Base year (red) travel time

Due to the high number of taxi vehicles removed, this corridor may become more attracted to private cars due to its new-found spare modal capacity. Therefore, a method of replicating what could possibly occur, and relating the current base year demand to capacity, was developed. This was done with the use of traffic count detectors in AIMSUN were the volume of each mode was detected. This is shown in Figure 41.

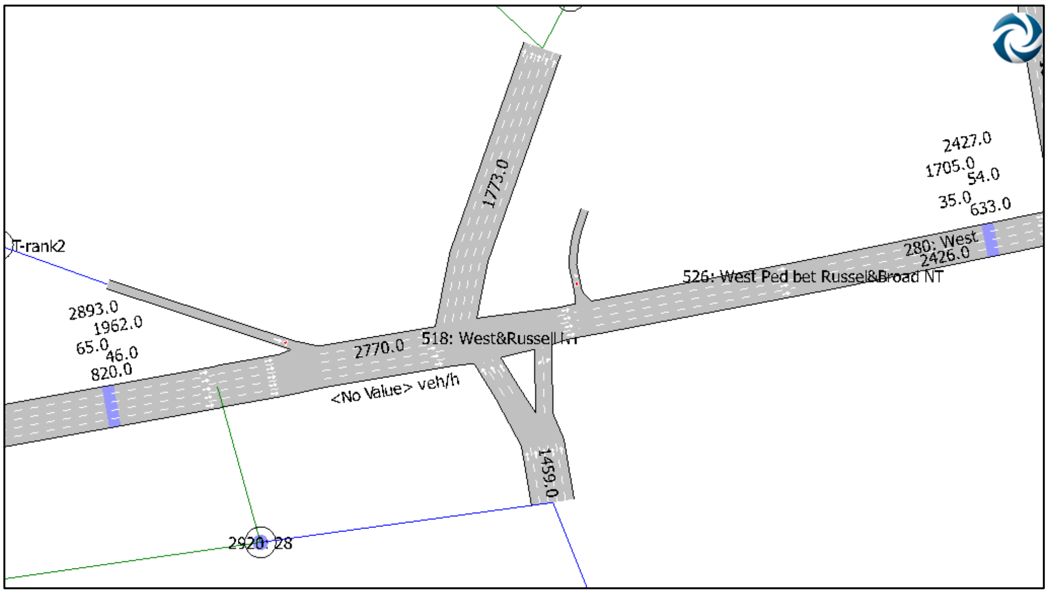


Figure 41: Detectors with counts for the Base year

Taking the capacity of the corridor from the base of 5000 and the V/C ratio of 0.94 [-], a method of calculating the new proposed capacity was formulated. There were two detectors placed on the links in AIMSUN. The Detectors output volumes along the corridor with all vehicles counts of 2893 veh/hr and 2427 veh/hr at detector 1 and detector 2. This needed to be adjusted to convert all modes along the corridor into PCU's.

The buses were multiplied by 2, the trucks were multiplied by 3 and mini-bus taxi's were multiplied by 1.8 due to their driving behaviour. This was shown in Table 6. The QBS 1A scenarios new corridor capacity calculation entailed taking the scenarios total PCU of 2745 veh/hr and total PCU of 3706 veh/hr from the Base year scenario with its corridor capacity of 5000 and the V/C ratio of 0.94 [-]. The equation is as follows:

(Base Count/Scenario Count) x Base Capacity/LOS = (3706/2745) x 5000/0.94 = 7181. This figure was then averaged with the similar corridor capacity calculated at detector 2 to give a new average corridor capacity of 7791 (rounded down to 7500) as illustrated in Table 6. The detector counts from QBS scenario 1A is shown in Figure 42.

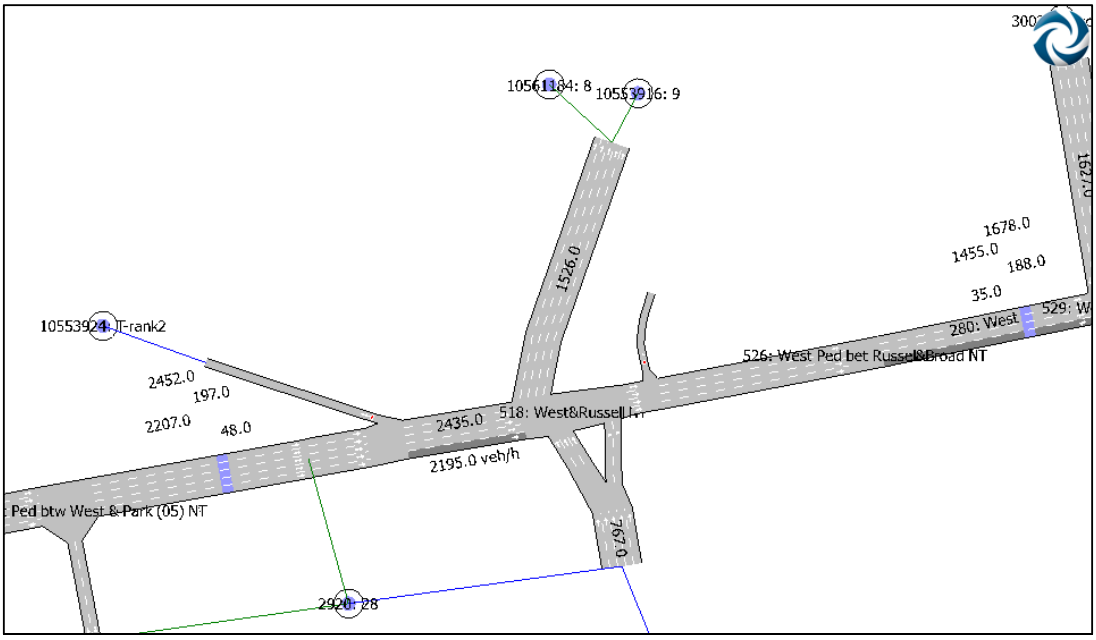


Figure 42: Detectors with counts for QBS scenario 1A

Table 6 Base and QBS 1A PCU

Base	Detector 1		Detector 2		QBS 1A	Detector 1		Detector 2	
All	2893		2427		All	2452		1678	
Cars	1962	1962	1705	1705	Cars	2207	2207	1455	1455
Bus	65x2	130	54x2	108	Bus	197	394	188	376
Truck	46x3	138	35x3	105	Truck	48	144	35	105
Taxi	820x1.8	1476	633x1.8	1139.4	Taxi		0		0
	Total PCU	**3706**	**Total PCU**	**3057.4**			**2745**		**1936**
	v/c	0.94	v/c	0.94		Old Cap	5000		
						New Cap	7181.336		8400.189
						Average Cap	**7790.762**		

A rounded down corridor capacity from 7791 to 7500 was tested from Table 6 in the QBS sub-scenario 1A.

4.2.2.1. <u>QBS Sub-scenario 1A</u>

The best possible outcome for this scenario would be if the mini-bus taxis are removed such that no other vehicles will be attracted into this corridor. But as discussed in chapter 2.5 vehicles from other corridors will be attracted into this corridor. This scenario aims to illustrate induced traffic as discussed by Noland (2001). As illustrated in Table 6, a new link capacity of 7500 was re-run in EMME and QBS sub-scenario 1A was created. This was done to illustrate the possible change of using the redistributed car demand from EMME due to the possible induced traffic. Note that the existing capacity for the corridor was 5000 in EMME for the base year. A new car matrix was extracted from EMME and tested in AIMSUN. The new private car matrix was extracted and imported into AIMSUN. A segment of the network for this scenario can be seen in Figure 43 from AIMSUN.

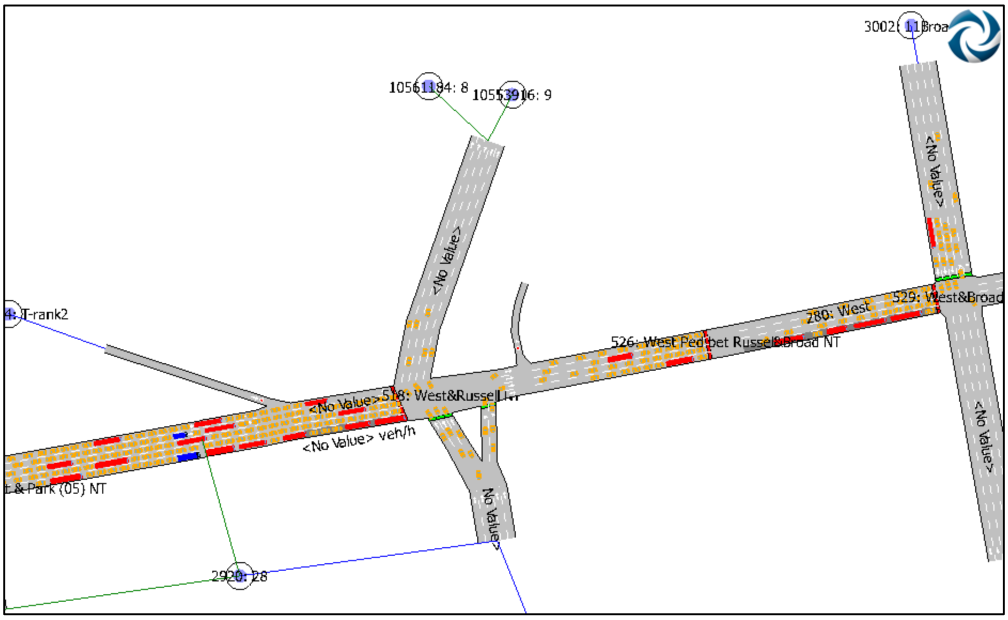


Figure 43: QBS Sub-scenario 1A snapshot from AIMSUN

After converting the mini-bus taxi demand into that of the buses, the network showed significant additional spare capacity as the mini-bus taxis were removed from the system. However, after using the new redistributed private car matrix in this scenario due to the taxis being removed, the corridor attracted more cars to it. This sub-scenario illustrated that additional private cars will induce into this corridor when capacity is increased along the corridor in EMME. The network shows some congestion as can be seen in Figure 43. Therefore, as illustrated in Table 7 for the column ttime (min) and in Figure 44, scenario1A in blue, a decrease in travel time across all modes was observed when compared to that of the base year scenario, in red.

Table 7: Output of the criteria for QBS Sub-scenario 1A for each mode.

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	0	Combined	463	8.2802	2.01816	7.866	1.80421	13.24	170.809	635.483	172.9409	581.302	171.303	11.721	803.59	367763.6
14WE	0	Combined	188	10.145	2.52576	9.601	2.28556	14.07	190.55	640.088	192.4051	576.754	189.521	12.186	423.36	158743.6
15WE	0	Combined	959	9.0378	1.80002	8.59	1.96166	8.20	130.63	384.599	135.5507	346.124	134.914	7.0584	1125.9	471861.7
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	1	Car	429	8.4286	1.9921	8.041	1.7656	12.95	156.916	615.658	155.1233	564.226	156.297	11.765	744.66	333403.4
14WE	1	Car	172	10.383	2.48037	9.879	2.23175	13.68	172.774	612.247	167.3948	554.625	172.99	12.192	387.4	141177.5
15WE	1	Car	856	9.3934	1.44339	9.164	1.45114	7.69	76.758	351.195	75.9192	315.218	80.6511	7.139	1005.2	394915.9
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	2	Bus	29	6.2792	1.34756	6.034	1.21535	17.23	199.277	908.938	199.099	819.672	214.576	11.103	50.251	29981.88
14WE	2	Bus	14	7.3742	1.27972	7.18	1.1823	18.78	189.663	968.211	190.399	839.036	204.397	12.143	31.459	15775.2
15WE	2	Bus	90	5.7387	1.51992	5.407	1.34002	13.01	179.851	695.708	179.066	635.833	193.812	6.2889	105.47	70247.11

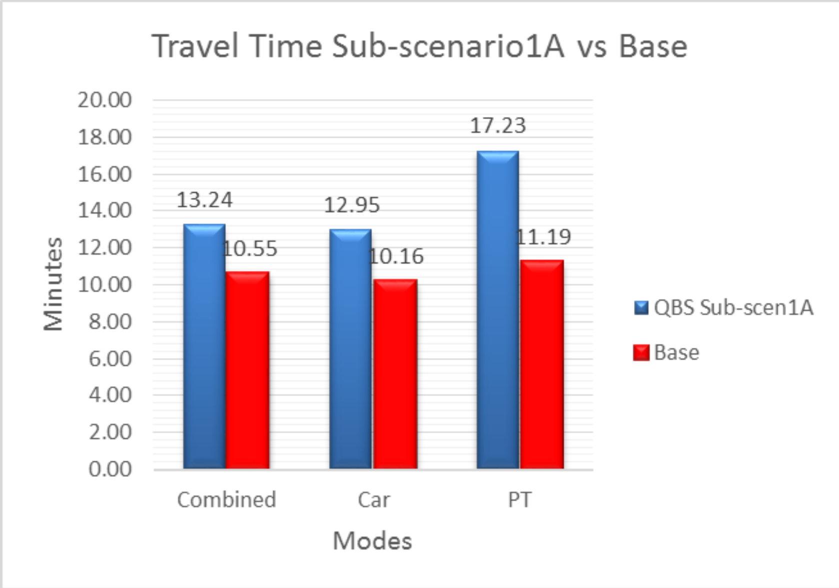


Figure 44: QBS Sub-scenario 1A (blue) and Base year (red) travel time

The combined travel time worsened by 2.69 minutes over 1.7 kilometres. Due to the induced demand to the corridor and with the high volume of buses travelling in mixed traffic similar to the mini-bus taxis showed that this may not be a feasible solution. This scenario illustrates additional traffic demand may be induced into the corridor. The private cars take up all the spare capacity left behind from the mini-bus taxi service, making the conditions worse than that of the Base. Therefore, the free capacity created needs to be locked-in with other TDM measures such as road diets, tolling, etc. This QBS sub-scenario for the combined travel speed is 8.28 km/h with a V/C ratio of 1 [-], which corresponds to a LOS F. Therefore, this proves that conditions have worsened to that of the Base year's LOS E.

A select link analysis for the corridor was done in EMME for both the Base capacity of 5000 veh/hr and with the new capacity of 7500 veh/hr. This is illustrated in Figure 45 and Figure 46. This illustrates that the private traffic in the EMME model is sensitive to capacity change. The PT along the corridor remained the same after the capacity change. There was no modal shift change as this was a limitation from the EMME model and only route choice change was shown by the private cars.

Figure 45: Base year select link analysis (5000 capacity along the corridor)

Figure 46: QBS Sub-scenario select link analysis (7500 capacity along the corridor)

A comparison was then done between the QBS scenario 1A and the QBS sub-scenario 1A shows a direct relationship of induced traffic. These scenarios are identical in terms of the network and QBS. These scenarios created spare capacity when the taxi service was removed QBS and this spare capacity would attract more traffic flow as illustrated in Figure 47. The vehicular traffic flows for QBS sub-scenario 1A are the green bars and QBS scenario 1A are the yellow bars as illustrated in the bar graph in Figure 47. The combined traffic flow and private car traffic flow increased by 139 and 154 vehicles from QBS sub-scenario 1A to QBS scenario 1A. The percentage shift of private cars is 56% that is attracted by the 50% increase of the capacity along the corridor. The QBS flow decreased by 12 buses along the corridor. This was due to the higher volume of private vehicles along the corridor that affects the QBS travelling in mixed traffic.

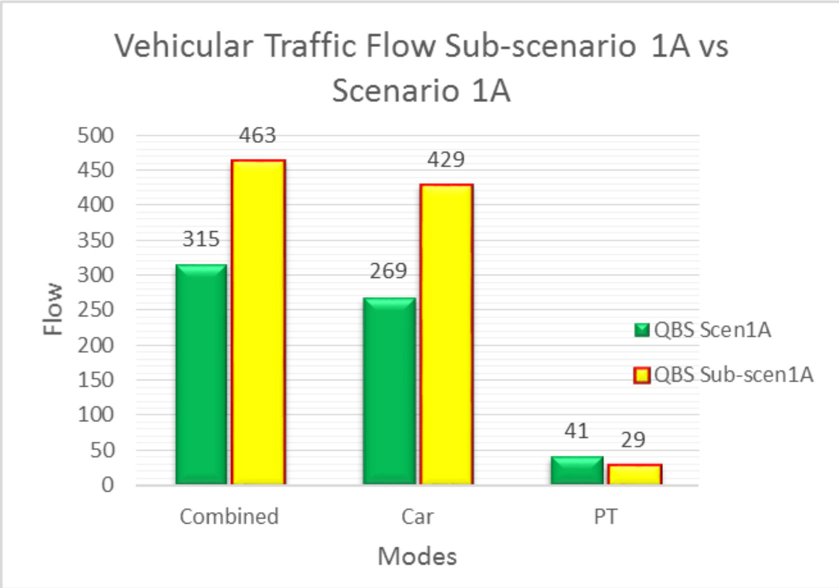


Figure 47: QBS Scenario 1A (green) and QBS Sub-scenario 1A (yellow) travel time

The QBS sub-scenario 1A, when compared to QBS scenario 1A, shows an increase in travel time across all modes in the scenario, as illustrated in Figure 48. The travel time for QBS scenario 1A are blue bars and QBS sub-scenario 1A are the light blue bars as illustrated in the bar graph in Figure 48. The private car travel times worsened by 7.40 minutes. The PT travel time worsened by 4.95 minutes.

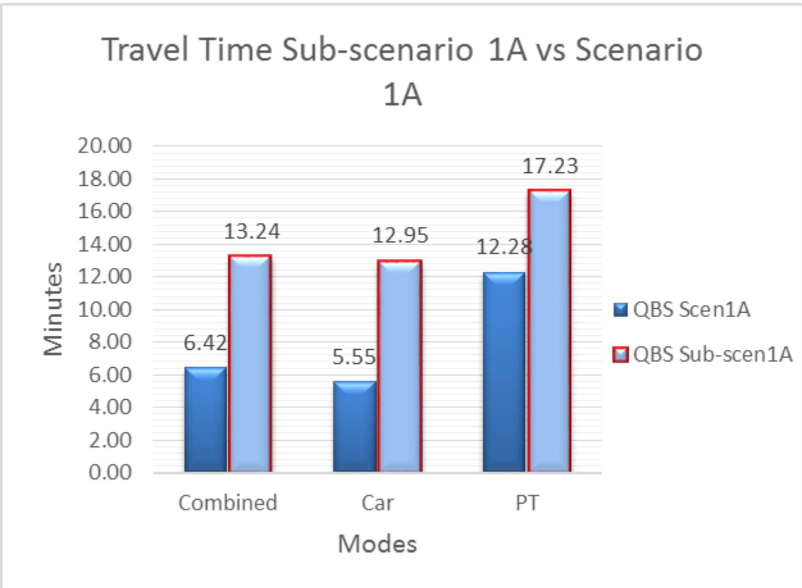


Figure 48: QBS Scenario 1A (blue) and QBS Scenario 1A (light blue) travel time

This scenario showed that traffic may possibly be induced into this corridor with an increase in *virtual* capacity as previously discussed by Noland (2001) in chapter 2.5. As all the spare capacity left behind in the QBS scenario 1A may induce more traffic as depicted in QBS sub-scenario 1A and make conditions worse. The QBS sub-scenario 1A together with QBS scenario 1A successfully illustrates induced traffic.

4.2.3. QBS Scenario 1B

The QBS Scenario 1B is also a quality bus service in mixed traffic similar to QBS Scenario 1A; however, this scenario also has an added NMT lane. The private car demand for this scenario is the same as the Base year scenario as the taxis will provide additional capacity but due to the NMT lane, this capacity will be reduced to that similar to the Base year. The network changes from the Base scenario are the NMT lane and the bus stops along Dr Pixley KaSema Street. This reduces the overall capacity of the roadway. A segment of the network for this scenario can be seen in Figure 49 from AIMSUN. This scenario illustrates that PT is not more attractive than the private car as both are travelling in mixed traffic. Due to the large volumes of buses required, and the added NMT lane, reducing the corridor capacity, congests the network further.

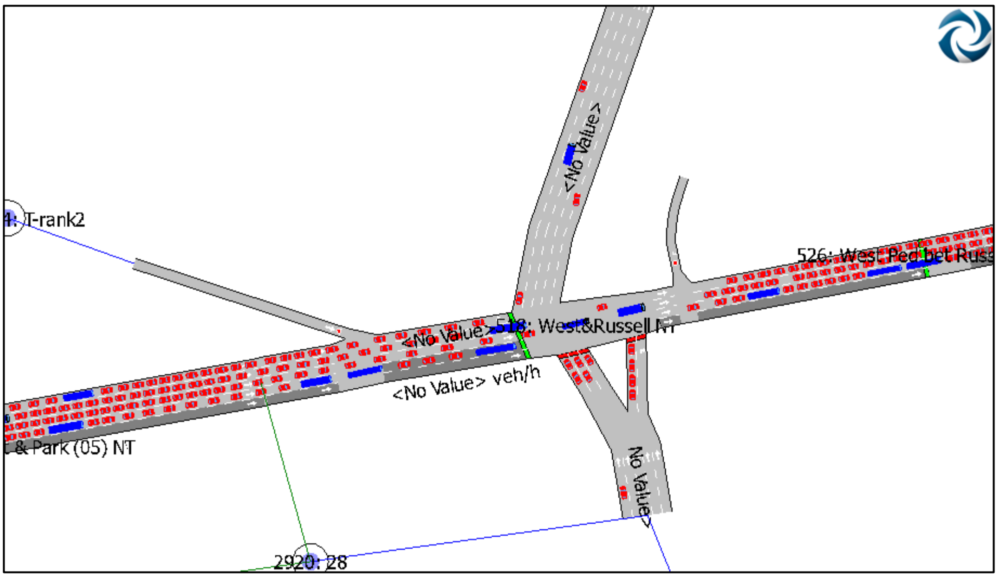


Figure 49: QBS Scenario 1B snapshot from AIMSUN

As illustrated in Table 8 for the column ttime (min) and in Figure 50, QBS scenario1B in blue, an increase in travel time was observed across all modes when compared to that of the Base year scenario, in red. The combined travel time worsened by 6.58 minutes over 1.7 kilometres. The decrease in capacity for the additional NMT lane had a detrimental effect on all modes using the corridor. Due to the limited space, the private cars were also travelling through the bus stops in the modelled scenario.

Table 8: Output of the criteria for QBS Scenario 1B for each mode.

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	0	Combined	128	6.8023	2.44805	6.084	2.0907	17.13	316.248	867.839	318.3023	806.133	313.187	13.563	222.27	131530.6
14WE	0	Combined	51	8.2658	2.55582	7.6	2.24935	17.78	291.587	858.911	292.839	791.559	291.585	14.078	114.84	54401.6
15WE	0	Combined	399	7.8705	1.30768	7.673	1.22997	9.18	85.536	444.699	92.4551	403.398	92.6885	7.5865	468.64	219867.4
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	1	Car	107	6.9619	2.52083	6.213	2.15752	16.77	312.798	840.167	311.9517	784.367	309.774	14.028	185.84	107694.7
14WE	1	Car	42	8.307	2.63047	7.626	2.27863	17.72	288.982	845.437	287.4232	788.321	285.706	14.881	94.612	44663.81
15WE	1	Car	318	8.108	1.19559	7.954	1.10614	8.86	70.1903	420.028	72.94743	382.005	73.9324	8.0503	373.6	169095.5
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	2	Bus	17	6.237	2.01552	5.662	1.80371	18.38	345.972	976.363	346.9495	886.368	340.955	10.353	29.483	18747.83
14WE	2	Bus	8	8.3916	2.24295	7.826	2.10355	17.23	306.589	873.403	313.7042	757.219	322.005	9.5	17.98	8270.89
15WE	2	Bus	68	6.8394	1.38469	6.627	1.18555	10.62	101.29	552.066	100.8952	499.015	113.747	5.4853	79.77	43336.84

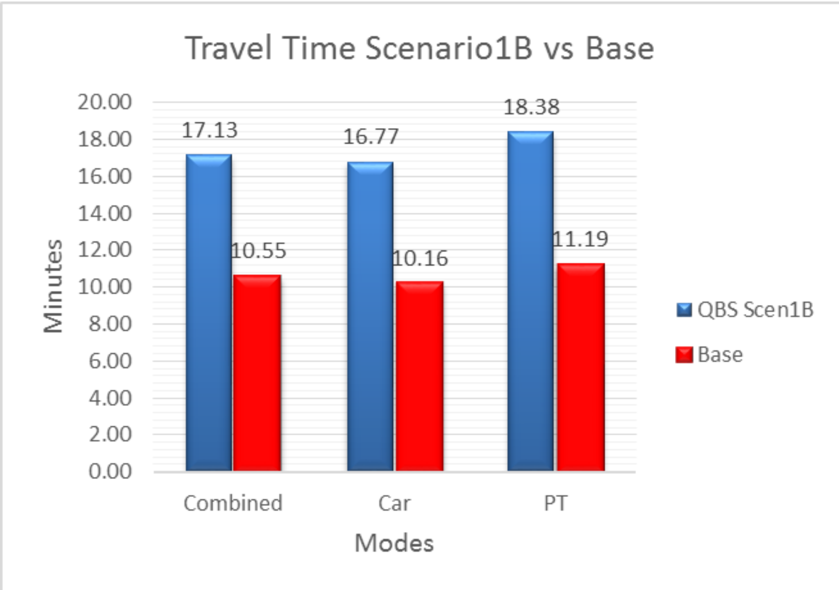


Figure 50: QBS Scenario 1B (blue) and Base year (red) travel time

This QBS scenario 1B's combined travel speed is 6.80 km/h with a V/C ratio of 1 [-], which is at maximum V/C ratio that corresponds to a LOS F. This illustrates that conditions have worsened substantially from the base years LOS E.

4.2.4. <u>BRT Scenario 2A</u>

The BRT scenario 2A is the application of a dedicated scheduled BRT service. Unlike the QBS scenario based on a matrix PT demand, this scenario was based on a PT line demand. Hence, the passengers that would use the system will be the same amount as the QBS scenario equaling the matrix of 42811 PT passengers in the morning peak hour in the study area. The corridor PT passenger demand was found by applying 10% of this PT matrix with a vehicular mode and assigned onto the network. The result of this is shown in Figure 51. The highest link volume when modelled was 1276. This volume was multiplied back by 10 to get 12760 passengers along a link in the corridor.

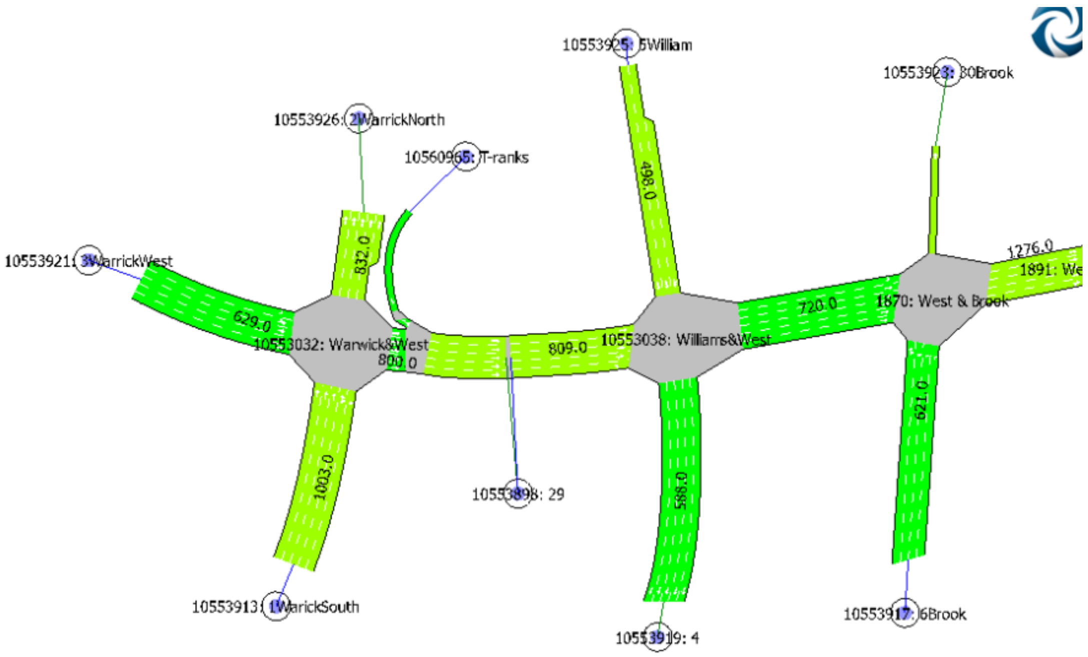


Figure 51: QBS Scenario 1B (blue) and Base year (red) travel time

The passengers will board and alight along the route of the corridor and would take midi-bus feeder services to their destinations outside of this corridor. These feeder services were not modelled in this scenario. The PT link demand was converted to an 18m articulated bus demand that can carry approximately 120 passengers. This required 107 bus trips to take the demand along the corridor in the morning peak hour. This equated to a bus requiring to travel every 33.3 seconds along the link of the corridor to cater for the required demand. A BRT system was modelled travelling every 30 seconds along the corridor which was rounded down from 33.3. Hence, having a higher frequency to that required to transport the existing demand of passengers along a dedicated route on Dr Pixley KaSema Street. Two bus lines were modelled travelling at 1-minute headways. These two bus lines had six stops each along the corridor similar to that of the QBS in the same locations. Each bus had a stopping dwell time of 20 seconds per bus stop.

A segment of the network of this scenario can be seen Figure 52 from AIMSUN. As illustrated in Table 9 for the column ttime (min) and in Figure 53, BRT scenario 2A in blue, an improvement in travel time across all modes was observed when compared to that of the Base year scenario, in red. The combined travel time improved by 3.73 minutes over 1.7 kilometres from the base year scenario.

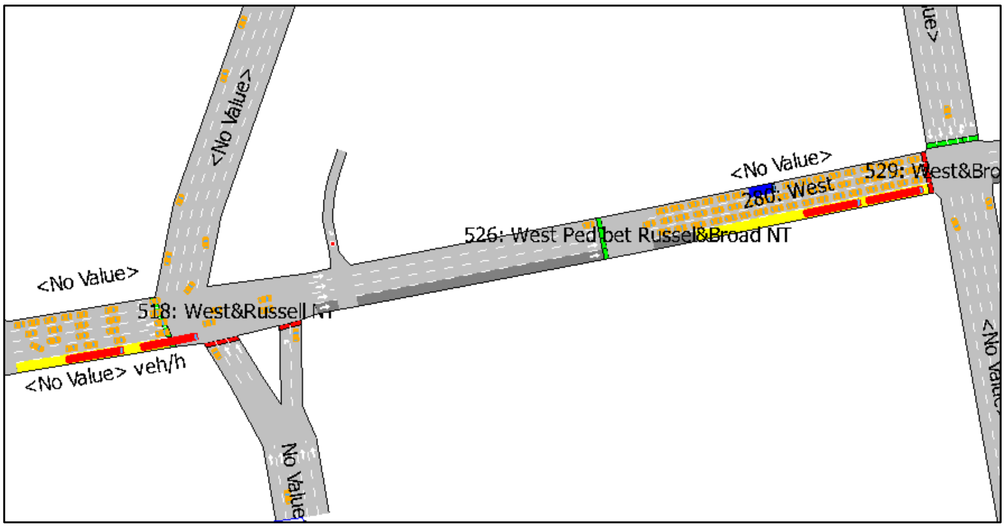


Figure 52: BRT Scenario 2A snapshot from AIMSUN

Table 9: Output of the criteria for BRT Scenario 2A for each mode.

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	0	Combined	352	15.721	2.76414	15.24	2.7032	6.82	1.2028	4.353	1.436281	3.64812	1.23508	6.9375	10.17	2401.719
14WE	0	Combined	146	17.066	3.2638	16.45	3.19376	8.20	1.58094	5.0992	1.91837	4.22611	1.64621	8.226	5.4703	1197.171
15WE	0	Combined	656	20.052	3.83226	19.19	4.05958	3.67	0.84343	1.92363	0.976572	1.5104	0.85857	3.654	12.822	2404.907
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	1	Car	228	17.263	2.09287	17.01	2.06096	6.12	0.74413	3.44128	0.745004	2.87933	0.65714	5.5219	6.5918	1394.808
14WE	1	Car	86	19.274	2.15079	19.04	2.12873	7.09	0.80042	3.66056	0.744668	3.02529	0.69642	6.093	3.2262	610.1367
15WE	1	Car	521	21.448	2.71337	21.07	2.8228	3.34	0.47144	1.51186	0.468154	1.15398	0.40983	3.0154	10.184	1740.08
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	2	Bus	119	12.817	0.99744	12.74	1.01751	8.16	0.66681	6.06459	0.667871	5.10116	0.63031	9.6891	3.4335	970.5257
14WE	2	Bus	58	13.723	1.14663	13.63	1.11657	9.88	0.80498	7.25538	0.814908	6.03944	0.78467	11.466	2.1693	572.907
15WE	2	Bus	120	14.095	1.62942	13.89	1.70452	5.07	0.65583	3.65548	0.656188	3.0424	0.59714	6.45	2.3451	607.9755

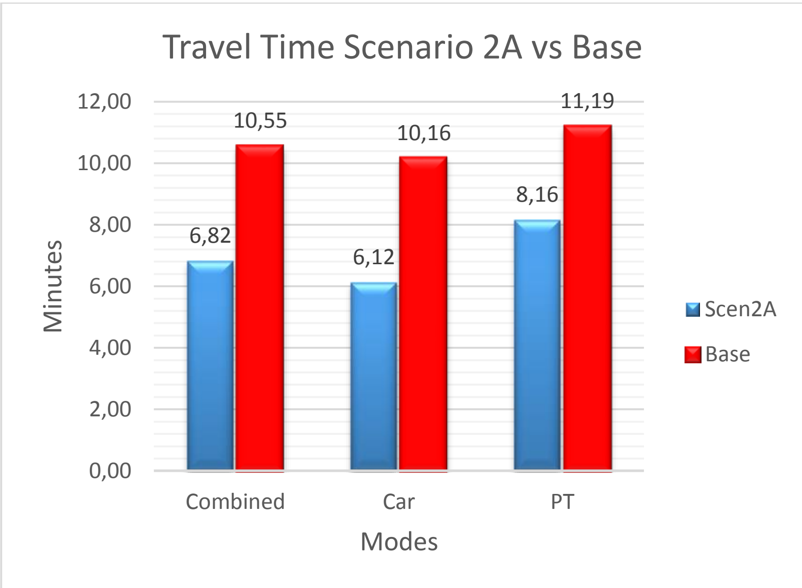


Figure 53: BRT Scenario 2A (blue) and Base year (red) travel time

The scheduled bus line service on its dedicated road space creates more capacity for other modes. Therefore, there is a net benefit for all modes in this scenario. The private car gains the most travel time with a reduction from 10.16 to 6.12 minutes, giving a difference of 4.04 minutes. The PT travel time also improved by 3.03 minutes, from 11.19 minutes for the mini-bus taxi service to 8.16 minutes. This BRT scenario 2A for the combined travel speed is 15.72 km/h with a V/C ratio of 0.42 [-] that corresponds to a LOS C. Therefore, this proves that conditions have improved from the Base year's LOS F.

Due to the mini-bus taxis being removed, this corridor may become more attractive to other modes along this corridor. The BRT scenario 2As new proposed capacity entailed doing a calculation taking the scenarios total PCU of 2475 and total PCU of 3706 vehicles from the base year scenario, the corridor capacity of 5000 and a LOS of 0.94 [-] V/C ratio. This gave a new potential corridor capacity of 7975. This figure was averaged with the similar corridor capacity calculated at detector 2 of 7453 to give a new average corridor capacity of 7709 (Due to the limited use of the EMME model this was rounded down to a corridor capacity of 7500) as illustrated in Table 10.

Table 10 Base and BRT scenario 2A PCU

Base	Detector 1		Detector 2		BRT 2A	Detector 1		Detector 2	
All	2893		2427		All	2552		2226	
Cars	1962	1962	1705	1705	Cars	2381	1962	2067	1705
Bus	65x2	130	54x2	108	Bus	120	360	120	360
Truck	46x3	138	35x3	105	Truck	51	153	39	117
Taxi	820x1.8	1476	633x1.8	1139.4	Taxi		0		0
Total PCU	veh. vol.	**3706**	veh. vol.	**3057.4**		veh. vol.	**2475**	veh. vol.	**2182**
	v/c ratio	0.94	v/c ratio	0.94		Old Cap	5000	cap	
						New Cap	**7964.754**	cap	**7453.147**
						Average Cap	**7708.95**	cap	

The original PCU values used in Table 10, for the BRT scenario 2A, were from the use of detectors in AIMSUN is shown in Figure 54.

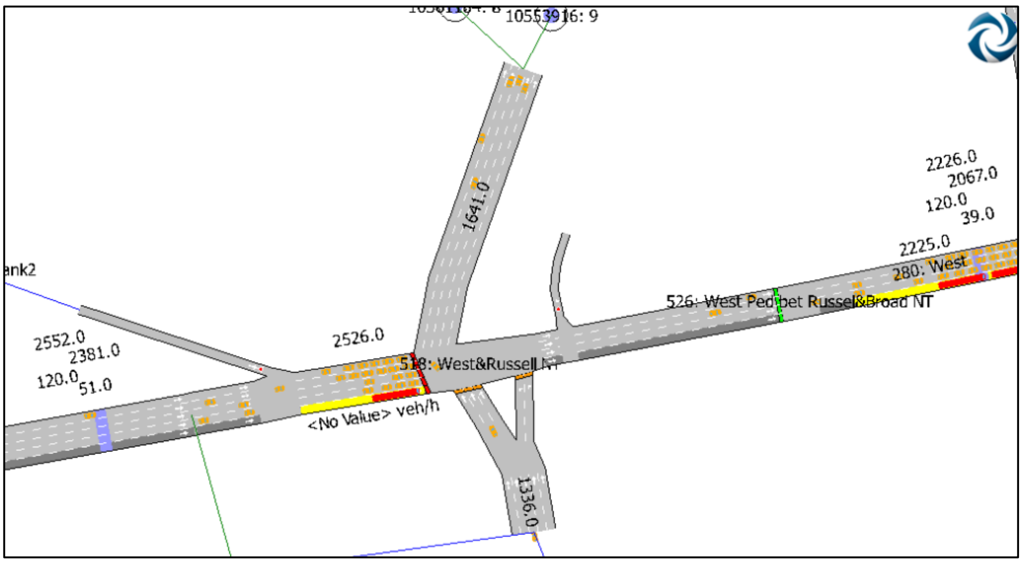


Figure 54: BRT Scenario 2A mode counts

4.2.4.1. BRT sub-scenario 2A

The best possible outcome for this scenario would be for the mini-bus taxis to be removed so that no other vehicles will induce into this corridor as shown in the BRT scenario 2A. The new capacity of 7500 was re-run in EMME and this BRT sub-scenario 2A was created. The new private car matrix was extracted from EMME and imported into AIMSUN. The BRT demand is the same as BRT scenario 2A with a scheduled bus service travelling every 30 seconds along the corridor to transport the existing demand of passengers along a dedicated route on Dr Pixley KaSema Street. The car demand remained the same as the base in this scenario. This was to illustrate the change of using the redistributed car demand from EMME. The new private car matrix was extracted and imported into AIMSUN. A segment of the network for this scenario can be seen in Figure 55 from AIMSUN.

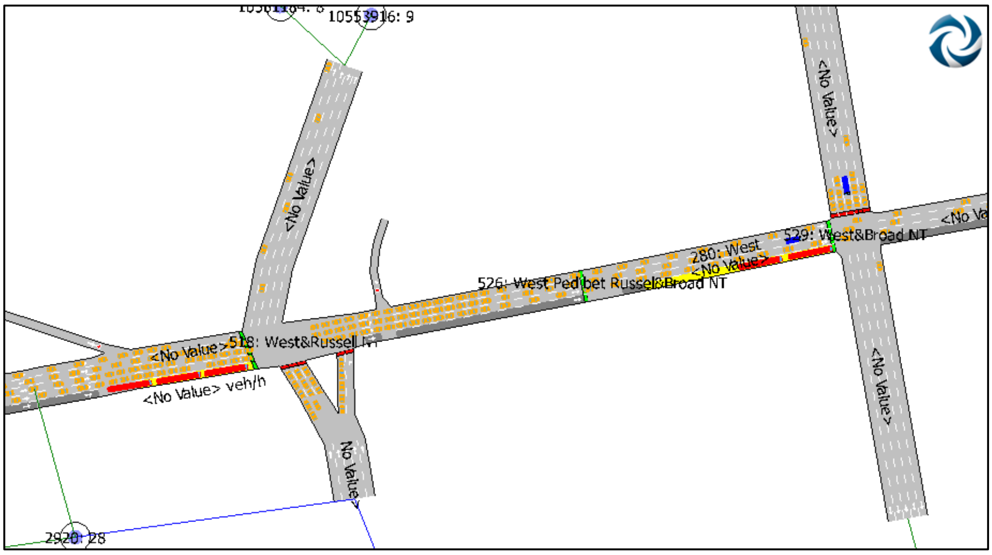


Figure 55: BRT Sub-scenario 2A snapshot from AIMSUN

Table 11: Output of the criteria for BRT Sub-scenario 2A for each mode.

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	0	Combined	620	9.261	1.75965	8.967	1.62406	11.61	2.0113	8.9941	2.107361	7.98694	2.05407	11.263	17.93	7198.194
14WE	0	Combined	257	11.115	2.16011	10.74	2.01264	12.58	2.26834	9.22721	2.451496	8.09874	2.32667	11.794	9.6407	3231.933
15WE	0	Combined	1081	10.651	1.45478	10.48	1.34259	6.72	0.81231	4.93708	0.778089	4.21125	0.74751	6.7983	21.144	7264.144
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	1	Car	514	9.4631	1.68011	9.212	1.52204	11.30	1.737	8.58278	1.746748	7.60545	1.66657	11.37	14.867	5810.281
14WE	1	Car	204	11.514	2.04546	11.2	1.87461	12.07	1.89814	8.53331	1.897648	7.4921	1.82317	11.672	7.6572	2461.272
15WE	1	Car	949	10.503	1.33388	10.36	1.23077	6.80	0.76272	4.96613	0.751973	4.27972	0.7023	6.8493	18.564	6452.709
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	2	Bus	100	8.2851	1.86571	7.929	1.68014	13.12	2.604	11.0104	2.604598	9.89388	2.73601	10.7	2.8892	1311.642
14WE	2	Bus	51	9.5782	1.93668	9.253	1.73563	14.56	2.55805	11.9161	2.570723	10.4752	2.62462	12.216	1.9084	742.5163
15WE	2	Bus	115	11.994	1.73594	11.76	1.66338	5.99	0.8315	4.56618	0.82841	3.5787	0.80217	6.3391	2.2482	688.3107

As illustrated in Table 11 for the column ttime (min) and in Figure 56 BRT sub-scenario 2A in blue, an increase in travel time was observed across all modes when compared to that of the Base year scenario, in red. The combined travel time increased by 1.06 minutes for this scenario from the Base scenario. This scenario illustrates induced traffic demand. The private cars take up all the spare capacity left behind from the taxi service, making the conditions worse than for the mixed traffic even from the base.

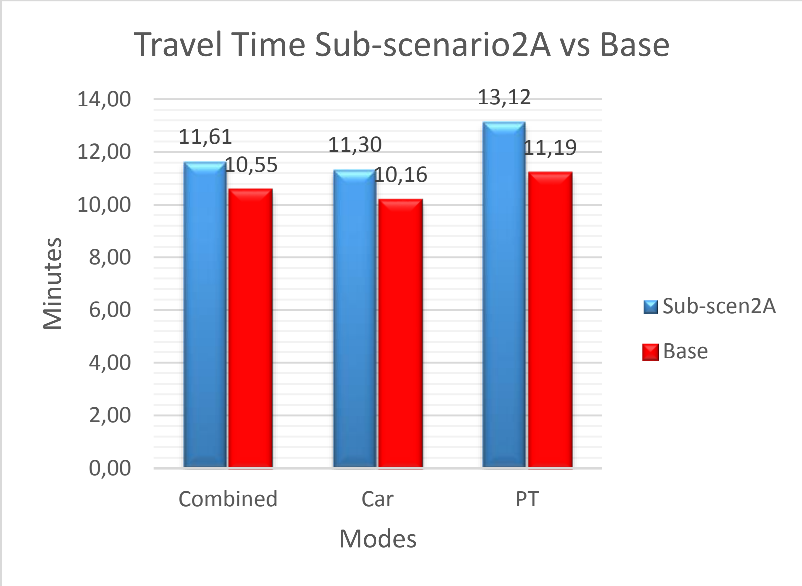


Figure 56: BRT Sub-scenario 2A (blue) and Base year (red) travel time

Speed-flow curves was used to determine LOS from the V/C ratio as shown in Figure 8. This BRT sub-scenario 2A for the combined travel speed is 9.26 km/h with a V/C ratio of 0.98 [-] which corresponds to a LOS F. This shows that conditions have worsened from the base years LOS E. This illustrates that the private traffic in the EMME model is sensitive to capacity change. The PT along the corridor remained the same after the capacity change in EMME. There was no modal shift change as this was a limitation from the EMME model and only route choice change was shown by the private cars. This scenario illustrates that even though the BRT is on its own dedicated corridor the PT travel time does increase in the AIMSUN model from 11.19 to 13.12 minutes.

A comparison between the BRT scenario 2A and the BRT sub-scenario 2A shows a direct relationship of induced traffic. These scenarios are identical in terms of the network and BRT service. BRT sub-scenario 2A created spare capacity when the taxi service was removed and converted to a BRT system and this spare capacity would attract more traffic flow as illustrated in Figure 57. The vehicular traffic flows for the BRT scenario 2A are the green bars and BRT sub-scenario 2A are the yellow bars as illustrated in the bar graph in Figure 57. The combined traffic flow and private car traffic flow increased by 268 and 286 vehicles respectively in BRT sub-scenario 2A. The percentage shift of private cars is 125.4% that is attracted by the 50% increase of the capacity along the corridor. The BRT flow decreased by nine vehicles in BRT sub-scenario 2A. This is due to the higher volume of private vehicles along the corridor that affects the BRT vehicle at the intersections.

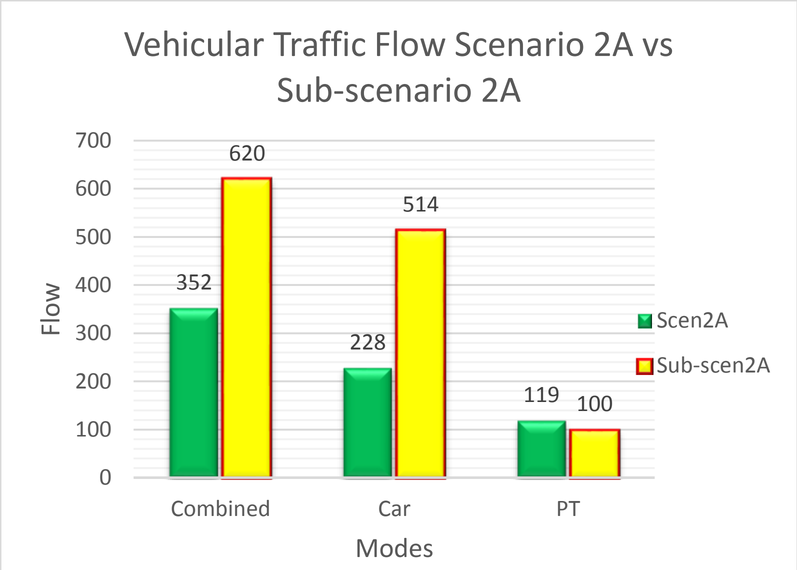


Figure 57: BRT Scenario 2A (green) and BRT Sub-scenario 2A (yellow) travel time

The BRT scenario 2A, when compared to the BRT sub-scenario 2A, illustrated an increase in travel time across all modes in the scenario, as illustrated in Figure 58. The travel time for BRT scenario 2A are blue bars and BRT sub-scenario 2A are the light blue bars as illustrated in the bar graph in Figure 58. The private car travel times worsened from 6.12 minutes to 11.30 minutes, giving a difference of 5.28 minutes from BRT scenario 2A to BRT sub-scenario 2A. The BRT service also increases in travel time from 8.16 to 13.12 minutes, giving a difference of 4.96 minutes. This scenario is similar to that done in sub-scenario 1A. This scenario showed that with an increase in *virtual* capacity that traffic may possibly be induced into this corridor as previously discussed by Noland (2001) in Chapter 2.5. This is because all the spare capacity left behind by the removed taxi service induces more traffic, as depicted in BRT sub-scenario 2A, thereby making conditions worse.

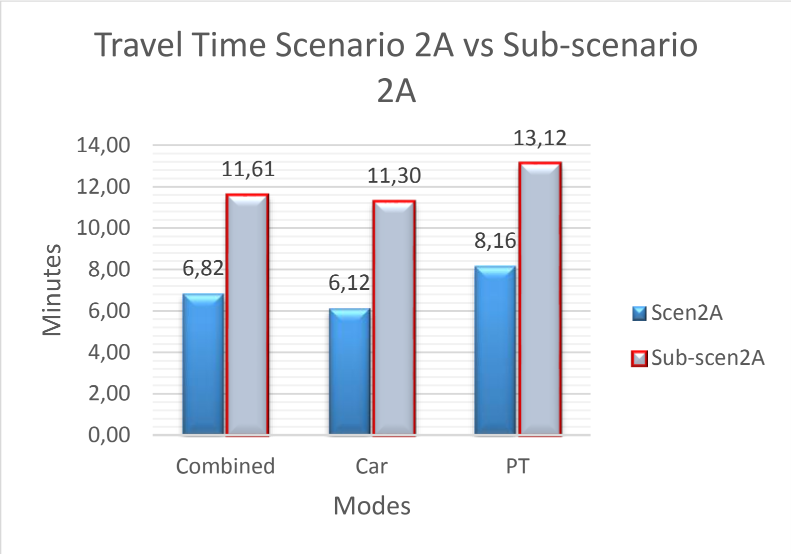


Figure 58: BRT Scenario 2A (blue) and BRT Sub-scenario 2A (light blue) travel time

This scenario successfully illustrates induced traffic.

4.2.5. BRT Scenario 2B

BRT scenario 2B is a BRT scenario similar to the BRT scenario 2A with an addition of an NMT lane. The BRT demand is the same as BRT scenario 2A with a scheduled bus service travelling every 30 seconds along the corridor to transport the existing demand of passengers along a dedicated route on Dr Pixley KaSema Street. The private car demand for this scenario is the same as the Base year scenario as the taxis will provide additional capacity. However, due to the additional NMT lane, this capacity will be reduced to that similar to the Base year's capacity of 5000 along the corridor. A segment of the network from the BRT scenario 2B can be seen in Figure 59 from AIMSUN.

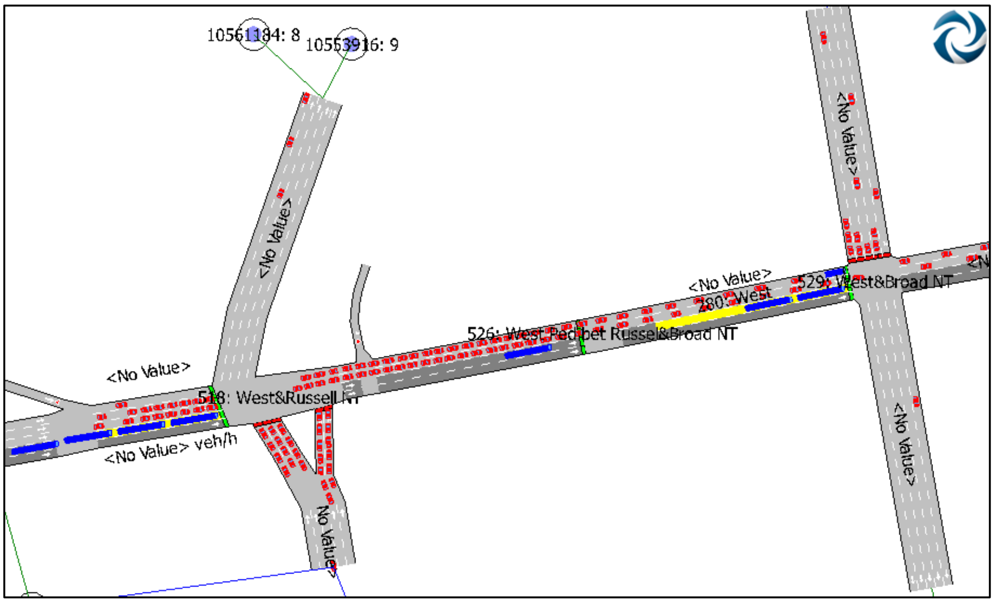


Figure 59: BRT Scenario 2B snapshot from AIMSUN

Table 12: Output of the criteria for BRT Scenario 2B for each mode.

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	0	Combined	257	10.464	2.96854	9.449	3.09652	11.01	3.91359	8.57913	3.756089	7.53876	3.51824	12.093	7.4248	2829.189
14WE	0	Combined	100	12.478	2.79738	11.69	3.03352	11.53	3.39603	8.54483	3.2731	7.41662	3.03028	12.28	3.7426	1152.669
15WE	0	Combined	486	11.28	4.35101	9.444	4.16465	7.45	3.34199	5.72425	3.268017	5.02364	3.06815	7.821	9.5025	3622.998
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	1	Car	137	8.8182	3.00659	7.915	2.67415	13.15	4.1521	10.439	4.172543	9.29197	3.90482	14.226	3.9608	1801.499
14WE	1	Car	41	10.922	3.5583	9.859	3.2367	13.69	4.32776	10.2002	4.478189	9.02409	4.10794	14.195	1.5373	561.2966
15WE	1	Car	354	10.055	4.08357	8.501	3.63397	8.28	3.33802	6.43676	3.336718	5.69347	3.13768	8.5226	6.9235	2932.105
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	2	Bus	118	12.446	1.14821	12.34	1.1291	8.42	0.76799	6.31059	0.751408	5.40593	0.71201	9.5085	3.4062	993.4688
14WE	2	Bus	58	13.641	1.16461	13.55	1.1384	9.93	0.83275	7.30443	0.840479	6.22134	0.76733	10.862	2.1678	576.1216
15WE	2	Bus	119	15.273	2.26478	14.96	2.15469	4.70	0.67113	3.28037	0.658747	2.7396	0.61094	5.5714	2.3251	559.4027

As illustrated in Table 12 and Figure 60, BRT scenario 2B in blue, an improvement in travel time was observed for the BRT over the existing PT of 2.77 minutes when compared to that of the Base year scenario, in red. The combined travel time worsened by 0.54 minutes over 1.7 kilometres. This was mainly due to the vehicles travelling in mixed traffic with the private car worsening by 2.99 minutes from that of the Base year's travel time. The scheduled bus line service on its dedicated road space helps its travel time considerably and is 8.42 minutes, which was 4.73 minutes faster than the private car of 13.15 minutes.

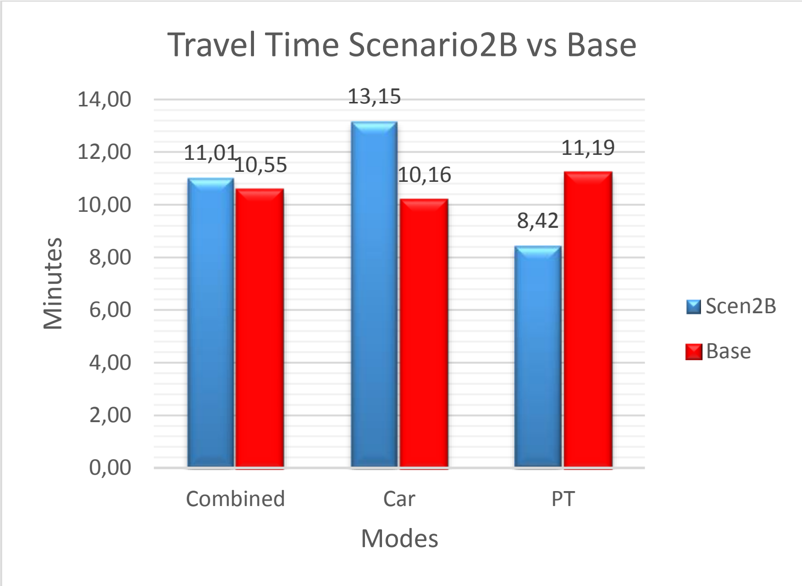


Figure 60: BRT Scenario 2B (blue) and Base year (red) travel time

This BRT scenario 2Bs combined travel speed is 10.46 km/h with an approximate V/C ratio of 0.95 [-] that corresponds to a LOS E. This illustrates that conditions have remained similar to that of the Base year's LOS E.

4.2.6. <u>BRT Scenario 2C</u>

The BRT scenario 2C has an identical network to the BRT scenario 2B. This scenario also shares the same BRT service as the BRT scenario 2B. This scenario tests a 20% reduction in private vehicle trip demand, in the morning peak hour, from that of the Base. NDoT (2007) is targeting a 20% reduction in private car trips during the peak hours. A segment of the network from the BRT scenario 2C can be seen in Figure 61 from AIMSUN.

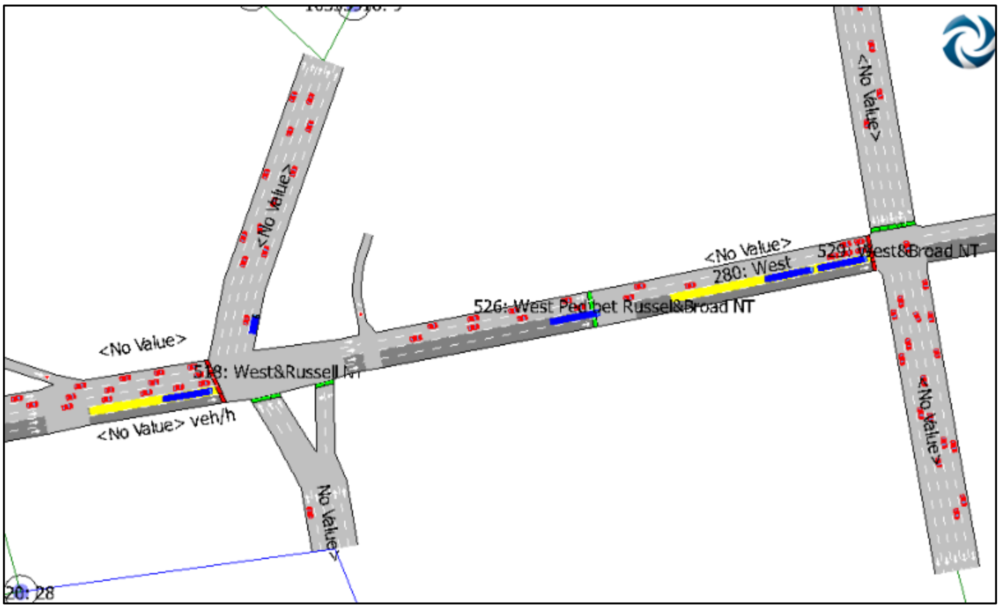


Figure 61: BRT Scenario 2C snapshot from AIMSUN

Table 13: Output of the criteria for BRT Scenario 2C for each mode.

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	0	Combined	282	15.034	2.71443	14.54	2.67337	7.15	79.2441	281.953	95.24981	239.771	85.4663	7.1099	488.84	121000.7
14WE	0	Combined	112	16.394	3.02897	15.87	2.87202	8.49	88.7092	326.432	114.4363	276.221	99.311	8.2589	251.56	57035.06
15WE	0	Combined	502	19.436	3.73856	18.63	3.87619	3.78	50.2044	124.129	58.37056	97.8003	53.4395	3.7948	588.69	113755.7
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	1	Car	159	16.935	1.8284	16.74	1.80609	6.22	40.5005	209.147	40.81367	175.142	35.034	5.673	275.78	59309.92
14WE	1	Car	51	19.156	1.9798	18.96	1.90834	7.12	42.5581	213.641	45.88391	179.029	37.1305	6.2745	114.72	21777.45
15WE	1	Car	367	20.944	2.74707	20.56	2.82522	3.42	29.3751	96.3945	29.76317	72.4925	25.8046	3.139	430.5	75396.77
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	2	Bus	119	12.451	1.18891	12.33	1.20025	8.43	50.4176	380.086	49.95611	327.366	48.3073	9.084	206.14	60164.04
14WE	2	Bus	59	13.932	1.06478	13.85	1.03365	9.71	42.9459	425.631	44.3125	362.644	39.9933	10.034	132.35	34389.14
15WE	2	Bus	121	14.732	2.24576	14.4	2.16986	4.88	44.3935	208.332	43.99747	176.188	40.9432	5.8347	141.79	35437.68

As illustrated in Table 13 for the column ttime (min) and in Figure 62, BRT Scenario 2C in blue, an improvement in travel time was observed across all modes when compared to that of the Base year scenario, in red. This scenario shows that due to the reduction in private car trips, the travel time for the private car was improved when compared to the base and to the BRT scenario 2B. The BRT or PT travel time remain the same. Therefore, with the use of TDM measures to make a reduction in private vehicles by 20% as targeted by NDoT (2007), an improvement is shown. The combined travel time improved by 3.86 minutes when compared to the BRT scenario 2B from 11.01 minutes to 7.15 minutes. This BRT scenario 2Cs combined travel speed is 15.03 km/h with an approximate LOS of 0.55 [-] V/C ratio which corresponds to a LOS D. This is a great improvement from the Base year's LOS E.

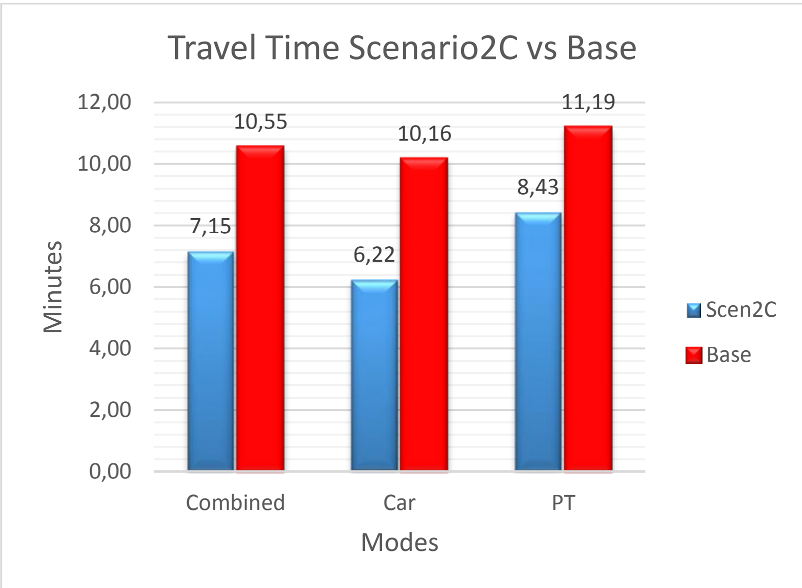


Figure 62: BRT Scenario 2C (blue) and Base year (red) travel time

4.2.7. BRT Scenario 2D

The BRT scenario 2D is a scenario similar to the BRT scenario 2A but with two additional NMT lanes. The BRT demand is the same as the BRT scenario 2A with a scheduled bus service travelling every 30 seconds along the corridor to transport the existing demand of passengers along a dedicated route on Dr Pixley KaSema Street. For this scenario, the truck demand was removed and private vehicle trips remained the same as the Base year scenario. A segment of the network from the BRT scenario 2D can be seen in Figure 63 from AIMSUN.

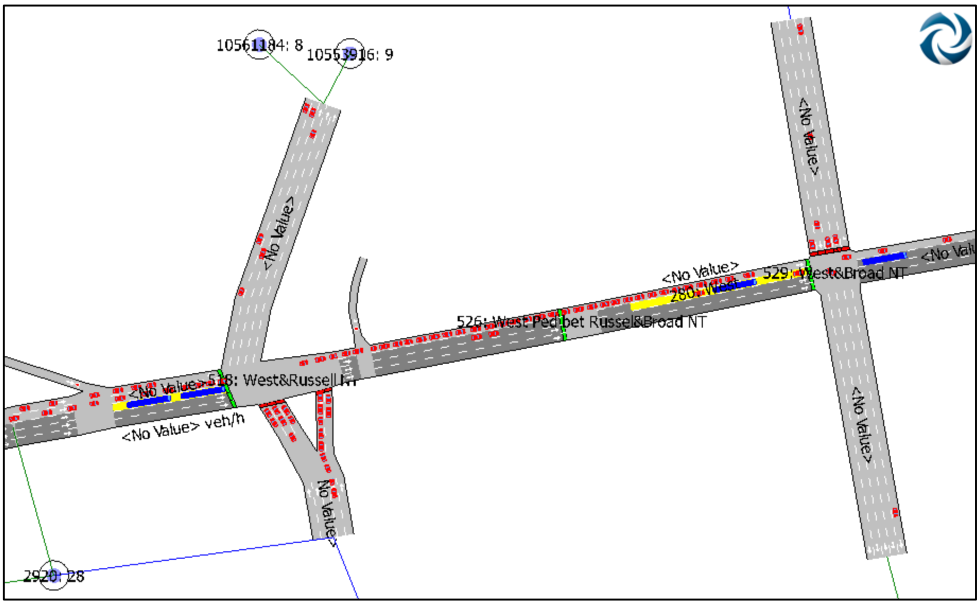


Figure 63: BRT Scenario 2D snapshot from AIMSUN

Due to the reduced capacity for the private vehicles, the model did not function well. Various changes were made to the scenario to make the scenario work, but the model did present a small bug with the BRT buses behaving very strangely with buses going slightly left of the lane at William Street and Dr Pixley KaSema Street needing a bit of general traffic lane for the scenario to work well. This is illustrated in Figure 64. This proved that with the reduction of capacity, by reducing the number of lanes, along a microscopic simulation model with a single corridor will not function well with the same private traffic. Demand along the corridor caused the BRT lane to not function. This was due to a single corridor modelled in the microscopic simulation model, the traffic within the model could not use alternative routes. The spillover of the BRT is an error in the model as can be seen in Figure 64.

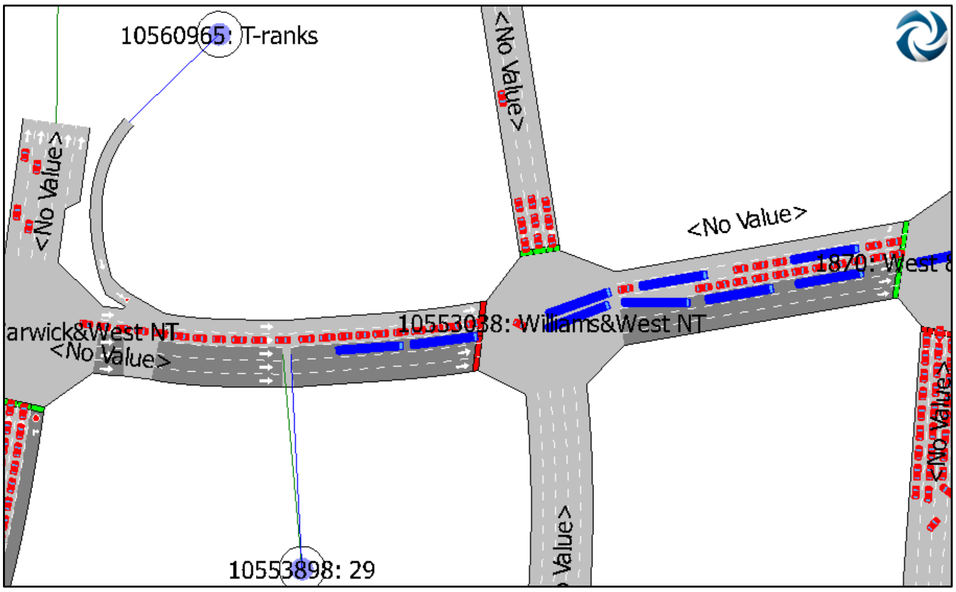


Figure 64: BRT Scenario 2D snapshot of the error with the BRT in AIMSUN

Table 14: Output of the criteria for BRT Scenario 2D for each mode.

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	0	Combined	47	6.3127	2.3639	5.606	1.98995	18.58	6.12376	15.9555	6.031167	14.9332	6.10622	14.936	1.3596	873.1078
14WE	0	Combined	23	8.072	3.20174	7.144	2.57494	18.90	6.04769	15.7132	6.008629	14.5223	5.93496	15.174	0.8625	434.7283
15WE	0	Combined	180	6.0498	1.52761	5.678	1.45208	12.42	3.2591	10.6151	3.235007	9.94417	3.36151	11.1	3.5259	2235.951
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	1	Car	44	6.131	2.18504	5.51	1.85035	18.90	5.96687	16.2366	5.902333	15.2009	5.99189	15.409	1.273	831.7838
14WE	1	Car	19	7.2764	2.38344	6.721	1.93213	20.10	5.2796	16.7767	5.37575	15.5237	5.36587	16.526	0.7129	381.8637
15WE	1	Car	177	5.973	1.41302	5.635	1.38046	12.52	3.19827	10.7034	3.18786	10.0306	3.321	11.186	3.4674	2215.788
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	2	Bus	3	8.9785	3.80646	7.554	3.27992	13.77	7.75137	11.8338	7.771521	11.0083	7.8093	8	0.0867	41.32403
14WE	2	Bus	4	11.851	4.24731	10.19	4.11452	13.22	6.98587	10.6612	7.08333	9.76563	7.00243	8.75	0.1496	52.8646
15WE	2	Bus	3	10.576	1.37764	10.45	1.16248	6.72	0.95626	5.40526	0.970978	4.84167	1.02853	6	0.0585	20.1625

As illustrated in Table 14 and Figure 65, BRT Scenario 2D in blue, showed a large increase in travel time across all modes when compared to that of the base year scenario, in red. The BRT travel time was expected to remain constant but due to the drastic reduction in capacity for the private vehicles, some vehicle spill over onto the BRT lane. Sections of the BRT also function strangely due to the relatively high volume of private traffic trying to squeeze into one lane as seen in Figure 64. The combined travel time worsened by 8.03 minutes over 1.7 kilometres. The decrease in capacity for the two additional NMT lanes had detrimental affects for all modes using the corridor. This BRT scenario 2Ds combined travel speed is 6.31 km/h of with a maximum V/C ratio of 1 [-] which corresponds to a LOS F. This illustrates that conditions have worsened from the Base year's speed of 10.54 km/h and LOS.

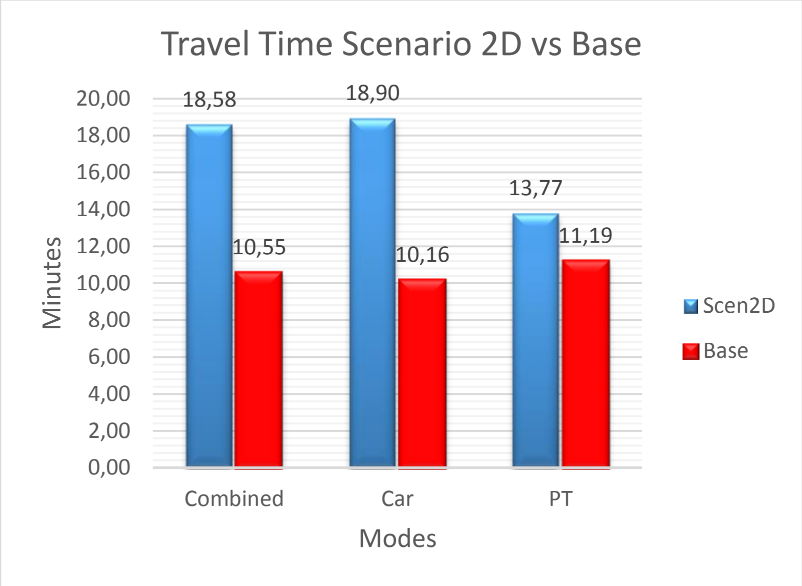


Figure 65: BRT Scenario 2D (blue) and Base year (red) travel time

4.2.7.1. BRT Sub-scenario 2D

The BRT sub-scenario 2D is a scenario similar to the BRT scenario 2D with two additional NMT lanes. The BRT demand is the same as the BRT sub-scenario 2D with a scheduled bus service travelling every 30 seconds along the corridor to transport the existing demand of passengers along a dedicated route on Dr Pixley KaSema Street. This sub-scenario was tested with a redistributed demand from EMME for the private cars, but instead of increasing the capacity as done in 2A, the capacity was reduced from 5000 to 2500. This was due to the two additional NMT lanes and the BRT lane reducing the existing capacity greater than half its original capacity from that of the Base year scenario. This scenario was done to portray the possible re-routing of traffic due to the reduction in capacity. A segment of the network from the BRT scenario 2D can be seen in Figure 66 from AIMSUN.

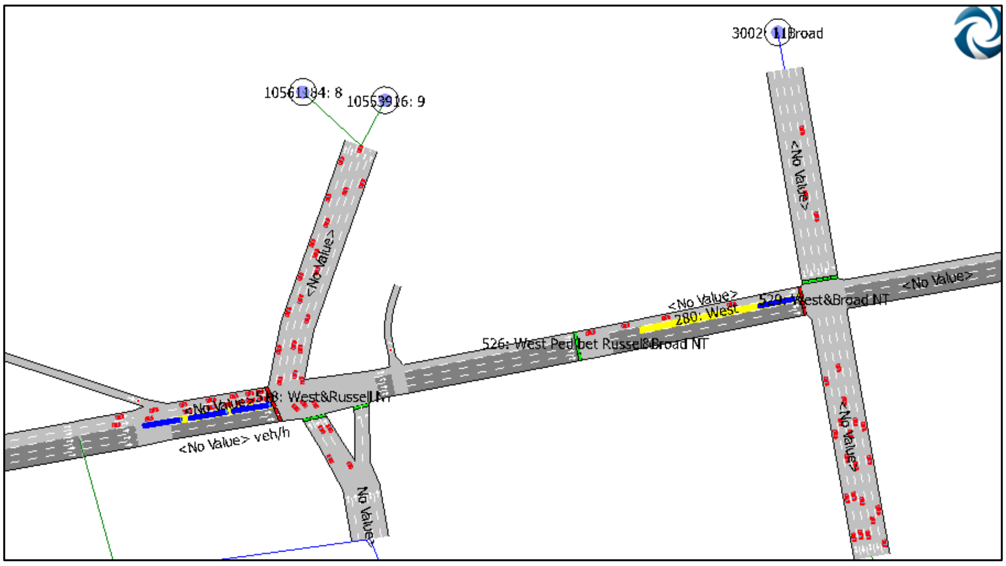


Figure 66: BRT Sub-scenario 2D snapshot from AIMSUN

Table 15: Output of the criteria for BRT Sub-scenario 2D for each mode.

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	0	Combined	131	14.592	3.0647	14.2	2.36092	7.32	0.9683	5.12585	1.132834	4.33492	0.97838	7.3282	3.7824	958.9519
14WE	0	Combined	61	15.756	0.58937	15.73	0.58819	8.55	0.32707	5.88385	0.44205	4.92459	0.44711	8.7377	2.2805	521.7949
15WE	0	Combined	224	19.363	4.97614	18.25	4.51082	3.85	0.89193	2.21602	1.10138	1.80558	0.95809	3.8661	4.3773	863.346
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	1	Car	19	20.517	4.7961	19.57	4.31403	5.32	1.1299	2.59973	0.830918	2.23618	0.87728	3.7368	0.5492	101.0448
14WE	1	Car	1	17.97	0	17.97	0	7.50		4.03225		3.3125		7	0.0374	7.495056
15WE	1	Car	111	23.667	3.52826	23.21	3.24079	3.03	0.40366	1.1716	0.40451	0.89955	0.33404	2.3874	2.1716	336.7604
eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	2	Bus	112	13.586	0.48962	13.57	0.50314	7.66	0.29759	5.55439	0.336789	4.69096	0.33826	7.9375	3.2333	857.9072
14WE	2	Bus	60	15.719	0.5184	15.7	0.52641	8.57	0.29911	5.91471	0.373688	4.95146	0.39814	8.7667	2.2431	514.2999
15WE	2	Bus	113	15.135	0.8263	15.08	0.92045	4.66	0.31913	3.24196	0.333928	2.69558	0.32461	5.3186	2.2056	526.5856

As illustrated in Table 15 for the column ttime (min) and in Figure 67, scenario 2D in blue showed an improvement in travel time across all modes when compared to that of the base year scenario, in red. There was a combined travel time improvement from 10.55 minutes to 7.32 minutes, with a difference of 3.23 minutes. This scenario illustrates suppressed traffic demand. The private cars divert from this corridor when the *virtual* capacity is constrained in EMME as they find alternative faster routes as described by Noland (2001).

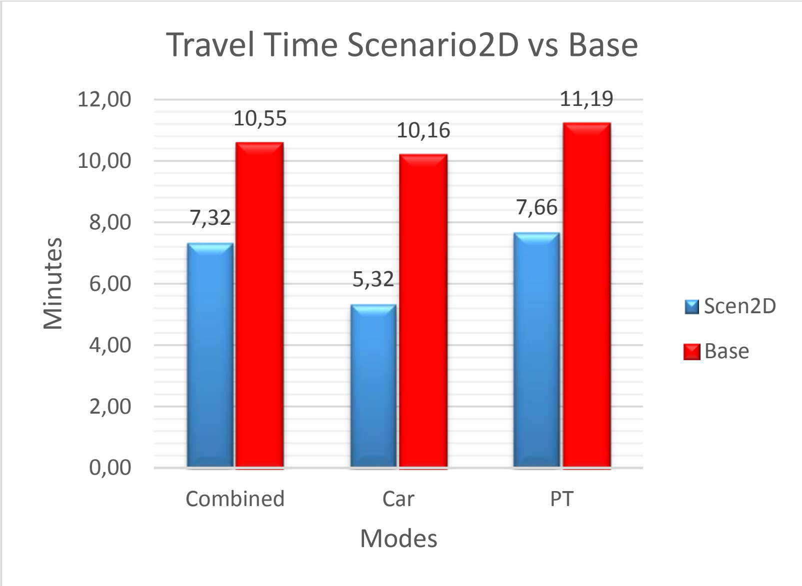


Figure 67: BRT Sub-scenario 2D (blue) and Base year (red) travel time

With the use of the reduction in capacity and the redistribution of traffic from EMME, the BRT sub-scenario 2D was aided to perform well. This scenario successfully illustrates suppressed traffic, where traffic was diverted away from this corridor. Due to the capacity being reduced to a two NMT lane and a BRT lane, this corridor will become less attractive for private cars. This BRT scenario 2B's combined travel speed is 14.59 km/h with an approximate V/C ratio of 0.61 [-] which corresponds to a LOS D. This is an improvement from the Base year's LOS E.

A comparison between the BRT Scenario 2D and the BRT sub-scenario 2D shows a good example of suppressed traffic. These scenarios are identical in terms of the network and the BRT service. Both have a BRT lane and two NMT lanes. When comparing these two scenarios it can be seen that the traffic diverts away from this corridor thereby improving the traffic flow drastically from the BRT scenario 2D to the BRT scenario 2D, as illustrated in Figure 68. Due to the traffic in the network being very congested in the BRT scenario 2D, the reduced flow from the reduction in traffic from EMME, aided the BRT to function well.

The BRT flow could operate with a largely improved inflow of 109 vehicles from 3 to 112 vehicles from BRT scenario 2D to the BRT scenario 2D. This allows the BRT to operate optimally. The combined flow in the network improved by 84 vehicles, from 131 to 47. The private car traffic flow decreased by 25, from 44 to 19 vehicles in the BRT scenario 2D. Therefore, for a decrease in capacity of 50% the private vehicle traffic decreases by 57%. Note that the BRT scenario 2D was substantially congested with the general traffic overflowing onto the BRT lane and BRT buses overflowing onto the private car lanes.

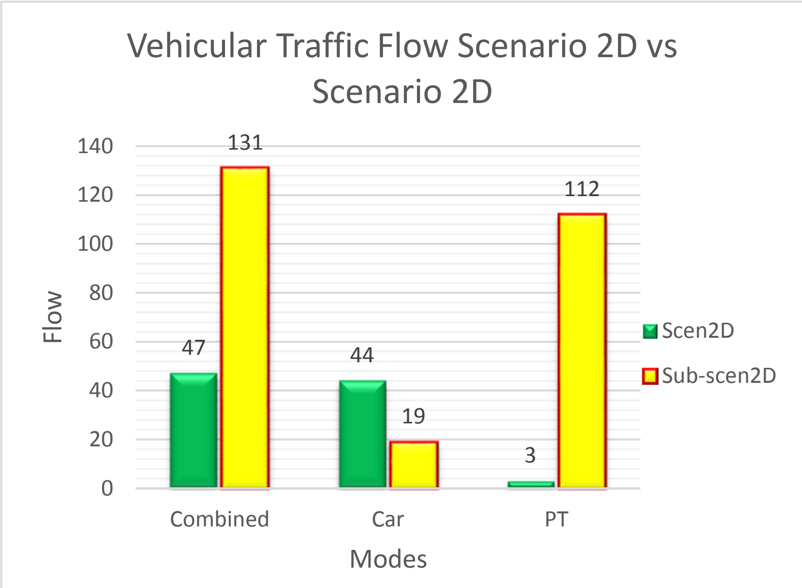


Figure 68: BRT Scenario 2D (green) and BRT Sub-scenario 2D (yellow) travel time

The comparison between the BRT scenario 2D and BRT sub-scenario 2D illustrated an improvement in travel time across all modes in the scenario, as illustrated in Figure 69. The travel time for the BRT scenario 2D are blue bars and BRT sub-scenario 2A are the light blue bars as illustrated in the bar graph in Figure 69. The private car travel times improves in the BRT sub-scenario 2D from 18.9 to 5.32 minutes, giving a difference of 13.58 minutes. The BRT service also improves in travel time from 13.77 to 7.66 minutes, giving a difference of 6.11 minutes from the BRT scenario 2D to BRT sub-scenario 2D. The reduction in capacity and the redistribution of traffic in EMME helped the BRT sub-scenario 2D to perform better as illustrated from the BRT scenario 2D.

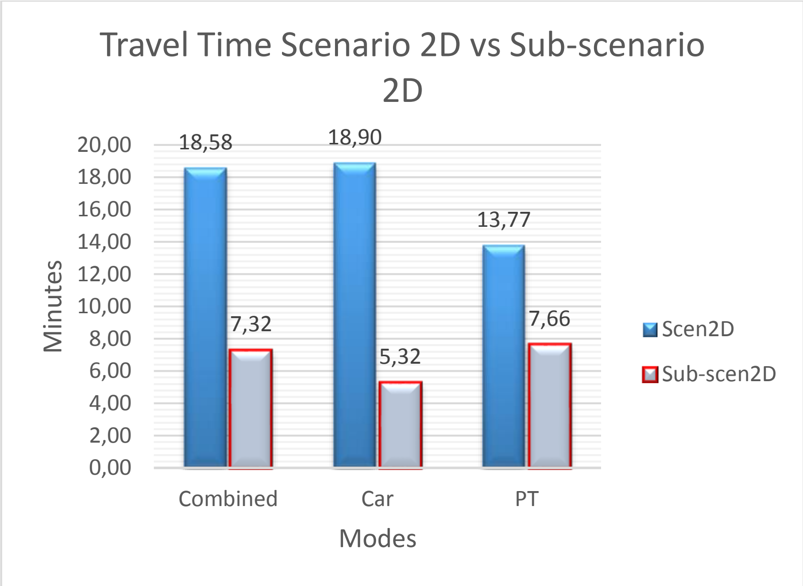


Figure 69: BRT Scenario 2D (blue) and BRT Sub-scenario 2D (light blue) travel time

This scenario successfully illustrates suppressed traffic, where traffic is diverted away from this corridor. Due to capacity being reduced in EMME for two NMT lanes and a BRT lane, this corridor will become less attractive to private cars as illustrated in the BRT sub-scenario 2D which may replicate reality.

4.2.8. MTS Scenario 3A

This scenario is a mini-bus taxi service (MTS) scenario with the removal of buses. This is similar to how the PT demand was converted to buses in scenarios 1A and 1B. The total calculated PT passenger demand of 42811 trips for the morning peak hour was converted to taxi vehicles trips. This was done by dividing this by 15, the maximum taxi occupancy. This resulted in 2854 taxi vehicles to transport the passengers along and through the study area. By optimising the amount of mini-bus taxis in the base year from 3363 and adding the busses passenger demand. The new service showed less congestion to that of the base year due to the fewer taxis and no buses in the network. The private car demand for this scenario is the same as the Base year scenario as this scenario is very similar to the base year scenario. A segment of the network for this scenario is shown in Figure 70 from AIMSUN.

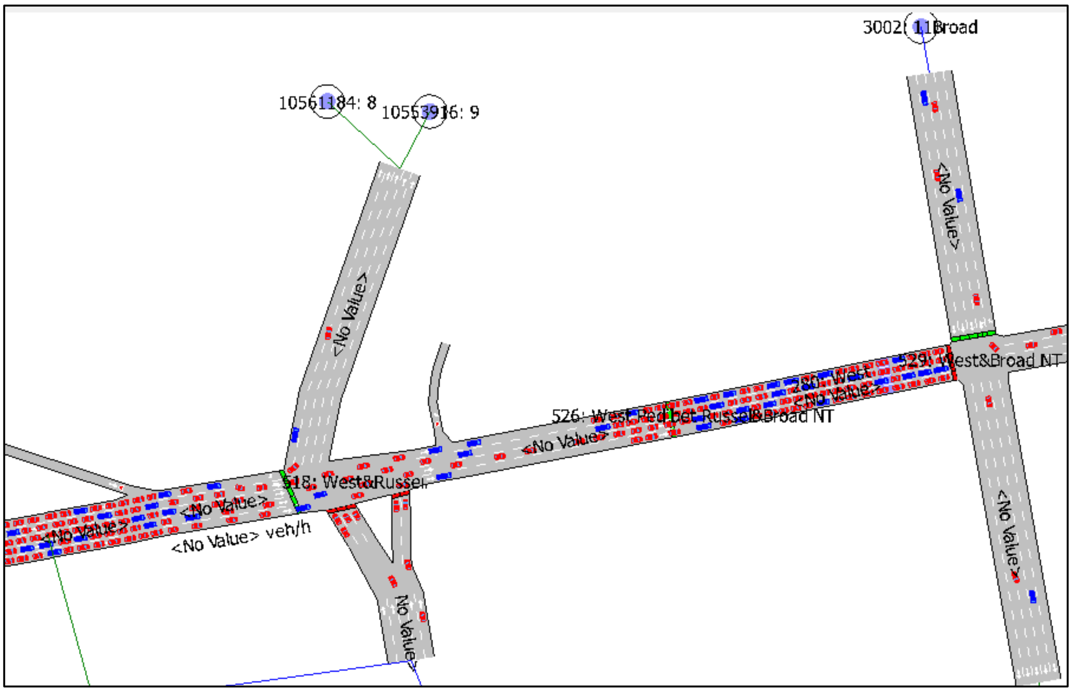


Figure 70: MTS Scenario 3A snapshot from AIMSUN

Table 16: Output of the criteria for MTS Scenario 3A for each mode.

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	0	Combined	374	11.49	1.8362	11.2	1.78535	9.29	88.9006	364.495	80.4584	308.549	89.9335	8.8209	648.59	208414.6
14WE	0	Combined	145	12.89	2.05138	12.55	2.04056	10.77	107.686	389.211	79.93566	329.343	94.9769	9.8207	326.61	93662.07
15WE	0	Combined	775	11.66	2.63858	11.1	2.49012	6.34	84.6561	251.344	78.22162	213.342	87.0544	5.9019	909.11	294755.1

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	1	Car	225	11.90	1.76564	11.65	1.69145	8.92	76.2611	375.137	75.23866	298.55	73.9226	8.6089	390.06	120481.4
14WE	1	Car	83	13.70	1.809	13.47	1.7477	10.03	77.314	396.18	75.67277	312.886	73.7069	9.2892	186.96	49952.02
15WE	1	Car	489	12.08	2.64654	11.55	2.48469	6.09	76.964	255.614	76.48477	204.279	74.3752	5.8119	573.26	178699.6

eid	sid	Mode	flow	speed	speed_D	spdh	spdh_D	ttime (m)	ttime_D	dtime	dtime_D	stime	stime_D	nstops	travel	traveltime
13WE	3	Taxi	144	10.83	1.75007	10.56	1.70951	9.86	96.3546	345.989	84.37773	323.557	108.948	9.1458	249.86	85207.1
14WE	3	Taxi	60	11.75	1.82796	11.46	1.81356	11.79	114.455	376.954	83.21975	351.362	115.385	10.583	135.15	42455.54
15WE	3	Taxi	271	10.89	2.43646	10.38	2.31587	6.79	91.1803	241.39	79.72052	229.328	104.607	6.0369	318.25	110403

As illustrated in Table 16 for the column ttime (min) and in Figure 71, the MTS Scenario 3A in blue showed an increase in travel time across all modes when compared to that of the base year scenario, in red. The taxi travel time improved by 1.33 minutes, from the Base year's of 11.19 minutes to 9.86 minutes. The private car travel time improved by 1.24 minutes, from that of the Bbase year of 10.16 minutes to 8.92 minutes. The combined travel time had an improvement of 1.26 minutes. It can be seen from Table 16 and Table 4, that the flow of the private car travelling through the corridor increased slightly by 24 vehicles from 201 to 225 vehicles. With fewer mini-bus taxis in this scenario there is less congestion to that of the Base year hence the flow of the mini-bus taxis in this scenario also increased by 10 from 134 to 144 mini-bus taxis.

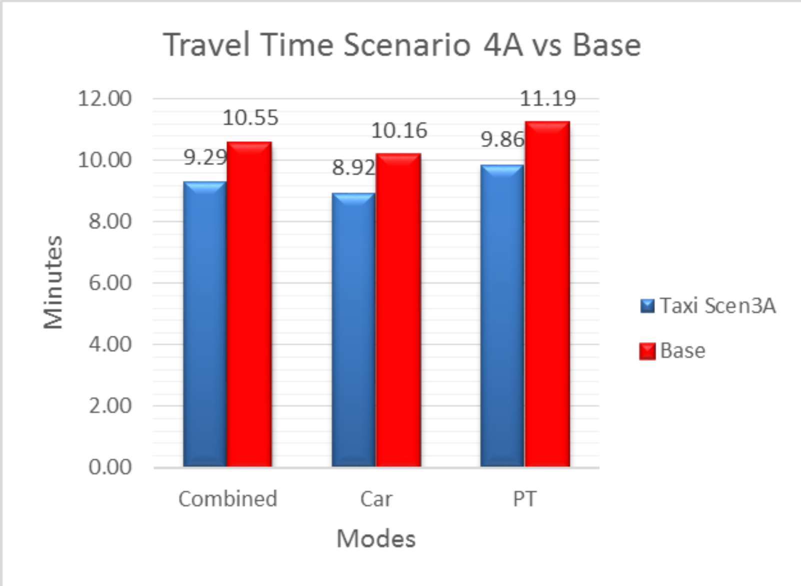


Figure 71: MTS Scenario 3A (blue) and Base year (red) travel time

The Taxi service will be operating at capacity. With no more space for additional taxis and stops along the entire length of the corridor to drop off passengers, this scenario will be rendered more unsafe than the existing Base scenario and BRT scenario 2A. This scenario's combined travel speed is 11.49 km/h with an approximate V/C ratio of 0.90 [-] which corresponds to a LOS E. This illustrates that conditions are similar to that of the Base years LOS E. The MTS was modelled with similar driver behavior to that of the Base year scenario. Therefore, the conditions may have improved slightly to that of the Base year scenario due to fewer mini-bus taxis on the road. However, this scenario did not function well when it was modelled similar to that of the BRT and QBS scenarios with dedicated bus stops along the corridor. This is because the MTS required too large platform sizes with the mini-bus taxis congesting the corridor to stand still conditions with its aim to drop off and pick up passengers along one lane. Therefore, the QBS scenario 3A is not a viable alternative as the current operations are unsafe, unpredictable and operate as para-transit service. In addition, this service cannot be a formalised MTS for this corridor due to its high passenger demand.

4.2.9. <u>Comparison between the scenarios and summary</u>

A comparison between all the scenarios with the objective to reallocate or prioritise road space for PT is given. The two main KPI's that were used to compare the scenarios are travel time and LOS. In each of the scenarios they were compared to the Base scenario. The figures below show the comparison of these KPI's with each of the various scenarios tested.

The combined averaged travel time for each of the scenarios is illustrated in Figure 72. It can be seen that the QBS scenario 1A, BRT scenario 2A, BRT scenario 2C, BRT sub-scenario 2D and MTS scenario 3A have a combined improved travel time over the base year scenario. Note that 20% less private vehicles in BRT scenario 2C was tested. The QBS sub-scenarios 1A, the QBS scenario 1B with 1 NMT lane and the BRT scenario 2D with two NMT lanes have travel times that have worsened considerably for the combined modes when compared to that of the base year.

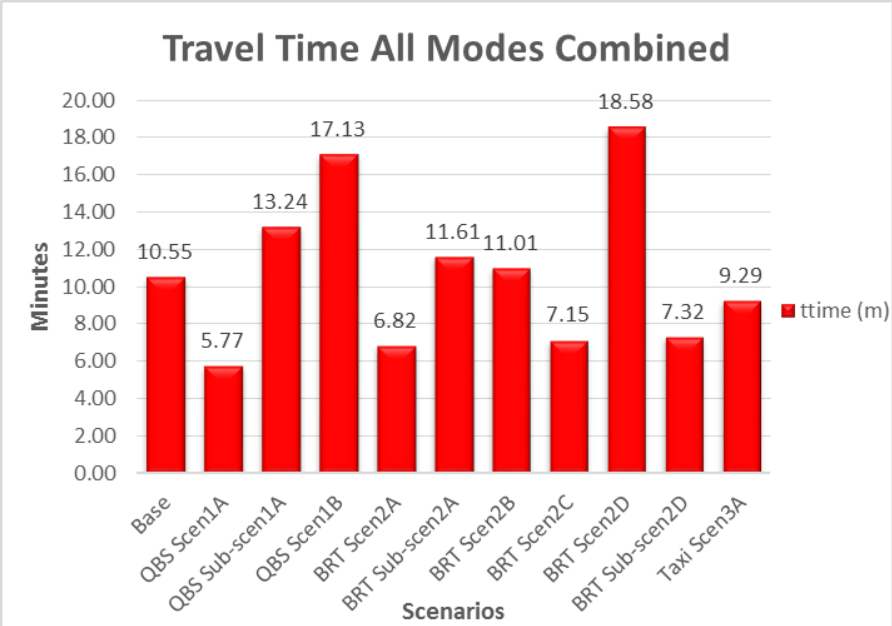


Figure 72: Travel time of all the modes combined for each scenario

The travel time for the private car has a similar pattern to that of the combined travel time. The travel times for the private cars and the travel times for the PT vehicles along the corridor for each scenario are illustrated in Figure 73 and Figure 74 respectively. The comparison between private car travel time and PT travel times are similar in most scenarios, were the PT travel time are within 1-3 minutes higher than the private car travel time. An exception however, is the BRT scenario 2B and the BRT scenario 2D where the PT travel times are substantially lower than that of the private vehicle travel times. This shows that even if the road gets very congested or even abnormally congested, the PT system will still operate under good travel times on its own dedicated right of way.

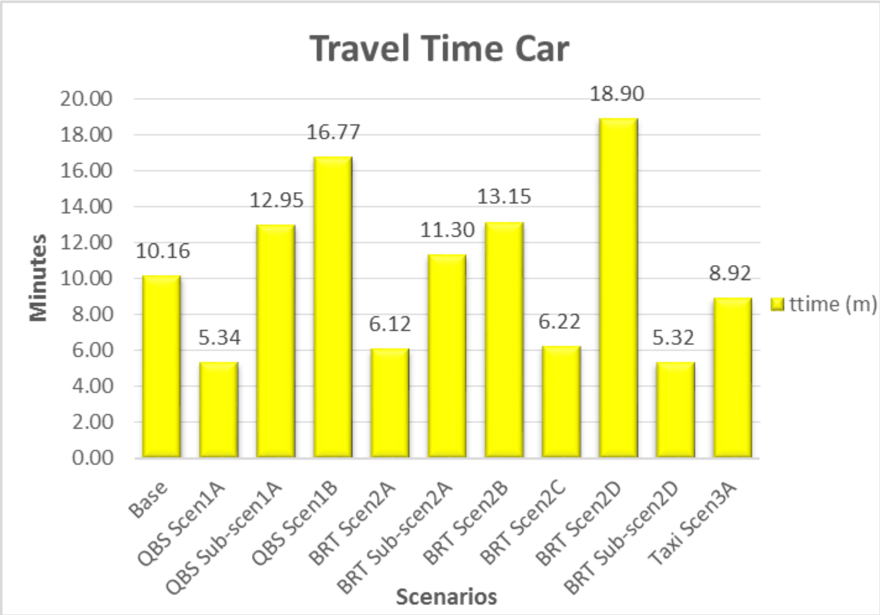


Figure 73: Travel time of the private car for each scenario

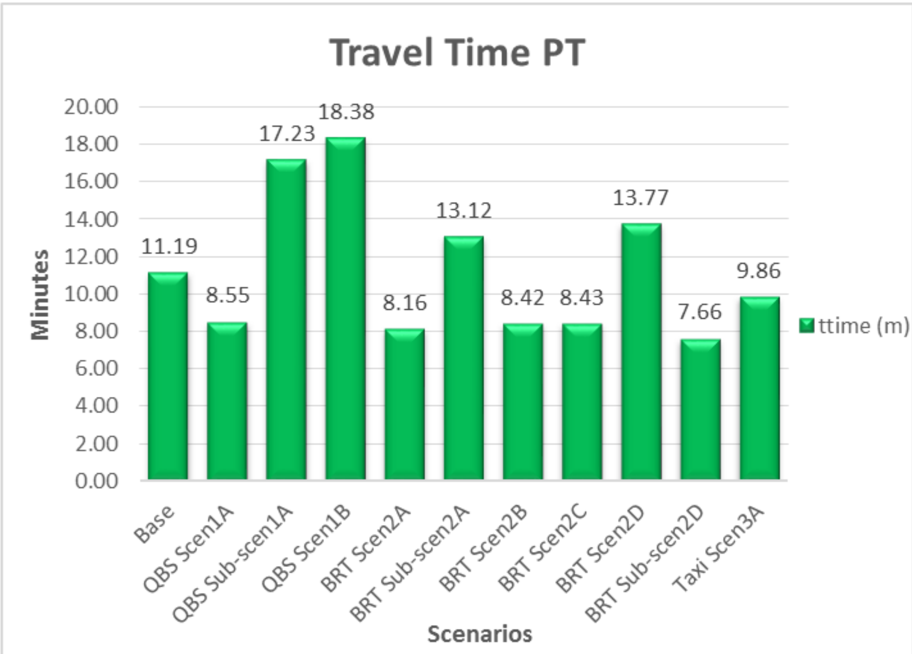


Figure 74: Travel time of PT for each scenario

The comparison of the PT vehicles travel time between each of the scenarios, as illustrated in Figure 74, show that the BRT scenarios 2A, 2B and 2C offers improved travel times due to its dedicated right of way. The BRT sub-scenario 2D illustrates the best PT travel time amongst all of the scenarios tested. The QBS scenario 1A, the BRT scenarios 2A, 2B, 2C, sub-scenario 2D and the MBS scenario 3A all show improvements in travel times from the Base. The re-run of scenarios after an increased capacity change from the macroscopic model show that the PT in the QBS sub-scenario 1A is significantly worse than the PT in the BRT sub-scenario 2A. Therefore illustrating that PT with its own dedicated right of way yields better results when traffic conditions along the corridor worsens.

The V/C ratio for each of the scenarios are shown in Figure 75. The QBS scenario 1A shows the best overall V/C ratio of zero which corresponds to a LOS A. The BRT scenario 2A also shows a very good V/C ratio of 0.42 [-] which corresponds to a LOS C. The BRT Scenario 2C and BRT Sub-scenario 2D show a similar V/C ratio that corresponds to a LOS D. The MTS scenario 3A show a slight improvement in the V/C ratio to the base year but with the same LOS E. The rest of the scenarios illustrate V/C ratios that were worse than the current base year.

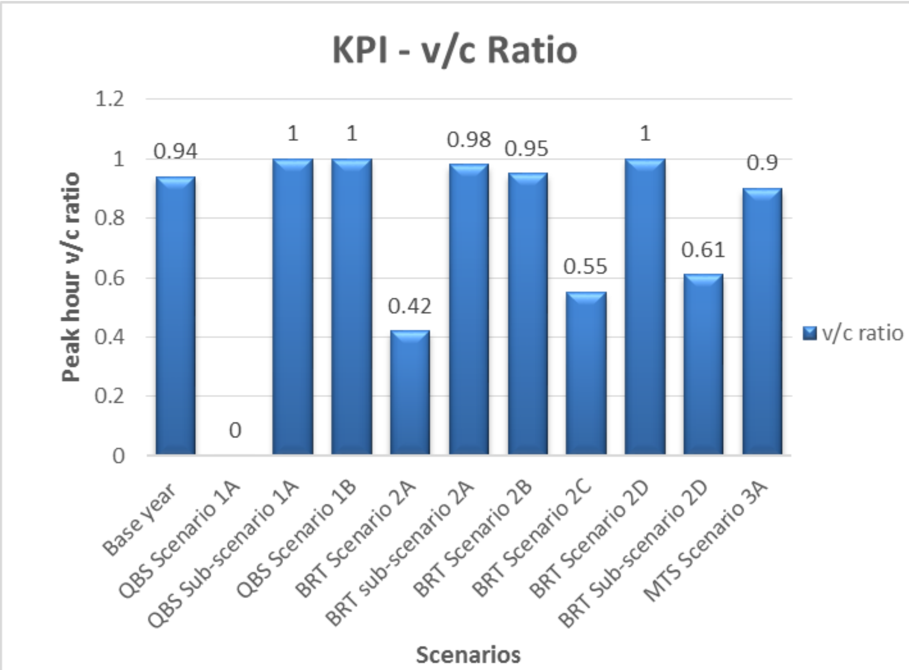


Figure 75: KPI LOS – V/C Ratio

The sub-scenario 2A did not perform as anticipated with the BRT maintaining its travel time similar to that of scenario 2A due to its own right of way. This was due to the high volume of private vehicles spilling over onto the BRT lane along the corridor. Note this was only in the model, but in reality, the prevention of cars on the BRT lane could be policed and a reduction in private cars along the corridor may occur over time due to the high congestion. A significant amount of time went into trying to prevent the spillover of private care onto the PT prioritised areas and ensure that PT flow and travel time was maintained, but due to the extent of the high volume of private cars this was the best it could have been modelled for this research.

Although QBS scenario 1A shows an improvement over the Base, once an NMT lane is added the scenario does not perform well. Overall, it can be seen that the BRT scenarios perform quite well among each of the scenarios tested. The BRT scenarios show a net benefit for all modes using the corridor. Scenarios 2B and 2C show that a BRT system with an NMT lane, a BRT lane and two private car lanes can function quite well. Furthermore, the testing of the suppression of traffic as tested in the sub-scenario 2D illustrates that the private cars can shift to alternative routes to the rest of the network. This will make the ultimate situation better for all modes along the corridor. Other corridors outside the study area were affected by the changes done in each of the scenarios modelled. These were not discussed in this research.

4.3. High level costing

A minor costing exercise was completed. This was based on the maximum PT link volume used in all scenarios of 12760 passenger trips along the corridor in the morning peak hour. The costing was done for the MTS scenario 3A with a vehicle capacity of 15 from the QBS scenario 1A, the 9-meter QBS with a vehicle capacity of 60 from QBS scenario 1B and the 18m articulated BRT service with a vehicle capacity of 120 from the BRT scenario 2B. The speeds for the PT vehicles were taken from each of the scenarios from row 14WE from each of the respective tables for the scenarios tested. The distance was fixed for all of the scenarios at an average of 2.1 kilometres and giving a return distance of 4.2 kilometres. The total amount of vehicles required for each mode is 305 mini-bus taxis, 107 (9m) buses or 33 articulated buses. This information is illustrated in Table 17.

Table 17: Vehicle costing part A

Scenarios	Variable Cost (R) per Km	Vehicle Cost (Mil)	Capacity	Fixed PT Demand	Distance Round trip (km)	Speed km/hr.	Cycle time	Vehicle Trips (Dem./Cap)	Vehicles
	Assumed	Research / Assumed	Model	Model	Model	Model	Dist. / Speed	Demand / Capacity	Cycle Time * Veh.Trips / 60
Taxi Scen 3A	5	0.4	15	12760	4.2	11.75	21.4468	851	305
9m QBS Scen 1B	10	1.4	60	12760	4.2	8.39	30.0358	213	107
18m BRT Scen 2B	18	3	120	12760	4.2	13.64	18.4751	107	33

The costing was based on Table 17 with the various variables taken into consideration such as distance, vehicle trips, vehicle cost per kilometre and variable costs. Table 18 describes the costing of the 3 PT services continued from Table 17. The initial capital cost required to purchase the total vehicles required for each of the scenarios were R122.0 Million (M) for the taxis required, R149.8M for the QBS required and R99.0M for the articulated buses required. The total operating cost for the budget for each scenario for the morning peak hour is R17 871.0M for the taxi scenario, R8 946.0M for the QBS scenario and R8 089.2M for the BRT scenario. Adding the fixed costs (Capital costs per hour), the overhead costs and the variable costs gives R 58 214.9M for the taxi scenario, R58 483.0M for the QBS scenario and R40 827.3M for the BRT scenario. The total cost per annum is R73.4M for the taxi scenario, R73.7M for the QBS scenario and R51.4M for the BRT scenario. Therefore, the BRT scenario has the lowest cost when compared to the other scenarios tested. The QBS and taxi scenario costs are higher than that of the BRT scenario, with the QBS scenario being slightly more expensive than the taxi scenario.

Table 18: Vehicle costing part B – Capital and operating cost based on 1 year.

Scenarios	Vehicle Cost (Million)	Operating Variable Cost	Fixed and overhead cost (F&O)	Fixed Cost	Fixed + Overhead and Variable Costs (X)	Total cost per annum (Million)
	Veh. * Veh. Cost	Veh.Trips * Dist. * Var Cost	Veh. Cost / 12Month / 21days / 12hrs	F&O * Vehicles	Operating Var. Cost + Fixed Cost	(X) * 12 month *21days * 5peak hrs.
Taxi Scen 3A	R 122.00	R 17 871.00	132.2751323	R 40 343.92	R 58 214.92	R 73.35
9m QBS Scen 1B	R 149.80	R 8 946.00	462.962963	R 49 537.04	R 58 483.04	R 73.69
18m BRT Scen 2B	R 99.00	R 8 089.20	992.0634921	R 32 738.10	R 40 827.30	R 51.44

4.4. Conclusion

The model and the costing shows that the 18m BRT scenario 2B with an NMT lane and with this level of PT demand is the most favourable as it has the lowest cost the fastest speed and the lowest travel time when compared to the other scenarios. The BRT scenario 2A exhibits a LOS C which is the second best performing LOS among all the scenarios tested, with the QBS scenario 1A having the best performing LOS A. The high PT demand favours PT systems that can carry higher demands due to it being much more efficient. In prioritising road space for PT, the BRT scenario proves to be the overall most successful. Although BRT scenario 1A has the second best performing LOS and would yield the lowest cost, this scenario could possibly attract more private vehicle traffic into the corridor as illustrated BRT sub-scenario 1A. Therefore, the scenario recommended is BRT scenario with one NMT lane, which is the most robust scenario. The dynamic nature of this priority scheme was modelled using a microscopic simulation model and was represented in scenarios 2B and 2C in this chapter.

5. Conclusion

This research aimed to explore, model and test strategies of road space prioritisation for alternative modes to that of the private car, such as PT and NMT, with an intention to contribute to a more sustainable transportation system in a South African City. This was completed with the literature on road space allocation and transportation modelling was researched and presented. This dissertation went on to develop a conceptual connection between a microscopic model and a macroscopic model with the use of the capacity in each of the models. The most appropriate modelling techniques for the calibration and validation process were used as prescribed by the DMRB standards.

A 2015 Base year model was calibrated to traffic counts and validated with travel time along the corridor of Dr Pixley KaSema Street (West Street) in the CBD of Durban, KwaZulu-Natal. This research presented substantial comparisons between various PT scenarios that were modelled along this corridor. The scenarios tested were a rigid QBS in mixed traffic, a BRT with the associated dedicated infrastructure and a mini-bus taxi service based on current demand. Each of these PT modes scenarios were modelled with various variants with NMT lanes and some sub-scenarios with change in corridor capacity being re-run in the macroscopic model. There were various parameters extracted from the model such as travel time, traffic flow and speed. These parameters were used in the evaluation of the various scenarios.

The results from the modelling showed the BRT scenarios perform well amongst each of the scenarios tested. The study demonstrated that with a 50% increase in capacity on the corridor there is the potential of 56% and 125% increase in private cars along the corridor. This was for the QBS sub-scenario 1A and the BRT sub-scenario 2A, when compared to QBS scenario 1A and the BRT scenario 2A respectively. These scenarios, with the use of a macroscopic model, EMME showed the reality that traffic may be induced into the corridor due to the additional capacity created by the mini-bus taxi service removed. The study also demonstrates that with a decrease in capacity of 50% on the corridor there is a potential of 57% decrease in private cars along the corridor. These trips divert away from this corridor to others with faster travel time. These scenarios successfully depict suppressed and induced demand as described by Noland (2001).

For each of the scenarios that were tested various KPI's such as travel time and LOS were used to compare to that of the Base year scenario. It was illustrated that with the use of the speed-flow curves to determine LOS. The QBS scenario 1A showed a LOS A which is the best LOS over all the scenarios. The second best LOS was for the BRT scenario 2A which corresponded to a LOS C for the combined modes along the corridor. These scenarios showed an improvement from that of the Base year which had a LOS E. The impact from the BRT scenario 2B showed the PT still operated with a good travel time and good flow. This scenario has one NMT lane and dedicated bus lane. The PT travels on its own dedicated lanes and showed an excellent travel time. The combined LOS for this scenario was a LOS E, but this was mainly due to the private vehicles travelling in reduced private vehicle operational lanes.

A costing assessment was undertaken as part of the overall evaluation. The costing was based on three scenarios namely the MTS scenario 3A - a scheduled taxi service with a vehicle capacity of 15, the QBS scenario 1B with a vehicle capacity of 60 and the BRT scenario 2B with a vehicle capacity of 120. The total cost per annum is R73.4M for the taxi scenario, R73.7M for the QBS scenario and R51.4M for the BRT scenario. The BRT scenario proves to be most economical of the three scenarios. The QBS scenario and the taxi scenario had similar costs to each other with the QBS scenario being slightly more expensive. Due to the nature of the BRT with its dedicated right of way and being able to transport high demands more efficiently when compared to the other modes makes this the most favourable for this environment. The BRT scenario 2B is therefore the one recommended, as it is the most appropriate scenario for the demand and has the lowest cost amongst the scenarios tested.

The BRT scenarios display a net benefit for all modes using the corridor. The recommended scenario is to reallocate the existing mixed use road space to two private car lanes, a BRT lane and an NMT lane. These can be seen in scenarios 2B and 2C, which operate effectively. Literature discussed in Chapter 2.2 suggests that the value placed on the reliability of PT services far outweighs that of an improved travel time within vehicles. Therefore, prioritised or dedicated lanes for PT will improve the reliability of the service (Currie *et al.*, 2003).

The constant debate over basic modes for the required road space prioritisation will continually occur with opposing enthusiastic supporters. This refers to one end of the scale favouring PT and criticising private vehicle transport and the other end vice versa (Vuchic, date unknown). It can be understood, and as demonstrated in this study, that endless supply of road infrastructure does not solve congestion because more traffic demand is attracted with more supply (Behrens and Kane, 2004). Therefore, prioritisation of existing road space for more sustainable modes of transport such as PT is required to sustainable economic growth. To deal with the increasing travel needs with growing populations, South African cities are implementing IRPTN's which is a car competitive system. This system will in most cases use existing road space and have reductions in road capacity for the private car. This study has illustrated this service can work in a busy CBD environment. The implementation of these services will give the captive para-transit mini-bus taxi users and car users a viable transport alternative (Behrens and Kane, 2004).

5.1. Recommendations for further research:

This study can be further expanded to a full costing exercise as well as an environmental air pollution exercise which could be developed from each mode with the use of emissions in the AIMSUN. Latest data from research on fuel usage and emissions captured into the model could be used. This emission data could be calibrated, and a determination of which mode could be the most environmentally friendly could be investigated.

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7. Appendix

Traffic count information

P.C.U.'s counted on 2015-May-04 — **Weather: GOOD**

Comments: . .

	MARKET ROAD					KHUZIMPI ROAD EXTE					MARKET ROAD					BUS LINK						
	From North					From South					From East					From West					Intersection	
End Time	**NL**	**NS**	**NR**	**App**	**Dep**	**SL**	**SS**	**SR**	**App**	**Dep**	**EL**	**ES**	**ER**	**App**	**Dep**	**WL**	**WS**	**WR**	**App**	**Dep**	**Total**	
06:15	93	315	0	408	0	0	0	0	0	354	0	0	0	0	127	0	34	39	73	0	481	
06:30	88	386	0	474	0	0	0	0	0	445	0	0	0	0	121	0	33	59	92	0	566	
06:45	91	194	0	285	0	0	0	0	0	260	0	0	0	0	128	0	37	66	103	0	388	
07:00	92	589	0	681	0	0	0	0	0	655	0	0	0	0	119	0	27	66	93	0	774	2209
07:15	146	395	0	541	0	0	0	0	0	445	0	0	0	0	167	0	21	50	71	0	612	2340
07:30	186	332	0	518	0	0	0	0	0	385	0	0	0	0	215	0	29	53	82	0	600	2374
07:45	205	405	0	610	0	0	0	0	0	464	0	0	0	0	226	0	21	59	80	0	690	2676
08:00	158	257	0	415	0	0	0	0	0	322	0	0	0	0	179	0	21	65	86	0	501	2403
08:15	164	306	0	470	0	0	0	0	0	356	0	0	0	0	190	0	26	50	76	0	546	2337
08:30	118	194	0	312	0	0	0	0	0	246	0	0	0	0	134	0	16	52	68	0	380	2117
08:45	124	134	0	258	0	0	0	0	0	194	0	0	0	0	140	0	16	60	76	0	334	1761
09:00	117	145	0	262	0	0	0	0	0	198	0	0	0	0	140	0	23	53	76	0	338	
09:15	112	253	0	365	0	0	0	0	0	304	0	0	0	0	117	0	5	51	56	0	421	
09:30	118	234	0	352	0	0	0	0	0	278	0	0	0	0	120	0	2	44	46	0	398	
09:45	80	270	0	350	0	0	0	0	0	321	0	0	0	0	88	0	8	51	59	0	409	
10:00	112	258	0	370	0	0	0	0	0	308	0	0	0	0	122	0	10	50	60	0	430	
10:15	103	265	0	368	0	0	0	0	0	322	0	0	0	0	119	0	16	57	73	0	441	
10:30	96	505	0	601	0	0	0	0	0	562	0	0	0	0	102	0	6	57	63	0	664	
10:45	125	372	0	497	0	0	0	0	0	435	0	0	0	0	131	0	6	63	69	0	566	
11:00	86	311	0	397	0	0	0	0	0	357	0	0	0	0	97	0	11	46	57	0	454	
11:15	125	290	0	415	0	0	0	0	0	376	0	0	0	0	138	0	13	86	99	0	514	
11:30	95	202	0	297	0	0	0	0	0	272	0	0	0	0	110	0	15	70	85	0	382	
11:45	107	231	0	338	0	0	0	0	0	298	0	0	0	0	117	0	10	67	77	0	415	
12:00	125	204	0	329	0	0	0	0	0	254	0	0	0	0	132	0	7	50	57	0	386	

From North		From West	
NL	NS	WS	WR
629	1721	98	228

Cars counted on 2015-May-04 — **Weather: GOOD**

Comments: . .

	MARKET ROAD					KHUZIMPI ROAD EXT					MARKET ROAD					BUS LINK					
	From North					From South					From East					From West					Intersection
End Time	**NL**	**NS**	**NR**	**App**	**Dep**	**SL**	**SS**	**SR**	**App**	**Dep**	**EL**	**ES**	**ER**	**App**	**Dep**	**WL**	**WS**	**WR**	**App**	**Dep**	**Total**
06:15	33	67	0	100	0	0	0	0	0	76	0	0	0	0	41	0	8	9	17	0	117
06:30	22	122	0	144	0	0	0	0	0	143	0	0	0	0	31	0	9	21	30	0	174
06:45	6	104	0	110	0	0	0	0	0	123	0	0	0	0	14	0	8	19	27	0	137
07:00	27	100	0	127	0	0	0	0	0	119	0	0	0	0	29	0	2	19	21	0	148
07:15	98	136	0	234	0	0	0	0	0	146	0	0	0	0	103	0	5	10	15	0	249
07:30	139	91	0	230	0	0	0	0	0	106	0	0	0	0	145	0	6	15	21	0	251
07:45	145	103	0	248	0	0	0	0	0	121	0	0	0	0	151	0	6	18	24	0	272
08:00	110	82	0	192	0	0	0	0	0	98	0	0	0	0	115	0	5	16	21	0	213
08:15	88	113	0	201	0	0	0	0	0	125	0	0	0	0	96	0	8	12	20	0	221
08:30	59	43	0	102	0	0	0	0	0	55	0	0	0	0	65	0	6	12	18	0	120
08:45	78	36	0	114	0	0	0	0	0	52	0	0	0	0	81	0	3	16	19	0	133
09:00	75	36	0	111	0	0	0	0	0	52	0	0	0	0	79	0	4	16	20	0	131
09:15	63	85	0	148	0	0	0	0	0	96	0	0	0	0	63	0	0	11	11	0	159
09:30	76	121	0	197	0	0	0	0	0	138	0	0	0	0	76	0	0	17	17	0	214
09:45	56	103	0	159	0	0	0	0	0	115	0	0	0	0	57	0	1	12	13	0	172
10:00	74	103	0	177	0	0	0	0	0	118	0	0	0	0	76	0	2	15	17	0	194
10:15	64	68	0	132	0	0	0	0	0	79	0	0	0	0	67	0	3	11	14	0	146
10:30	71	155	0	226	0	0	0	0	0	178	0	0	0	0	73	0	2	23	25	0	251
10:45	64	102	0	166	0	0	0	0	0	122	0	0	0	0	66	0	2	20	22	0	188
11:00	58	118	0	176	0	0	0	0	0	137	0	0	0	0	62	0	4	19	23	0	199
11:15	86	80	0	166	0	0	0	0	0	105	0	0	0	0	96	0	10	25	35	0	201
11:30	63	54	0	117	0	0	0	0	0	76	0	0	0	0	70	0	7	22	29	0	146
11:45	69	61	0	130	0	0	0	0	0	69	0	0	0	0	75	0	6	8	14	0	144
12:00	80	57	0	137	0	0	0	0	0	75	0	0	0	0	81	0	1	18	19	0	156

From North		From West	
NL	NS	WS	WR
409	430	19	62

Taxis counted on 2015-May-04 Weather: GOOD

Comments: . .

	MARKET ROAD					KHUZIMPI ROAD EXT					MARKET ROAD					BUS LINK					
	From North					From South					From East					From West					Intersection
End Time	NL	NS	NR	App	Dep	SL	SS	SR	App	Dep	EL	ES	ER	App	Dep	WL	WS	WR	App	Dep	Total
06:15	56	206	0	262	0	0	0	0	0	230	0	0	0	0	78	0	22	24	46	0	308
06:30	62	210	0	272	0	0	0	0	0	236	0	0	0	0	84	0	22	26	48	0	320
06:45	69	56	0	125	0	0	0	0	0	87	0	0	0	0	98	0	29	31	60	0	185
07:00	57	457	0	514	0	0	0	0	0	490	0	0	0	0	80	0	23	33	56	0	570
07:15	34	235	0	269	0	0	0	0	0	267	0	0	0	0	50	0	16	32	48	0	317
07:30	41	215	0	256	0	0	0	0	0	241	0	0	0	0	60	0	19	26	45	0	301
07:45	56	276	0	332	0	0	0	0	0	309	0	0	0	0	71	0	15	33	48	0	380
08:00	40	153	0	193	0	0	0	0	0	190	0	0	0	0	56	0	16	37	53	0	246
08:15	54	165	0	219	0	0	0	0	0	189	0	0	0	0	72	0	18	24	42	0	261
08:30	49	123	0	172	0	0	0	0	0	153	0	0	0	0	59	0	10	30	40	0	212
08:45	32	78	0	110	0	0	0	0	0	116	0	0	0	0	41	0	9	38	47	0	157
09:00	22	77	0	99	0	0	0	0	0	110	0	0	0	0	41	0	19	33	52	0	151
09:15	19	136	0	155	0	0	0	0	0	166	0	0	0	0	24	0	5	30	35	0	190
09:30	16	87	0	103	0	0	0	0	0	102	0	0	0	0	18	0	2	15	17	0	120
09:45	16	123	0	139	0	0	0	0	0	158	0	0	0	0	19	0	3	35	38	0	177
10:00	14	129	0	143	0	0	0	0	0	152	0	0	0	0	18	0	4	23	27	0	170
10:15	23	141	0	164	0	0	0	0	0	181	0	0	0	0	34	0	11	40	51	0	215
10:30	21	218	0	239	0	0	0	0	0	246	0	0	0	0	23	0	2	28	30	0	269
10:45	21	174	0	195	0	0	0	0	0	209	0	0	0	0	25	0	4	35	39	0	234
11:00	12	139	0	151	0	0	0	0	0	162	0	0	0	0	17	0	5	23	28	0	179
11:15	21	146	0	167	0	0	0	0	0	199	0	0	0	0	22	0	1	53	54	0	221
11:30	18	102	0	120	0	0	0	0	0	140	0	0	0	0	24	0	6	38	44	0	164
11:45	18	98	0	116	0	0	0	0	0	149	0	0	0	0	20	0	2	51	53	0	169
12:00	25	89	0	114	0	0	0	0	0	113	0	0	0	0	31	0	6	24	30	0	144

From North		From West	
NL	NS	WS	WR
188	1183	73	124

Heavies counted on 2015-May-04 Weather: GOOD

Comments: . .

	MARKET ROAD					KHUZIMPI ROAD EXT					MARKET ROAD					BUS LINK					
	From North					From South					From East					From West					Intersection
End Time	NL	NS	NR	App	Dep	SL	SS	SR	App	Dep	EL	ES	ER	App	Dep	WL	WS	WR	App	Dep	Total
06:15	2	10	0	12	0	0	0	0	0	12	0	0	0	0	3	0	1	2	3	0	15
06:30	1	20	0	21	0	0	0	0	0	21	0	0	0	0	2	0	1	1	2	0	23
06:45	6	4	0	10	0	0	0	0	0	7	0	0	0	0	6	0	0	3	3	0	13
07:00	3	8	0	11	0	0	0	0	0	10	0	0	0	0	3	0	0	2	2	0	13
07:15	6	5	0	11	0	0	0	0	0	5	0	0	0	0	6	0	0	0	0	0	11
07:30	2	8	0	10	0	0	0	0	0	9	0	0	0	0	3	0	1	1	2	0	12
07:45	1	5	0	6	0	0	0	0	0	7	0	0	0	0	1	0	0	2	2	0	8
08:00	3	8	0	11	0	0	0	0	0	10	0	0	0	0	3	0	0	2	2	0	13
08:15	10	10	0	20	0	0	0	0	0	13	0	0	0	0	10	0	0	3	3	0	23
08:30	5	11	0	16	0	0	0	0	0	13	0	0	0	0	5	0	0	2	2	0	18
08:45	5	8	0	13	0	0	0	0	0	8	0	0	0	0	7	0	2	0	2	0	15
09:00	7	14	0	21	0	0	0	0	0	14	0	0	0	0	7	0	0	0	0	0	21
09:15	12	11	0	23	0	0	0	0	0	14	0	0	0	0	12	0	0	3	3	0	26
09:30	12	11	0	23	0	0	0	0	0	16	0	0	0	0	12	0	0	5	5	0	28
09:45	4	19	0	23	0	0	0	0	0	19	0	0	0	0	5	0	1	0	1	0	24
10:00	12	10	0	22	0	0	0	0	0	13	0	0	0	0	13	0	1	3	4	0	26
10:15	8	23	0	31	0	0	0	0	0	23	0	0	0	0	8	0	0	0	0	0	31
10:30	2	57	0	59	0	0	0	0	0	59	0	0	0	0	2	0	0	2	2	0	61
10:45	20	44	0	64	0	0	0	0	0	45	0	0	0	0	20	0	0	1	1	0	65
11:00	8	18	0	26	0	0	0	0	0	20	0	0	0	0	9	0	1	2	3	0	29
11:15	8	29	0	37	0	0	0	0	0	30	0	0	0	0	9	0	1	1	2	0	39
11:30	7	18	0	25	0	0	0	0	0	21	0	0	0	0	8	0	1	3	4	0	29
11:45	9	28	0	37	0	0	0	0	0	30	0	0	0	0	10	0	1	2	3	0	40
12:00	9	26	0	35	0	0	0	0	0	27	0	0	0	0	9	0	0	1	1	0	36

From North		From West	
NL	NS	WS	WR
12	26	1	5

Buses counted on 2015-May-04 **Weather: GOOD**

Comments: . .

	MARKET ROAD					KHUZIMPI ROAD EXT					MARKET ROAD					BUS LINK					
	From North					From South					From East					From West					Intersection
End Time	**NL**	**NS**	**NR**	**App**	**Dep**	**SL**	**SS**	**SR**	**App**	**Dep**	**EL**	**ES**	**ER**	**App**	**Dep**	**WL**	**WS**	**WR**	**App**	**Dep**	**Total**
06:15	0	11	0	11	0	0	0	0	0	12	0	0	0	0	1	0	1	1	2	0	13
06:30	1	7	0	8	0	0	0	0	0	12	0	0	0	0	1	0	0	5	5	0	13
06:45	2	13	0	15	0	0	0	0	0	18	0	0	0	0	2	0	0	5	5	0	20
07:00	1	8	0	9	0	0	0	0	0	13	0	0	0	0	2	0	1	5	6	0	15
07:15	1	7	0	8	0	0	0	0	0	11	0	0	0	0	1	0	0	4	4	0	12
07:30	1	5	0	6	0	0	0	0	0	10	0	0	0	0	2	0	1	5	6	0	12
07:45	1	8	0	9	0	0	0	0	0	10	0	0	0	0	1	0	0	2	2	0	11
08:00	1	3	0	4	0	0	0	0	0	7	0	0	0	0	1	0	0	4	4	0	8
08:15	1	4	0	5	0	0	0	0	0	8	0	0	0	0	1	0	0	4	4	0	9
08:30	0	3	0	3	0	0	0	0	0	6	0	0	0	0	0	0	0	3	3	0	6
08:45	2	2	0	4	0	0	0	0	0	5	0	0	0	0	2	0	0	3	3	0	7
09:00	3	2	0	5	0	0	0	0	0	4	0	0	0	0	3	0	0	2	2	0	7
09:15	3	5	0	8	0	0	0	0	0	7	0	0	0	0	3	0	0	2	2	0	10
09:30	1	2	0	3	0	0	0	0	0	3	0	0	0	0	1	0	0	1	1	0	4
09:45	0	3	0	3	0	0	0	0	0	5	0	0	0	0	1	0	1	2	3	0	6
10:00	0	3	0	3	0	0	0	0	0	6	0	0	0	0	1	0	1	3	4	0	7
10:15	0	5	0	5	0	0	0	0	0	8	0	0	0	0	1	0	1	3	4	0	9
10:30	0	9	0	9	0	0	0	0	0	10	0	0	0	0	1	0	1	1	2	0	11
10:45	0	4	0	4	0	0	0	0	0	7	0	0	0	0	0	0	0	3	3	0	7
11:00	0	9	0	9	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	9
11:15	1	3	0	4	0	0	0	0	0	6	0	0	0	0	1	0	0	3	3	0	7
11:30	0	5	0	5	0	0	0	0	0	7	0	0	0	0	0	0	0	2	2	0	7
11:45	1	8	0	9	0	0	0	0	0	10	0	0	0	0	1	0	0	2	2	0	11
12:00	1	3	0	4	0	0	0	0	0	6	0	0	0	0	1	0	0	3	3	0	7

From North		From West	
NL	NS	WS	WR
4	28	2	16

A similar process was done for each of the following intersections.

Market-Southern Freeway	2016-02-09 01:47 ...	Microsoft Excel W...	62 KB
West and Stanger (Stalwart Simelane Stre...	2015-10-27 10:34 ...	Microsoft Excel W...	74 KB
West Street and Aliwal (Samora Machel S...	2015-10-27 10:23 ...	Microsoft Excel W...	65 KB
West-Brickhill	2015-09-16 09:47 ...	Microsoft Excel W...	61 KB
west-Broad2_	2015-10-27 09:59 ...	Microsoft Excel W...	35 KB
West-Brook	2015-10-27 09:42 ...	Microsoft Excel W...	60 KB
West-Field	2015-10-27 10:03 ...	Microsoft Excel W...	61 KB
West-Gardiner	2015-10-27 10:09 ...	Microsoft Excel W...	60 KB
West-Gillespie	2015-09-19 06:35 ...	Microsoft Excel W...	62 KB
West-Market Williams	2015-10-27 09:36 ...	Microsoft Excel W...	60 KB
West-Park	2015-10-27 10:52 ...	Microsoft Excel W...	57 KB
West-Prince Alfred	2015-10-27 10:37 ...	Microsoft Excel W...	60 KB
West-Russell	2015-10-27 09:52 ...	Microsoft Excel W...	61 KB
West-Shepstone	2015-09-20 12:23 ...	Microsoft Excel W...	60 KB
West-Stanger	2015-10-13 09:38 ...	Microsoft Excel W...	59 KB
West-Warwick	2015-10-26 10:11 ...	Microsoft Excel W...	62 KB

did	oid	eid	flow	Count					GEH	<5	<10	Total
652	10561271	10EN	221	485		0			14,0513	0	0	1
652	10561271	10EN	221			0			21,0238			
652	10561272	10ES	385	381		385			0,20439	1	1	1
652	10561272	10ES	385			0			27,74887			
652	10561274	10NE	94	114		94			1,961161	1	1	1
652	10561274	10NE	94			0			13,71131			
652	10561275	10NS	797	618		797			6,729609	0	1	1
652	10561275	10NS	797			0			39,92493			
652	10561287	10SE	198	91		198			8,901227	0	1	1
652	10561287	10SE	198			0			19,89975			
652	10561273	10SN	730	497		730			9,406946	0	1	1
652	10561273	10SN	730			0			38,20995			
652	10561270	10WE	548	574		548			1,097721	1	1	1
652	10561270	10WE	548			0			33,10589			
652	10561279	11SE	22	62		22			6,172134	0	1	1
652	10561279	11SE	22			0			6,63325			
652	10561278	11SN	561	932		561			13,57873	0	0	1
652	10561278	11SN	561			0			33,49627			
652	10561276	11WE	361	563		361			9,397891	0	1	1
652	10561276	11WE	361			0			26,87006			
652	10561277	11WN	327	415		327			4,568732	1	1	1
652	10561277	11WN	327			0			25,57342			
652	10561283	12NE	173	24		173			15,01302	0	0	1
652	10561283	12NE	173			0			18,60108			
652	10561282	12NS	2382	1761		2382			13,64423	0	0	1
652	10561282	12NS	2382			0			69,02174			
652	10561280	12WE	379	231		379			8,474455	0	1	1
652	10561280	12WE	379			0			27,5318			
652	10561281	12WS	4	263		4			22,41605	0	0	1
652	10561281	12WS	4			0			2,828427			
652	10561242	1SE	791	352		791			18,36354	0	0	1
652	10561242	1SE	791			0			39,77436			
652	10561236	1SN	372	323		372			2,628565	1	1	1
652	10561236	1SN	372			0			27,27636			
652	10561232	1WE	716	532		716			7,365895	0	1	1
652	10561232	1WE	716			0			37,84178			
652	10561237	1WN	0	67		0			11,57584	0	0	1
652	10561237	1WN	0			0			#DIV/0!			
652	10561244	2ES	350	118		350			15,16631	0	0	1
652	10561244	2ES	350			0			26,45751			
652	10561246	2NE	1	59		1			10,5893	0	0	1
652	10561246	2NE	1			0			1,414214			
652	10561245	2NS	555	432		555			5,536834	0	1	1
652	10561245	2NS	555			0			33,31666			
652	10561243	2WE	1104	574		1104			18,29763	0	0	1
652	10561243	2WE	1104			0			46,98936			
652	10561254	3SE	1152	1677		1152			13,95911	0	0	1
652	10561254	3SE	1152			0			48			
652	10561285	3SN	0	18		0			6	0	1	1
652	10561285	3SN	0			0			#DIV/0!			
652	10561252	3WE	1099	426		1099			24,37222	0	0	1
652	10561252	3WE	1099			0			46,88283			
652	10561253	3WN	5	13		5			2,666667	1	1	1
652	10561253	3WN	5			0			3,162278			
652	10561256	4WS	42	124		42			9,000669	0	1	1
652	10561256	4WS	42			0			9,165151			
652	10561257	5NE	0	29		0			7,615773	0	1	1
652	10561257	5NE	0			0			#DIV/0!			
652	10561261	6SE	370	131		370			15,10059	0	0	1
652	10561261	6SE	370			0			27,20294			
652	10561260	6SN	772	571		772			7,75663	0	1	1
652	10561260	6SN	772			0			39,29377			
652	10561258	6WE	1353	1443		1353			2,407071	1	1	1
652	10561258	6WE	1353			0			52,01923			
652	10561259	6WN	752	886		752			4,682339	1	1	1
652	10561259	6WN	752			0			38,78144			
652	10561248	7ES	204	155		204			3,657328	1	1	1
652	10561248	7ES	204			0			20,19901			
652	10561247	7EW	1485	974		1485			14,57326	0	0	1
652	10561247	7EW	1485			0			54,49771			
652	10561249	7NE	252	189		252			4,242641	1	1	1
652	10561249	7NE	252			0			22,44994			
652	10561250	7NS	1221	1180		1221			1,183322	1	1	1
652	10561250	7NS	1221			0			49,4166			
652	10561269	8SE	287	139		287			10,14079	0	0	1
652	10561269	8SE	287			0			23,9583			
652	10561268	8SN	941	601		941			12,2448	0	0	1
652	10561268	8SN	941			0			43,38202			
652	10561262	8WE	1072	1005		1072			2,079082	1	1	1
652	10561262	8WE	1072			0			46,30335			
652	10561263	8WN	328	322		328			0,33282	1	1	1
652	10561263	8WN	328			0			25,6125			
652	10561267	9NE	475	529		475			2,410138	1	1	1
652	10561267	9NE	475			0			30,82207			
652	10561266	9NS	1342	1139		1342			5,763651	0	1	1
652	10561266	9NS	1342			0			51,80734			
652	10561264	9WE	847	756		847			3,214324	1	1	1
652	10561264	9WE	847			0			41,15823			
652	10561265	9WS	207	352		207			8,673155	0	1	1
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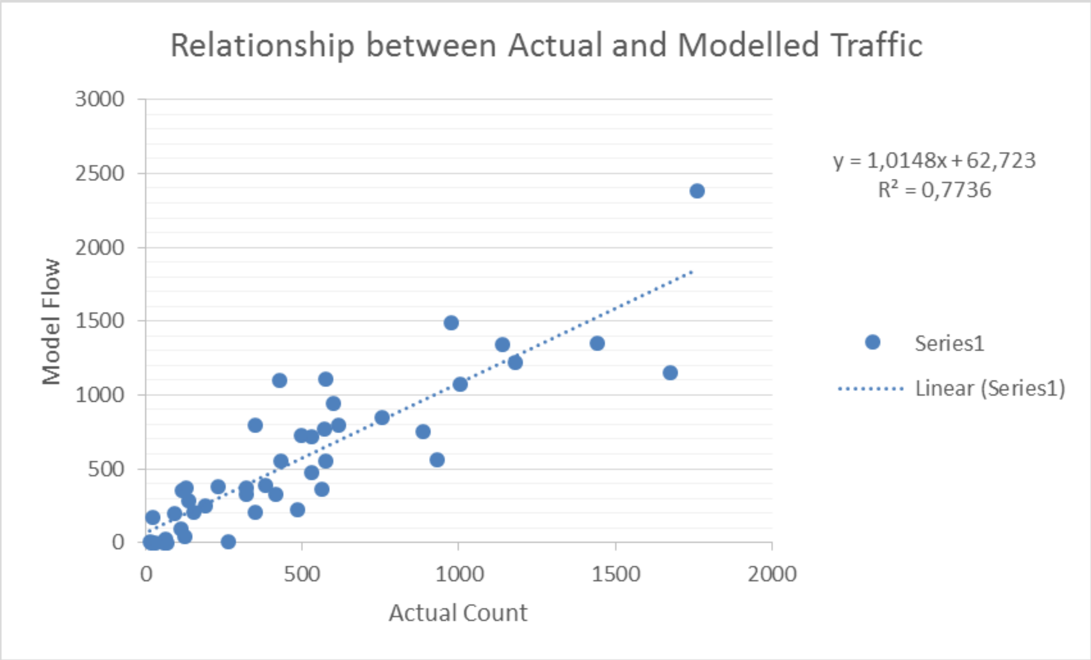
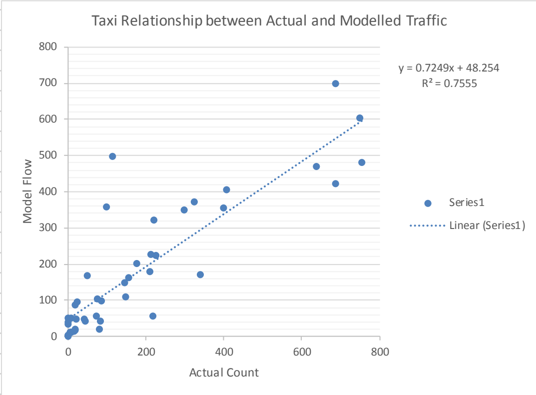
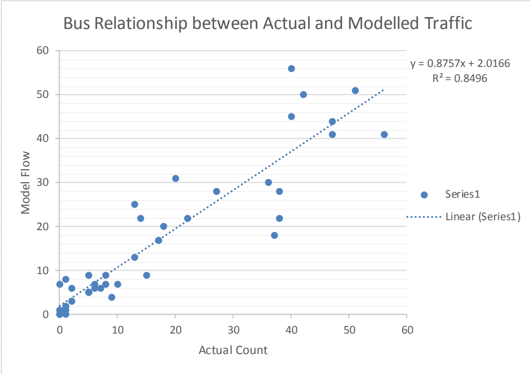
			50554	22127								
			25277							0,333333	0,644444	


Relationship between Actual and Modelled Traffic
Model Flow
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
Actual Count
y = 1,0148x + 62,723
R² = 0,7736
Series1
Linear (Series1)

oid	eid	flow	Count	GEH	<5	<10	Total
10561271	10EN	47	20	4.664889	1	1	1
10561271	10EN	0		#DIV/0!			
10561272	10ES	20	81	8.58389	0	1	1
10561272	10ES	0		#DIV/0!			
10561274	10NE	51	0	10.0995	0	0	1
10561274	10NE	0		#DIV/0!			
10561275	10NS	3	1	1.414214	1	1	1
10561275	10NS	0		#DIV/0!			
10561287	10SE	4	0	2.828427	1	1	1
10561287	10SE	0		#DIV/0!			
10561273	10SN	11	9	0.632456	1	1	1
10561273	10SN	0		#DIV/0!			
10561270	10WE	323	220	6.25104	0	1	1
10561270	10WE	0		#DIV/0!			
10561279	11SE	33	0	8.124038	0	1	1
10561279	11SE	0		#DIV/0!			
10561278	11SN	11	8	0.973329	1	1	1
10561278	11SN	0		#DIV/0!			
10561276	11WE	179	210	2.222808	1	1	1
10561276	11WE	0		#DIV/0!			
10561277	11WN	168	51	11.18095	0	0	1
10561277	11WN	0		#DIV/0!			
10561283	12NE	39	1	8.497058	0	1	1
10561283	12NE	0		#DIV/0!			
10561282	12NS	20	18	0.458831	1	1	1
10561282	12NS	0		#DIV/0!			
10561280	12WE	202	177	1.816082	1	1	1
10561280	12WE	0		#DIV/0!			
10561281	12WS	11	6	1.714986	1	1	1
10561281	12WS	0		#DIV/0!			
10561242	1SE	355	399	2.266115	1	1	1
10561242	1SE	0		#DIV/0!			
10561236	1SN	405	407	0.099258	1	1	1
10561236	1SN	0		#DIV/0!			
10561232	1WE	227	214	0.875466	1	1	1
10561232	1WE	0		#DIV/0!			
10561237	1WN	225	225	0	1	1	1
10561237	1WN	0		#DIV/0!			
10561244	2ES	110	148	3.345713	1	1	1
10561244	2ES	0		#DIV/0!			
10561246	2NE	56	219	13.90069	0	0	1
10561246	2NE	0		#DIV/0!			
10561245	2NS	358	100	17.04912	0	0	1
10561245	2NS	0		#DIV/0!			
10561243	2WE	470	639	7.176884	0	1	1
10561243	2WE	0		#DIV/0!			
10561254	3SE	499	114	21.99103	0	0	1
10561254	3SE	0		#DIV/0!			
10561285	3SN	18	19	0.232495	1	1	1
10561285	3SN	0		#DIV/0!			
10561252	3WE	481	755	11.0219	0	0	1
10561252	3WE	0		#DIV/0!			
10561253	3WN	44	44	0	1	1	1
10561253	3WN	0		#DIV/0!			
10561256	4WS	57	74	2.100527	1	1	1
10561256	4WS	0		#DIV/0!			
10561257	5NE	0	0	#DIV/0!	0	0	
10561257	5NE	0		#DIV/0!			
10561261	6SE	16	15	0.254	1	1	1
10561261	6SE	0		#DIV/0!			
10561260	6SN	99	85	1.459601	1	1	1
10561260	6SN	0		#DIV/0!			
10561258	6WE	698	686	0.456172	1	1	1
10561258	6WE	0		#DIV/0!			
10561259	6WN	162	157	0.395904	1	1	1
10561259	6WN	0		#DIV/0!			
10561248	7ES	95	23	9.373602	0	1	1
10561248	7ES	0		#DIV/0!			
10561247	7EW	605	750	5.570746	0	1	1
10561247	7EW	0		#DIV/0!			
10561249	7NE	49	41	1.19257	1	1	1
10561249	7NE	0		#DIV/0!			
10561250	7NS	349	299	2.777778	1	1	1
10561250	7NS	0		#DIV/0!			
10561269	8SE	88	19	9.433486	0	1	1
10561269	8SE	0		#DIV/0!			
10561268	8SN	103	75	2.967994	1	1	1
10561268	8SN	0		#DIV/0!			
10561262	8WE	421	687	11.30126	0	0	1
10561262	8WE	0		#DIV/0!			
10561263	8WN	172	341	10.5522	0	0	1
10561263	8WN	0		#DIV/0!			
10561267	9NE	50	9	7.548712	0	1	1
10561267	9NE	0		#DIV/0!			
10561266	9NS	150	146	0.328798	1	1	1
10561266	9NS	0		#DIV/0!			
10561264	9WE	372	325	2.517656	1	1	1
10561264	9WE	0		#DIV/0!			
10561265	9WS	43	84	5.145138	0	1	1
10561265	9WS	0			26	36	44
			7901				
					0.590909	0.818182	



eid	flow	bus	eid	GEH	<5	<10	Total
10EN	5	5	10EN	0	1	1	1
10EN	5						
10ES	28	38	10ES	1.740777	1	1	1
10ES	28						
10NE	1	1	10NE	0	1	1	1
10NE	1						
10NS	7	8	10NS	0.365148	1	1	1
10NS	7						
10SE	0	1	10SE	1.414214	1	1	1
10SE	0						
10SN	0	0	10SN	#DIV/0!	1	1	1
10SN	0						
10WE	30	36	10WE	1.044466	1	1	1
10WE	30						
11SE	3	2	11SE	0.632456	1	1	1
11SE	3						
11SN	17	17	11SN	0	1	1	1
11SN	17						
11WE	18	37	11WE	3.623158	1	1	1
11WE	18						
11WN	9	5	11WN	1.511858	1	1	1
11WN	9						
12NE	6	6	12NE	0	1	1	1
12NE	6						
12NS	5	5	12NS	0	1	1	1
12NS	5						
12WE	20	18	12WE	0.458831	1	1	1
12WE	20						
12WS	1	0	12WS	1.414214	1	1	1
12WS	1						
1SE	25	13	1SE	2.752989	1	1	1
1SE	25						
1SN	51	51	1SN	0	1	1	1
1SN	51						
1WE	22	38	1WE	2.921187	1	1	1
1WE	22						
1WN	17	17	1WN	0	1	1	1
1WN	17						
2ES	7	10	2ES	1.028992	1	1	1
2ES	7						
2NE	5	5	2NE	0	1	1	1
2NE	5						
2NS	22	22	2NS	0	1	1	1
2NS	22						
2WE	41	47	2WE	0.904534	1	1	1
2WE	41						
3SE	31	20	3SE	2.178325	1	1	1
3SE	31						
3SN	0	0	3SN	#DIV/0!	1	1	1
3SN	0						
3WE	45	40	3WE	0.766965	1	1	1
3WE	45						
3WN	1	0	3WN	1.414214	1	1	1
3WN	1						
4WS	8	1	4WS	3.299832	1	1	1
4WS	8						
5NE	0	0	5NE	#DIV/0!	1	1	1
5NE	0						
6SE	2	1	6SE	0.816497	1	1	1
6SE	2						
6SN	9	8	6SN	0.342997	1	1	1
6SN	9						
6WE	56	40	6WE	2.309401	1	1	1
6WE	56						
6WN	9	15	6WN	1.732051	1	1	1
6WN	9						
7ES	6	2	7ES	2	1	1	1
7ES	6						
7EW	50	42	7EW	1.179536	1	1	1
7EW	50						
7NE	4	9	7NE	1.961161	1	1	1
7NE	4						
7NS	13	13	7NS	0	1	1	1
7NS	13						
8SE	7	0	8SE	3.741657	1	1	1
8SE	7						
8SN	7	6	8SN	0.392232	1	1	1
8SN	7						
8WE	44	47	8WE	0.44475	1	1	1
8WE	44						
8WN	6	7	8WN	0.392232	1	1	1
8WN	6						
9NE	22	14	9NE	1.885618	1	1	1
9NE	22						
9NS	28	27	9NS	0.190693	1	1	1
9NS	28						
9WE	41	56	9WE	2.153874	1	1	1
9WE	41						
9WS	1	0	9WS	1.414214	1	1	1
9WS	1				45	45	45
	1460	730					
	730				1	1	



did	oid	eid	flow		eid	trucks counts
652	10561271	10EN	2		10EN	2
652	10561271	10EN	2			
652	10561272	10ES	2		10ES	6
652	10561272	10ES	2			
652	10561274	10NE	0		10NE	0
652	10561274	10NE	0			
652	10561275	10NS	6		10NS	5
652	10561275	10NS	6			
652	10561287	10SE	2		10SE	0
652	10561287	10SE	2			
652	10561273	10SN	5		10SN	5
652	10561273	10SN	5			
652	10561270	10WE	21		10WE	9
652	10561270	10WE	21			
652	10561279	11SE	2		11SE	2
652	10561279	11SE	2			
652	10561278	11SN	8		11SN	8
652	10561278	11SN	8			
652	10561276	11WE	13		11WE	8
652	10561276	11WE	13			
652	10561277	11WN	7		11WN	3
652	10561277	11WN	7			
652	10561283	12NE	2		12NE	2
652	10561283	12NE	2			
652	10561282	12NS	11		12NS	10
652	10561282	12NS	11			
652	10561280	12WE	15		12WE	12
652	10561280	12WE	15			
652	10561281	12WS	1		12WS	2
652	10561281	12WS	1			
652	10561242	1SE	13		1SE	7
652	10561242	1SE	13			
652	10561236	1SN	21		1SN	20
652	10561236	1SN	21			
652	10561232	1WE	10		1WE	7
652	10561232	1WE	10			
652	10561237	1WN	4		1WN	4
652	10561237	1WN	4			
652	10561244	2ES	4		2ES	2
652	10561244	2ES	4			
652	10561246	2NE	1		2NE	2
652	10561246	2NE	1			
652	10561245	2NS	23		2NS	21
652	10561245	2NS	23			
652	10561243	2WE	20		2WE	12
652	10561243	2WE	20			
652	10561254	3SE	31		3SE	29
652	10561254	3SE	31			
652	10561285	3SN	3		3SN	3
652	10561285	3SN	3			
652	10561252	3WE	21		3WE	11
652	10561252	3WE	21			
652	10561253	3WN	0		3WN	4
652	10561253	3WN	0			
652	10561256	4WS	2		4WS	1
652	10561256	4WS	2			
652	10561257	5NE	0		5NE	
652	10561257	5NE	0			
652	10561261	6SE	3		6SE	3
652	10561261	6SE	3			
652	10561260	6SN	16		6SN	16
652	10561260	6SN	16			
652	10561258	6WE	36		6WE	22
652	10561258	6WE	36			
652	10561259	6WN	14		6WN	19
652	10561259	6WN	14			
652	10561248	7ES	5		7ES	7
652	10561248	7ES	5			
652	10561247	7EW	35		7EW	18
652	10561247	7EW	35			
652	10561249	7NE	6		7NE	5
652	10561249	7NE	6			
652	10561250	7NS	19		7NS	18
652	10561250	7NS	19			
652	10561269	8SE	2		8SE	1
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652	10561268	8SN	10		8SN	10
652	10561268	8SN	10			
652	10561262	8WE	29		8WE	34
652	10561262	8WE	29			
652	10561263	8WN	7		8WN	7
652	10561263	8WN	7			
652	10561267	9NE	6		9NE	5
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652	10561266	9NS	11		9NS	11
652	10561266	9NS	11			
652	10561264	9WE	22		9WE	11
652	10561264	9WE	22			
652	10561265	9WS	5		9WS	6
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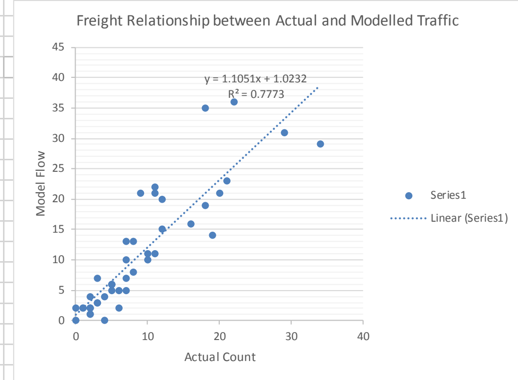
			476			390



eid	flow	Combined Count
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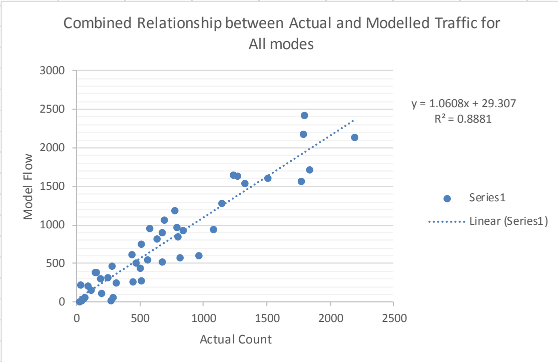
10EN	0	
10ES	434	506
10ES	0	
10NE	147	115
10NE	0	
10NS	812	632
10NS	0	
10SE	204	92
10SE	0	
10SN	746	511
10SN	0	
10WE	922	839
10WE	0	
11SE	60	66
11SE	0	
11SN	597	965
11SN	0	
11WE	572	818
11WE	0	
11WN	512	474
11WN	0	
12NE	221	33
12NE	0	
12NS	2417	1794
12NS	0	
12WE	617	438
12WE	0	
12WS	17	271
12WS	0	
1SE	1184	771
1SE	0	
1SN	849	801
1SN	0	
1WE	974	791
1WE	0	
1WN	246	313
1WN	0	
2ES	470	278
2ES	0	
2NE	62	285
2NE	0	
2NS	958	575
2NS	0	
2WE	1635	1272
2WE	0	
3SE	1711	1840
3SE	0	
3SN	21	40
3SN	0	
3WE	1645	1232
3WE	0	
3WN	50	61
3WN	0	
4WS	108	200
4WS	0	
5NE	0	29
5NE	0	
6SE	390	150
6SE	0	
6SN	896	680
6SN	0	
6WE	2140	2191
6WE	0	
6WN	936	1077
6WN	0	
7ES	308	187
7ES	0	
7EW	2172	1784
7EW	0	
7NE	311	244
7NE	0	
7NS	1602	1510
7NS	0	
8SE	384	159
8SE	0	
8SN	1061	692
8SN	0	
8WE	1564	1773
8WE	0	
8WN	513	677
8WN	0	
9NE	553	557
9NE	0	
9NS	1531	1323
9NS	0	
9WE	1279	1148
9WE	0	
9WS	257	442
9WS	0	
	34361	31148



EBE Faculty: Assessment of Ethics in Research Projects (Rev2)

Any person planning to undertake research in the Faculty of Engineering and the Built Environment at the University of Cape Town is required to complete this form before collecting or analysing data. When completed it should be submitted to the supervisor (where applicable) and from there to the Head of Department. If any of the questions below have been answered YES, and the applicant is NOT a fourth year student, the Head should forward this form for approval by the Faculty EIR committee: submit to Ms Zulpha Geyer (Zulpha.Geyer@uct.ac.za; Chem Eng Building, Ph 021 650 4791).
NB: A copy of this signed form must be included with the thesis/dissertation/report when it is submitted for examination

This form must only be completed once the most recent revision EBE EiR Handbook has been read.

Name of Principal Researcher/Student: LAVERN MOODLEY   Department: Civil Engineering

Preferred email address of the applicant: lavern.mooldey@durban.gov.za

If a Student: Degree: MEng (CIVIL)   Supervisor: Mark Zuidgeest

If a Research Contract indicate source of funding/sponsorship:

Research Project Title: Public Transport Road prioritisation with the use of Aimsun Modelling

Overview of ethics issues in your research project:

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

If you have answered YES to any of the above questions, please append a copy of your research proposal, as well as any interview schedules or questionnaires (Addendum 1) and please complete further addenda as appropriate. Ensure that you refer to the EiR Handbook to assist you in completing the documentation requirements for this form.

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

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

Signed by:

Principal Researcher/Student:		Date

This application is approved by:

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

previously approved request for clearance signed by prof. Behrens in November '15 got misplaced.