



**UNIVERSITY OF CAPE TOWN**  
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

**EVALUATION OF WHEN ROAD SPACE  
PRIORITISATION/INFRASTRUCTURAL IMPROVEMENTS FOR  
PARATRANSIT VEHICLES IS WARRANTED: A CASE STUDY OF  
MITCHELLS PLAIN, CAPE TOWN**

**A 60 Credit Master's Dissertation Submitted to the Department  
of Civil Engineering at the University of Cape Town**

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## **ABSTRACT**

In many developing countries, the cities have confined or absolute non-availability of modern quality public transport systems, therefore residents of these cities solely rely on non-scheduled, informal, flexible route transportation system referred to as 'Paratransit' to move from one point to another. South Africa being a partly developed and partly developing country also have this particular problem in terms of its public transport system. Some 65% of public transport users make use of paratransit services as a day to day means of transport in South Africa. Paratransit is the most commonly used public transport mode in South African cities as it is relatively affordable and highly flexible. However, it is referred to be very unreliable in terms of journey time and passenger's waiting time at stops mostly, due to time wasted in traffic congestion and at signalised intersections.

So, actions are needed to be taken to improve the travel speed, safety and reliability of paratransit vehicles.

In 2007, South Africa's department of transport envisioned some strategies to revitalise public transport system in South Africa whereby one of the strategies is to replace paratransit called Mini-bus taxi in South Africa with scheduled trunk-feeder services. However, this has proven unachievable, due to resistant from the paratransit association.

This dissertation aims to investigate under which traffic condition is road prioritisation/infrastructural improvement is warranted for paratransit vehicles in a trunk-feeder hybrid setting. The dissertation also explored how operations of the paratransit feeders service can be improved through infrastructural improvements and prioritisation on road space using the Mitchells Plain public transport interchange as a case study.

An agent-based simulation modelling tool is employed to simulate the present trunk-feeder operations at the Mitchells Plain interchange thereby investigating how the passenger travel performance has been impacted by the configuration and operational characteristics of the current trunk-feeder public transport system. The modelling tool mimic an intermodal trunk-feeder operation which include: Passengers arrival at the rank and stops to wait for taxi; boarding and

alighting of passengers along the feeder's route; transfers of passengers alighting from the taxi and walking of the passengers through the interchange to connect to their respective available trunk service public transport system. The main aim of this dissertation is to develop and investigate various infrastructure developments to the road network using road space prioritisation that can be implemented and their effect on the overall efficiency of the paratransit feeder's system. Each of the proposed infrastructural improvements through prioritisation of paratransit vehicles on road space was tested in a normal and congested traffic condition to evaluate their effectiveness on the operational efficiency of paratransit feeder's service at varying level of traffic congestion.

The effect of the various network infrastructure improvements is being tested using the agent-based simulation tool with the main objectives of improving the operational performance of the paratransit feeder's services which will lead to a more coordinated, integrated and sustainable trunk-feeder public transport system.

The result of the model analysis showed that provision of dedicated lanes for paratransit vehicles is the most efficient infrastructural improvement strategy through road space prioritisation, especially in a traffic-congested route.

# Table of Contents

Plagiarism Declaration.....	i
Acknowledgement .....	ii
Abstract.....	iv
Table of content .....	vi
List of tables .....	ix
List of figures.....	x
<b>1.0 INTRODUCTION .....</b>	<b>1</b>
<b>1.1 Motivation for the research .....</b>	<b>3</b>
<b>1.2 Research objectives.....</b>	<b>4</b>
1.2.1 Sub-objectives.....	4
1.2.2 Research questions.....	5
<b>1.3 Research framework .....</b>	<b>6</b>
<b>1.4 Dissertation structure .....</b>	<b>6</b>
<b>2.0 LITERATURE REVIEW.....</b>	<b>8</b>
<b>2.1 The role of a transport system .....</b>	<b>8</b>
<b>2.2 Public transport system.....</b>	<b>8</b>
2.2.1 Types of public transport services.....	9
2.2.1.1 Formal services .....	9
2.2.1.2 Paratransit Services .....	10
<b>2.3 Paratransit definitions .....</b>	<b>10</b>
2.3.1 The South African paratransit industry.....	12
2.3.1.1 Brief history of South African paratransit Industry.....	12
<b>2.4 The role of paratransit in South Africa’s public transport and way forward for improvement .....</b>	<b>13</b>
2.4.1 Paratransit prioritisation through road space management.....	16
2.4.1.1 Busways/Lanes.....	18

2.4.1.2 Intersections .....	19
2.4.1.3 Bus Stops.....	21
<b>2.5 Introduction to transport modelling.....</b>	<b>22</b>
2.5.1 Introduction to traffic flow models.....	23
2.5.2 Safe - distance models .....	25
2.5.3 Stimulus-response models.....	25
<b>2.6 Microsimulation and its role in modern-day transport planning .....</b>	<b>26</b>
<b>2.7 Public transport performance measures .....</b>	<b>28</b>
2.7.1 Key performance indicators(KPIs) to evaluate the effect of infrastructural improvement on paratransit feeder’s service .....	30
<b>2.8 Resume .....</b>	<b>31</b>
<b>3.0 STUDY AREA AND DATA.....</b>	<b>33</b>
<b>3.1 Data required to set up the model.....</b>	<b>35</b>
<b>3.2 Data collection .....</b>	<b>36</b>
<b>4.0 METHODOLOGY .....</b>	<b>39</b>
<b>4.1 Introduction .....</b>	<b>39</b>
<b>4.2 Model development .....</b>	<b>39</b>
<b>4.3 About Commuter.....</b>	<b>43</b>
4.3.1 Model parameters in commuter .....	44
4.3.2 Zoning plan .....	45
4.3.3 Network .....	46
4.3.4 Public transport service and timetable .....	46
4.3.5 Defining demand .....	47
4.3.6 Generating trips .....	48

4.3.7 Collating result .....	48
<b>4.4 Simulation .....</b>	<b>49</b>
<b>4.5 limitation of using commuter as the modelling tool to model paratransit feeder's     service .....</b>	<b>53</b>
<b>4.6 Model verification, Calibration and Validation .....</b>	<b>54</b>
<b>4.7 Infrastructure improvement scenarios modelled .....</b>	<b>55</b>
4.7.1 Introduction of traffic signals at some strategic intersections.....	55
4.7.2 Introduction of queue jumpers only at all intersections along the feeder's route .....	57
4.7.3 Combination of traffic signal and queue jumpers .....	58
4.7.4 Introduction of dedicated lanes for paratransit vehicles along the feeder's route .....	59
<b>5.0 RESULTS AND ANALYSIS .....</b>	<b>61</b>
<b>5.1 Crawling time .....</b>	<b>61</b>
<b>5.2 Number of boarded passengers .....</b>	<b>63</b>
<b>5.3 Total distance covered .....</b>	<b>64</b>
<b>5.4 Feeder's waiting time .....</b>	<b>66</b>
<b>5.5 Overall trip time .....</b>	<b>67</b>
<b>5.6 Analysis of simulation result .....</b>	<b>69</b>
5.6.1 MCA performance matrix .....	70
5.6.2 Scoring and weighting of KPI/criteria .....	70
5.6.3 Criteria standardization .....	71
5.6.4 Evaluation using Weighted Sum method .....	72
<b>6.0 CONCLUSION AND RECOMMENDATION .....</b>	<b>74</b>
<b>6.1 Conclusion .....</b>	<b>74</b>
<b>6.2 Recommendation .....</b>	<b>78</b>

6.2.1 Incorporation of Route deviation option.....	78
6.2.2 Incorporating cost of implementing the infrastructural improvements scenario tested .....	79
6.2.3 Incessant update of traffic counts record.....	79
<b>7.0 REFERENCES</b> .....	<b>81</b>

## LIST OF TABLES

Table 1-1 Public transport mode share and amount spent by the government on each mode in South Africa .....	3
Table 2-1 Overview of traffic flow model classifications .....	24
Table 4-1 Capabilities of different software packages considered.....	44
Table 5-1 Crawling times of each of the infrastructural improvements with different level of traffic conditions .....	61
Table 5-2 Number of passengers boarded with each scenario as the traffic condition increases .....	63
Table 5-3 Total distance covered against each infrastructural improvement at varying traffic conditions .....	65
Table 5-4 Waiting time by each infrastructural improvement scenario at varying traffic conditions .....	66
Table 5-5 Overall in-vehicle trip time of each infrastructural improvement scenario as traffic condition increases .....	68
Table 5-6 Performance matrix table of infrastructure improvement scenarios tested against each KPI .....	70
Table 5-7 Score and Weight of each criterion .....	71
Table 5-8 Standardised performance matrix .....	72
Table 5-9 Weighted sum method .....	72
Table 5-10 Ranking of the infrastructural improvements scenario based on their performance at varying level of traffic .....	73
Table 6-1 Performance matrix of scenarios tested against KPIs .....	76
Table 6-2 Traffic level at which each infrastructural improvement scenario needs to be implemented and the expected KPIs results .....	78

## LIST OF FIGURES

Figure 1-1 Conceptual Research Framework .....	6
Figure 2-1 Paratransit in developing countries around the world .....	11
Figure 2-2 Various paratransit vehicles used in some cities across the world .....	11
Figure 2-3 Traffic Pre-emption design .....	19
Figure 2-4 Bus advance at an intersection .....	20
Figure 2-5 Queue jump at an intersection.....	21
Figure 2-6 Embayment for public transport vehicles .....	21
Figure 2-7 Bus Boarders for public transport vehicles .....	22
Figure 2-8 Factors that affect travel time in public transport .....	31
Figure 3-1 Map of Mitchel Plain on Google map .....	34
Figure 3-2 Feeder’s route used for this research .....	35
Figure 3-3 ODK form on the mobile phones at the start of the survey.....	37
Figure 3-4 The final data points along the feeder's route captured during the survey .....	37
Figure 4-1 Methodology flow chart.....	39
Figure 4-2 Overview of the network used in the model in google earth and commuter software .....	40
Figure 4-3 Westgate to Hazeldene trail with the associated timetable for the paratransit service in commuter .....	41
Figure 4-4 Passenger O-D matrix used in the model .....	42
Figure 4-5 O-D matrix for cars, bus and trucks .....	42
Figure 4-6 Paratransit vehicle waiting for passengers at Westgate mall before starting its trip .....	50
Figure 4-7 Passengers waiting for Paratransit vehicle at a stand along the feeder's route.....	50

Figure 4-8 Paratransit vehicle in its dedicated lane with vehicular traffic at a signalised intersection .....	51
Figure 4-9 Paratransit vehicle alighting passengers at a stand on the feeder's route .....	51
Figure 4-10 Paratransit vehicle travelling on its dedicated lane .....	52
Figure 4-11 Paratransit vehicle alighting passengers at the Hazeldene interchange and passenger walking through the walkway to either connect to a trunk service or end their trip at the interchange .....	52
Figure 4-12 Commuter producing the level of service at Intersections and at pedestrian walkway only.....	54
Figure 4-13 Observed travel time vs modelled travel time .....	55
Figure 4-14 The feeders route with new and existing signalised intersections .....	56
Figure 4-15 A redesigned intersection along the feeder's route where priority was given to vehicles flowing in the direction of the paratransit vehicles by giving them more green time.....	57
Figure 4-16 Part of the feeder's route showing before and after the introduction of queue jumpers .....	58
Figure 4-17 An intersection before and after the introduction of queue jumper and traffic signal along the feeder's route .....	59
Figure 4-18 Portion of the feeder's route showing before and after the introduction of the dedicated lanes .....	60
Figure 5-6 Ranking of tested scenarios using weighted sum method.....	73

## 1.0 INTRODUCTION

A well planned and managed public transport system plays a significant role in meeting the mobility needs of passengers. But this is not the case in many developing countries as the quality of public transport available to passengers is extremely poor and inefficient and thus needs improvement, which forces most passengers to use non-scheduled, informal, flexible route transportation system referred to as 'Paratransit' for their mobility obligations.

Public Transportation in South Africa is in a poor state and suffers from negative perception. It is primarily a mode of transit for captive user's i.e. those cannot afford to use a more comfortable, safer and dignified mode (Chikauta, 2015). The services rendered by the paratransit operators are also often condemned, due to competitive driving, lack of safety and comfortability, and inferior vehicle maintenance, which usually leads to an incessant vehicle breakdown, additional road traffic congestion and high levels of emissions. There has been recent studies and research which are all directed towards finding some innovative and transformational ideas on how to transform public transport systems in developing countries.

South Africa, being a partly developed and partly developing country, its current public transport transformation processes are aimed towards the integration of, and complementarity between, formal and paratransit services (Ferro et al., 2012; Behrens & Ferro, 2014, Del Mistro & Behrens, 2012; Wilkinson, 2010). Paratransit is the most commonly used public transport in South Africa because of its flexibility, affordability and demand responsiveness, especially for the low-income commuters. The common challenges facing the paratransit industry in other developing countries are also the problems facing South Africa's paratransit industry, which is mostly due to poor management and weak public-sector regulations.

The large-scale replacement of unscheduled paratransit services with full specification bus rapid transit trunk-feeder networks in South African cities, as envisioned in the Public Transport Strategy (DoT 2007), has proven costly and difficult to achieve (HvR, 2014; Von der Heyden *et al.*, 2015; Behrens and Ferro, 2016). Consequently, the South African government launched a public transport reform programme to address the declining services with specific attention to the problems of paratransit (Schalekamp, 2015). The programme aims at exploring the prospect of having a hybrid network which incorporates unscheduled paratransit service and scheduled trunk

services to form a trunk-feeder public transport network, which is regarded as a means of executing a more realistic public transport transformation. The trunk-feeder public transport system is such that mini-bus taxis serve as feeders - providing services from local neighbourhoods to the interchange while the large buses provide trunk-line services from the interchange to the central business centres (Birungi, 2017). The trunk-feeder system typically allows smaller vehicles to operate in low-density areas while main corridors can operate more efficiently with large trunk-line vehicles (ITDP, 2007).

There have been relatively few studies that have been carried out especially in Africa to look into the degree of compatibility in terms of operational efficiency and quality of service between an unscheduled paratransit feeder/distribution services and scheduled train/bus trunk services. Among few types of research that have been carried out on paratransit, none have actually looked in to simulation modelling of paratransit operation and its integration with scheduled trunk services or the effect of infrastructural improvement through road space prioritisation on the operation efficiency of paratransit, which depict there is a lack of deep understanding in to operations of integrated unscheduled paratransit feeder/distributor service and scheduled train/Bus trunk feeder services.

The few studies that have looked into the problem of lack of coordination between unscheduled paratransit feeder's system and scheduled trunk services using simulation models were carried out in Europe and America. Examples are Sivakumaran et al., (2011) developed a mathematical model to explore how the coordination of vehicle schedules in an idealised trunk-feeder system can affect user and operator costs. Moskowitz et al., (1987) also developed a simulation model to evaluate the scheduling procedure and operation in transit systems in order to determine the conditions under which timed transfers provide improved and quality transit services as compared to unscheduled arrivals. The recent studies in Africa by Behrens (2015), Schalekamp (2015), Wilkinson (2008), Ferro et al., (2012) and many others have been conducted to look and understand the quality of paratransit and why it needs to be integrated with other modes of transportation. Chitauka (2015) also did some studies to investigate the performance of full BRT and partial Bus priority strategies on arterial roads using microsimulation model. Birungi (2017), is the latest person to carry out research on the effect of feeder network operations on trunk-feeder

network performance, and this dissertation is based on the model built by her. Her work involves modelling of the actual operating pattern of paratransit vehicles and how their integration with scheduled trunk service can be improved.

This study aims to investigate infrastructural improvement through prioritisation of paratransit vehicles on road space that will enhance the operational efficiency of paratransit feeder/distributor services to bring about a more efficient and coordinated paratransit- schedule trunk service complementarity using an agent-based simulation modelling tool.

### 1.1 MOTIVATION FOR THIS RESEARCH

Movement of people between their homes, employment, recreation, and services has been made easy and efficient through the use of on-road public transport which make use of lesser road space per passenger than what private cars require.

Minibus taxis is the colloquial name given to the vehicles used by the paratransit industry in South Africa. Paratransit is the most commonly used public transport in South Africa, as it currently serves more than 65% of the country’s public transport users, but the industry has not been getting the necessary attention and support needed despite arguably being the backbone of the public transport system in South Africa.

*Table 1.1 Public transport mode share and amount spent by the government on each mode in South Africa*

Public transport mode	Metropolitan public transport users in 2013		National govt metro spend 2006/07 - 2016/17	
	No.	%	R b.	%
Rail	823 000	17.5%	144.1	60.5%
Bus	768 000	16.3%	89.2	37.4%
Minibus Taxi	3 110 000	<b>66.2%</b>	5.1	<b>2.1%</b>
Total	4 701 000	100.0%	238.4	100.0%

Source: David Schmidt (2017)

From table 1.1, it can be seen that more attention and supports were given to other public transport modes despite the fact that the paratransit remains the most sought-after public transport mode. Due to the significant role the paratransit industry play in the country's public transport system, they have been included in the trunk-feeder system envisioned by the national department of transport and their role will be to provide feeder's service to the larger carrier of people which is the scheduled trunk service. If the paratransit is to function in this role efficiently, they have to be given the same priority being given to the scheduled trunk vehicles on the road space as they are currently being caught in general congestion which subsequently leads to delays and unreliable journey times because they currently operate in mixed traffic without any priority given to them on road space and at the intersections.

Therefore, actions are needed to be taken to improve the travel time, safety and reliability of paratransit vehicles.

## **1.2 RESEARCH OBJECTIVES**

The main objective of this research is to work on an already developed model that depict the current operations of paratransit rendering a feeder service to scheduled trunk services. The research will investigate the current level of service rendered by paratransit in order to have a deep understanding of how the paratransit operates and subsequently to explore possible additional operational improvements strategies with a focus on improving the operational efficiency of the paratransit feeder's service. The focus will be on identifying various infrastructural improvements through prioritisation on road space and at intersections that can enhance the operational efficiency of the paratransit feeder's service and further evaluating the effect of these infrastructural improvements under different traffic conditions on the overall operational performance of the paratransit feeder's service.

### **1.2.1 SUB- OBJECTIVES**

The following specific objectives will also be investigated in the research.

- To give an outline of the operational pattern of public transport in South Africa with a focal point on the paratransit operations, their travel pattern, transfer of passengers, working hours and duration etc.

- To identify the input parameters required for a trunk-feeder system configuration.
- To create familiarisation with the Commuter software that was used to develop the trunk-feeder simulation model.
- To simulate the operations of paratransit and scheduled trunk service
- To generate Key Performance Indicators (KPIs) on service operations from the output of the developed simulation models.
- To develop additional scenarios/strategies to improve the operation efficiency of the paratransit feeders service.
- To investigate the effect of infrastructural improvement through road space prioritisation on the operational efficiency of feeder services in a normal and congested traffic situation.
- To investigate the types of infrastructure development that can be implemented and their effect on the operational efficiency of the paratransit feeder services.
- To investigate the level of traffic congestion where infrastructure improvement through road space prioritisation needs to be implemented.
- To investigate the level of traffic each infrastructural improvement can withstand without affecting the normal operation or reducing the overall operation efficiency of the paratransit feeder's service.
- To use the obtained KPIs and tested scenario/strategies to assess the trunk-feeder system.
- To use the obtained result from tested scenario to help in policy formulation and practice.

### **1.2.2 RESEARCH QUESTIONS**

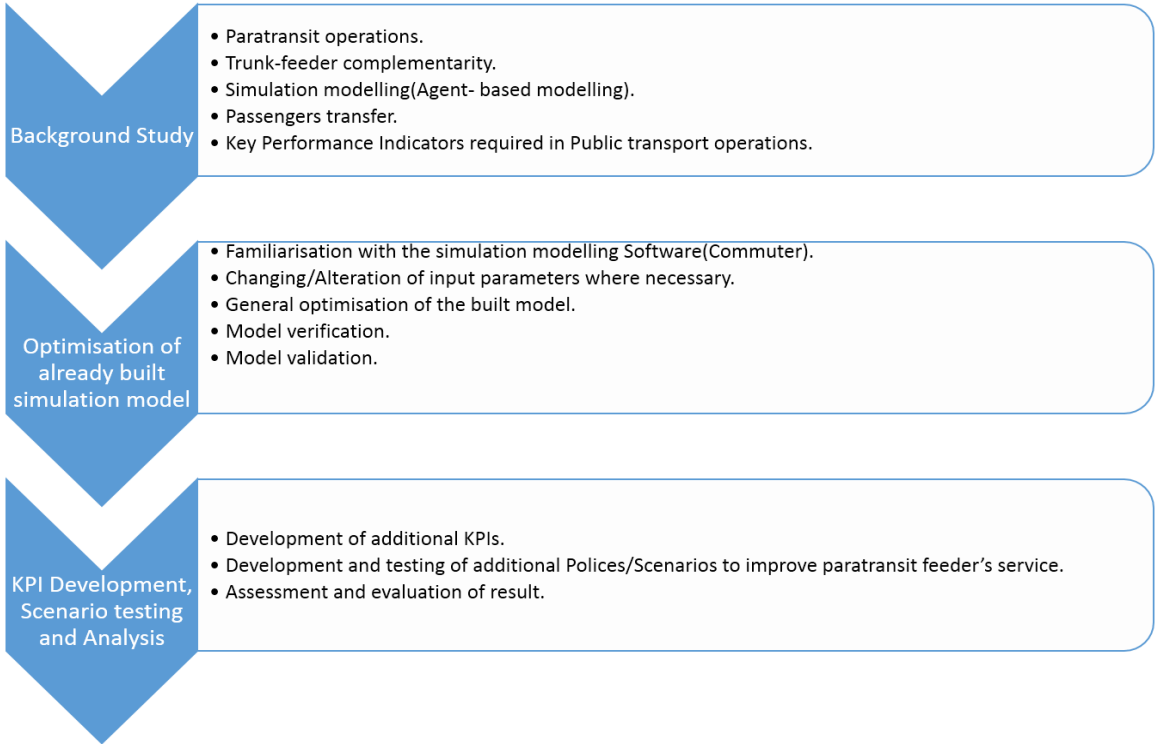
The important questions for this research are

- What are the infrastructural improvements that can be implemented to enhance the operational efficiency of the paratransit feeder's service?
- What are the effects of these infrastructural developments on the overall performance of the paratransit feeder's service?
- At what level of traffic can each of these infrastructural improvements enhance the operational efficiency of paratransit feeder's service.
- At what level of traffic congestion are each of these infrastructural improvements required?

- What are the other non-infrastructural improvement strategies that can be implemented to also enhance the overall performance of the paratransit feeder’s service?

**1.3 RESEARCH FRAMEWORK**

Figure 1-1 below shows the process that this research will follow



*Figure 1-1 Conceptual Research Framework*

**1.4 DISSERTATION STRUCTURE**

This dissertation consists of six chapters, the current chapter explores the background, the problems being investigated and the aim and objectives of this study.

The second chapter review literature about the role of a transport system, public transport system and the types of public transport services. The chapter goes on to review various definitions for paratransit, a brief history of paratransit in South Africa and its role in South Africa public transport system together with how paratransit can be improved in South Africa, and paratransit prioritisation through road space management. The chapter later goes on to introduce what transport modelling is, traffic flow models and microsimulation and its role in modern-day

transport planning. The chapter ends by highlighting performance measures used in assessing the performance of public transport system.

Chapter 3 discussed the characteristics of the study area used in this study which is Mitchel Plain in Cape Town, South Africa. The chapter later highlighted the data required to set up a model and the data collection processes.

Chapter 4 describes the data processing and methodology used in this study. The chapter discussed in depth about commuter which is the transport modelling tool used to build the model used for this study. The chapter ends with highlighting the various Key performance indicators(KPIs) used to assess the performance of each infrastructural improvement scenario modelled and later discusses the infrastructural improvement scenario investigated in this study.

Chapter 5 presented and discusses the results of the simulation for each of the scenario modelled. The chapter presented how each of the infrastructural improvement scenario performed against each KPI discussed in the previous chapter. The chapter ends by using Multi-Criteria Analysis(MCA) to rank the scenario according to their performance at varying traffic levels.

Chapter 6 gives the summary of the result presented in the previous chapter and further supplies the answers to some of the research questions from chapter 1. The chapter presented some recommendation based on the results of the study.

## **2.0 LITERATURE REVIEW**

This chapter review literature and provide theoretical information to understand the paratransit system in South Africa, the paratransit industry and their role in South Africa's public transport system. The chapter also gives an overview of transport modelling, it's concept, the steps involved in setting up transport models and the reasons why transportation should be modelled. The chapter also goes into the detail of micro-simulation which is a subsidiary of general transport modelling concept, uses of microsimulation and why microsimulation is required in modern-day transport planning. The chapter also reviews some literature on traffic signal designs which is part the infrastructural improvements investigated in this research, so therefore, knowledge of traffic signal design is useful in implementing this scenario and its effect on the overall performance of the paratransit is investigated. The chapter lastly discussed the Key Parameter Indicators (KPIs) required to evaluate a Public transport system.

### **2.1 THE ROLE OF A TRANSPORT SYSTEM**

The primary role of a transport system is to convey people and their goods from their current location to wherever they want to be, i.e. overcoming the distance barrier between people and their goods and where they need to be. Transport does not only serve to overcome the barrier of distance to an activity or event but it also influences the location where the activity or event takes place.

The CoCT,2006 quoted that “*Transport is the lifeblood of a city and various organs within a city cannot function without a transport system that works for all*”, which literally means that no city can function without a well-planned and a functioning transport system. The transport system consists of infrastructure and service components, and transport planning has to be dealt with in a holistic approach (Mbara,2002).

### **2.2 PUBLIC TRANSPORT SYSTEM**

A Public transport is an important component of a city's transport system. Public transport provides alternative means of mobility for the low-income segment of the population that does not have access to a private vehicle, especially, in a developing country, such as South Africa where a larger proportion of their population are lower income earners, which make them become public transport captives.

Duff-Riddel (2009) describes the role of public transport as follows: *“The role of public transport is to provide access to economic opportunities, reduce the cost of doing business, to provide environmental sustainability to support other broader strategies, to provide access to social opportunities and to achieve shared growth and integrated development. Public transport goes wider than the provision of a public transport service and it means the determination of policy, the making of legislation, the regulation and control, the provision of public transport services and the provision of infrastructure for public transport.”*

The ability of public transport to cater for the mobility of larger number of passengers at a time makes it an obvious choice mode of transport that can help in saving the need for space and infrastructure along the route they are plying and also for parking spaces when they are not in use. Where a larger number of people need to be conveyed from one place to another, public transport is the most energy efficient, causing lesser emission than private vehicles to convey the same number of passengers. Public transport has also been regarded as a useful Travel Demand Management strategy when it comes countering climate changes. But for a public transport to contribute to both social and economic development of a city, it must be safe, affordable, reliable, efficient and demand-responsive.

## **2.2.1 TYPES OF PUBLIC TRANSPORT SERVICE**

There are basically two main types of public transport service which are the formal and the informal(Paratransit) Public transport services.

### **2.2.1.1 Formal services**

Formal public transport services are services that operate on fixed routes and bus stops, observes some fixed timetables and schedules, make use of some ticketing system either by using a smart card or manual ticketing as some proof of payment before passengers can board. The formal public transport services consist of the road and rail-based transport system. In South African cities, rail forms a central component of the public transport system even though road-based public transport is the most available mode especially in areas outside the walkable catchment

of the rail network (City of Cape Town, 2011). Example of road-based public transport services in South Africa are the normal Bus (e.g. Golden Bus Arrow etc.), Bus Rapid Transit (BRT) (e.g. My-Citi Buses in Cape Town, Rea-Vaya in Johannesburg, Are-yeng in the city of Tshwane etc.).

### **2.2.1.2 Paratransit Services**

Paratransit services are public transport services that don't operate on any fixed route (they only operate on routes where passenger demand is pretty high), doesn't observe a fixed timetable or schedules, doesn't make use of any ticketing system and the driver can be behind the wheel as long as he feels i.e. no limitation on the number of hours he can work.

## **2.3 PARATRANSIT DEFINITIONS**

Paratransit provides a valuable service providing a flexible service that stands between a formal service and private cars. Paratransit often takes different forms depending on each city's context. However, researchers all over the world have observed the operations of paratransit and they have come to define it based on its most salient features (Ferro, 2015).

Wilkinson et al. (2012) based on different analyses in Africa define paratransit due to its nature of service flexibility. The study defines paratransit as a flexible mode of transport that lacks schedules or frequencies which make use of small to medium-sized vehicles (often ageing minibuses).

Behrens et al. (2012) who studied paratransit in some Sub-Saharan African cities defines paratransit based on its regulatory framework. They defined paratransit as "informal and unregulated".

Chapain (2005) in Mexico defined paratransit based on the capacity of the vehicle being used. The vehicle being used ranges from minibuses (10-15 seaters) to midibuses with intermediate capacity (20-40 seaters) and to larger buses with 50 or more seaters capacity.

## INFORMAL TRANSIT PROVIDES MOBILITY IN THE DEVELOPING WORLD



Figure 2-1 Paratransit in developing countries around the world

Source: - [http://s3.amazonaws.com/kc-assets/TRB13514/previews/14-5280\\_E-2.jpg](http://s3.amazonaws.com/kc-assets/TRB13514/previews/14-5280_E-2.jpg)

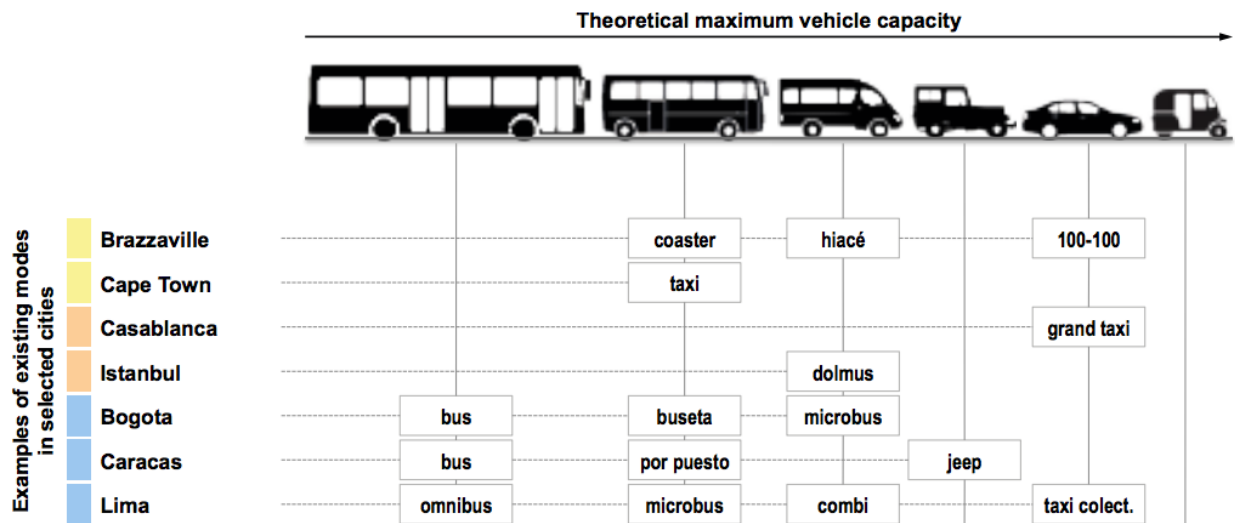


Figure 2-2 Various paratransit vehicles used in some cities across the world.

Source: (Ferro,2015)

## **2.3.1 THE SOUTH AFRICAN PARATRANSIT INDUSTRY**

### **2.3.1.1 Brief history of South African Paratransit Industry**

Paratransit across the world often emerge because of non-availability of formal transit or as a result of low-quality or unstable service. The paratransit which is fondly referred to as the minibus taxi in South Africa emanated as a result of segregation in South Africa from 1948 to 1994. Public transport became periodical and uncertain.

In the earlier years, transportation of passengers without a permit was prohibited by the motor carrier transportation act of 1930 which made transport a monopoly being held by the South African Transport Service (SATS). The act was put in place as to shred off any competition by the road transport with the state-owned railways. The taxis available were restricted from carrying more than four passengers. The quality of service rendered by the trains was very poor, as the commuter does not know when trains will arrive. Therefore, the waiting time was always uncertain, and the load capacities of the trains were also uncertain because the commuters do not know if the incoming train will be able to accommodate even half of the passengers waiting to board at the station. Because of this, many taxis started operating illegally, especially, in the rural areas that were not serviced by the railway.

In the late 1970s, the legislation does not give the full definition of taxis but was regarded as a bus/vehicle that cannot carry more than 9 people (driver inclusive) at a time. This flaw in the legislation allowed mini-bus taxis to start operating legally without having to adhere to the strict regulations of the public transport vehicles. The first taxi permit was area-based whereby the authorised taxi drivers were only allowed to operate within a 100km radius of a central point. The competition for passengers was aggressive as drivers started arguing over route's ownership.

The Minister of transport (Hendrick Schoeman) then from 1980-1984 recommended that the taxis should go back to using four passenger's sedan vehicles. The recommendation was countered by the taxi owners implying the policy will kill the taxi industry. The South African Black Taxi Association (SABTA), which happens to be the only recognised taxi associated at the end of 1989 also argued that deregulation of such manner will allow many operators to enter the market, which will eventually lead to chaos and violence.

Thereafter, local taxi liaison committee was set up, which was later referred to as the local taxi council. This was set up in major centres and the local authorities were then bestowed with the responsibility of regulating the industry.

## **2.4 THE ROLE OF PARATRANSIT IN SOUTH AFRICA'S PUBLIC TRANSPORT AND WAY FORWARD FOR IMPROVEMENT**

The Paratransit industry with a colloquial name “Minibus Taxi” industry in South Africa is the backbone of public transport in major South Africa’s cities as it accounts for transporting majority of public transport users, this is likely to remain the same for some time to come. The industry stands as a major economic sector on its own serving as an economic empowerment especially for the black portion of South Africa’s population. It is an industry with great prospect for huge innovations and development. However, the industry is faced with many challenges, which range from governance, infrastructure, regulation, operations, delivery of passenger-friendly service and its economic model. In recent years, the focus of national government has been to improve the public transport system in country which has brought about the strategy of implementing Integrated Rapid Public transport network (IRPTN) using BRT as the backbone of the system, but the role of the paratransit industry has been neglected and initiated strategy, such as Taxi recapitalisation and inclusion of paratransit in the BRT operations has an under-par effort, which has not necessarily look in to various ways in which the paratransit industry services can be improved and develop the industry as a full partner in delivering a high-quality public transport services.

According to Bruun and Behrens (2016), the following strategy options can be employed to develop the business and improve the services rendered by the paratransit industry.

- 1) **Business Development-** This tends to look into various ways by which paratransit business can be more viable. Viable business can be achieved through the following
  - *Consolidation-* Bringing together of fragmented small operators to form a corporate entity. This can be achieved by introducing route association requirements in operating licensing or cooperative/management company membership before issuing out operating license. Consolidating the fragmented paratransit operators will reduce the “in the market”

competition, which is the norms of the taxi drivers and also provide an avenue for easy and effective policy engagement with the paratransit sector.

- *Bulk purchasing discounts*- The consolidated paratransit operators can request for bulk purchasing discounts on vehicle parts and fuel by negotiating with the supplier for their collective business. This will help in reducing the operating and vehicle repair cost.
- *Diversification*- This is a way in which other businesses can be incorporated into the paratransit industry, for example, the consolidated operators can purchase a filling station in order to sell fuel to its members at a cheaper rate but at a normal rate for non-member and private car users. Consolidated operators can also reach an agreement with advertising agencies/companies whereby its member's vehicles can be used for advertisement of some certain product or services. Diversifying business will reduce exposure to risk and leads to more viable business for the paratransit operators.
- *Skills training*- This is a way of capacitating the drivers by changing their mindset and upgrading their skills set. The skills set can range from regulation training to business skill training. This acquired skills by the operators can be used to establish and improved vehicle depreciation costing, leads to more viable business for the operators and increase their awareness about better labour relations.
- *Passenger-side subsidy incentives*- This is a mechanism where paratransit operators are incentivized through fare bonuses by providing a specific service for particular groups in a way that makes it stands as complementary to an integrated public transport. This mechanism encourages more equity in the distribution of subsidy, it also has the potential to increase the viability of the business and it provides an avenue for paratransit to be integrated into IRPTN.

2) **Improvement of operating environment**- This strategy tends to look into various ways in which the operating environment of the paratransit can be improved that will ease their operations and deliver better quality services.

- *Provision of ranks/interchange*- Provision of ranks/interchange at some strategic point within the cities and along some major corridor is very important for smooth and orderly operations of the paratransit. The ranks should have boarding and alighting berths, wayfinding signage, and vehicle storage facilities. Provision of interchange

facilities will facilitate easier and safer passenger transfer which will enable easier implementation of trunk-feeder relationship. Provision of ranks will also reduce congestion on the road as a result of reduction from vehicles using street space and roads for route termination and transfers of passengers.

- *Provision of exclusive right of way for paratransit vehicles-* This will require allocation of road space exclusively for paratransit vehicles either in the form of a queue jumper or bus lane. Providing exclusive right of way for paratransit vehicles will bring about some level of relief for the public transport users from traffic congestion caused by private car users, it will also improve the vehicle operating speeds and bring some multi-modal benefits with better lane balance. This is the motive behind this research, to investigate how infrastructural improvement such as queue jumper, dedicated lane and the introduction of traffic signals control at some significant intersections can improve the overall efficiency of the paratransit feeder's service.
- *Provision of embayment and stops-* Provision of boarding and alighting facilities on some strategic locations along the road corridors is essential as it will reduce illegal in-corridor stopping for commuters boarding and alighting, improve the comfort of the waiting passengers and also improve the information available to the passengers.

**3) Vehicle fleets-** This tends to into various incentives that can be used to modernise paratransit fleets and improve their roadworthiness.

- *Vehicle renewal incentives-* This helps to set aside some funds for vehicle replacement and to take full consideration of vehicle depreciation cost. Implementing vehicle renewal incentives will ensure use of constant modernize fleets with operating, safety and comfort benefits and also serves as an avenue for improvement of service quality.
- *Accessibility to cooperative loans-* Cooperative loans can serve as a source of vehicle finance especially when it seems difficult to get loans from formal financial institutions. Constant access to vehicle finance helps in keeping the fleet modernized with comfort, safety and operating benefits.

**4) Operations-** This tends to look into various incentives that can be used to improve paratransit service operations.

- *Driver training*- This is a way of equipping paratransit driver's educational background by improving their driving skills, stopping behaviours, fare collections practices, and how to relate to their customers professionally. Improved driver's skills will enhance the provision of improved passenger service quality, safety and comfort.
- *Payment of salary to drivers*- Paratransit drivers should be paid on a daily, weekly or monthly basis or base on the kilometres driven instead of the 'target system' commonly known with the paratransit operators. The benefits of paying salary to the drivers include the removal of the urge to drive aggressively and unsafely in order to maximize fare revenue and trips frequency, especially during peak hours. It also brings about better labour relation between the owner and the driver.
- *Consolidated vehicle crew recruitment and vehicle management*- Prior to payment of salaries to drivers often involves recruitment of vehicle crew and their management which include vehicle and route rostering, monitoring and discipline of passenger's complaint. This has the benefit of improving driver and fleet management, provide equal access to more lucrative routes and periods and systematic maintenance.
- *Speed Governors*- Installation of speed governors into paratransit vehicles will limit the vehicle speed which will subsequently improve safety and reduce consumption of fuel.
- *Introduction of cashless ticketing system*- This involves usage of tickets, vouchers or cards to pay for transport fares instead of the drivers collecting cash for fares payment. This will improve income for the business owners, discourage traffic police corruption and enable feeder service and universal access incentives.

#### **2.4.1 PARATRANSIT PRIORITISATION THROUGH ROAD SPACE MANAGEMENT**

Public transport (PT) is less flexible and most times always take longer times to get to traveller's destinations, because several stops are made to pick up and drop off passengers, transfer to other modes of transport or routes, thereby made it not attractive to citizens compare to private cars. But this perceptions and problems can be counteracted by creating priority systems for public transport vehicles on the road and at intersections.

However, reallocation of available road space to provide public transport priority is increasing at a rapid rate worldwide (Currie et al., 2003). Volumes of PT vehicles and passengers sourced from experimental or other static modelling studies are primarily used for the provision of PT priority schemes. Warrants for public transport prioritisation are rarely determined by using dynamic traffic simulation method. It is arguably clear that implementation of PT priority measure will reduce travel time for public transport vehicles.

Research has shown that passengers value reliability of PT services than an improved PT vehicle travel time. Improving travel times and the reliability of PT services has proven to have a direct relationship to increasing ridership (Currie et al., 2003) which will, in turn, reduce traffic congestion, reduce accident cost, reduce vehicle-operating costs, and reduce environmental impacts and emissions (Currie et al., 2003; Targa and Rodriguez, 2004). Road space needs to be prioritised for PT such as BRT, buses and paratransit vehicles in place of private vehicles with the sole objective of planning towards a sustainable transport system in relation to cost, environment and physical space constraint. PT prioritisation on road space will provide a more balanced allocation of road space among road users rather than private vehicles on the road. With limited road reserved for PT vehicles, the current road conditions show a rapid increase in private vehicles which eventually leads to traffic congestion, urban sprawl, and air pollution.

Therefore, there is a need to improve transportation systems around urban cities of the world (Gautam et al., 2012, cited in Gautam et al., 2013).

It has been suggested by literature that restriction of access to cities congested areas can actually improve mobility for all road users instead of allowing those areas to get more congested. Even if spaces have to be taken from private cars, dedication of road space to more sustainable transport modes like public transport vehicles can improve accessibility for all modes (Gonzales, 2011). Most recent transport planning and modelling exercises majorly focused on private cars Mobility based on cars have been proven to increase economic growth and therefore still remain an integral part of traffic management planning. However, there is now a shift from car planning towards person trip planning by looking for ways to encourage the use of alternative modes of transport such as PT and NMT (Wallström, 2004).

Road space Management involves finding a way to balance the needs of competing demands for limited road space and time.

The most logical approach to road space prioritisation is to provide sufficient road spaces that will allow other modes of transport apart from private cars to be promoted in these spare spaces. (Behrens, 2007). However, this must not be done to adversely affect the mobility of private cars especially during peak hours which can lead to more traffic congestion. The outcome should be 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.

As paratransit caters for the transportation of more than 65% of the South African passengers, but they are always caught in general traffic congestion leading to delayed and unreliable journey times. Therefore, actions are needed to improve the travel speed, safety and reliability of paratransit vehicles. One of the actions to achieve these is through prioritisation of paratransit vehicles on road spaces. Priority can be given to paratransit vehicles through Busways/lanes, at the intersections and at the Bus stops.

#### **2.4.1.1 Busways/Lanes**

A Busway is used to describe part of roadways which are dedicated to being completely used by buses. A bus lane is a lane on a roadway that is restricted to be used by buses/public transport vehicles only, probably at certain days and times or at all the time of the day, generally to increase the speed of public transport vehicles that would otherwise be held up by traffic congestion. It is an infrastructural improvement/road space prioritisation strategy which can be achieved through separation, marking or total guidance on road space, it is implemented to improve travel time and reliability of public transport by reducing delay caused by other traffic.

The different types of busways/lane are

- High occupancy vehicles(HOV)/High occupancy toll(HOT)/'No car' Lanes,
- No stopping routes (red routes),
- Parallel bus lanes,
- Contraflow bus lanes,
- Median (centre stations) bus lanes,
- Median (side stations) bus lanes,

- Median(elevated) bus lanes,
- Kerbside bus lanes,
- Malls.

**2.4.1.2 Prioritisation at Intersections**

Priority can be given to paratransit vehicles at intersections through traffic signal pre-emption, bus advances and queue jump lanes.

- *Traffic signal Pre-emption*- Signal pre-emptions works on the principle that it detects when a bus/public transport vehicle is coming and turns or keep the traffic light green to allow the bus pass through an intersection. There is a detector on the road which is linked to the traffic light, it sends messages ahead to the traffic light when it detects that a bus just passed it. The message sent by the detectors instruct the traffic light that a bus is on its way thereby keeping the traffic light green if they are about to turn red until the bus passes, and if the lights are red, the green phase is brought forward.

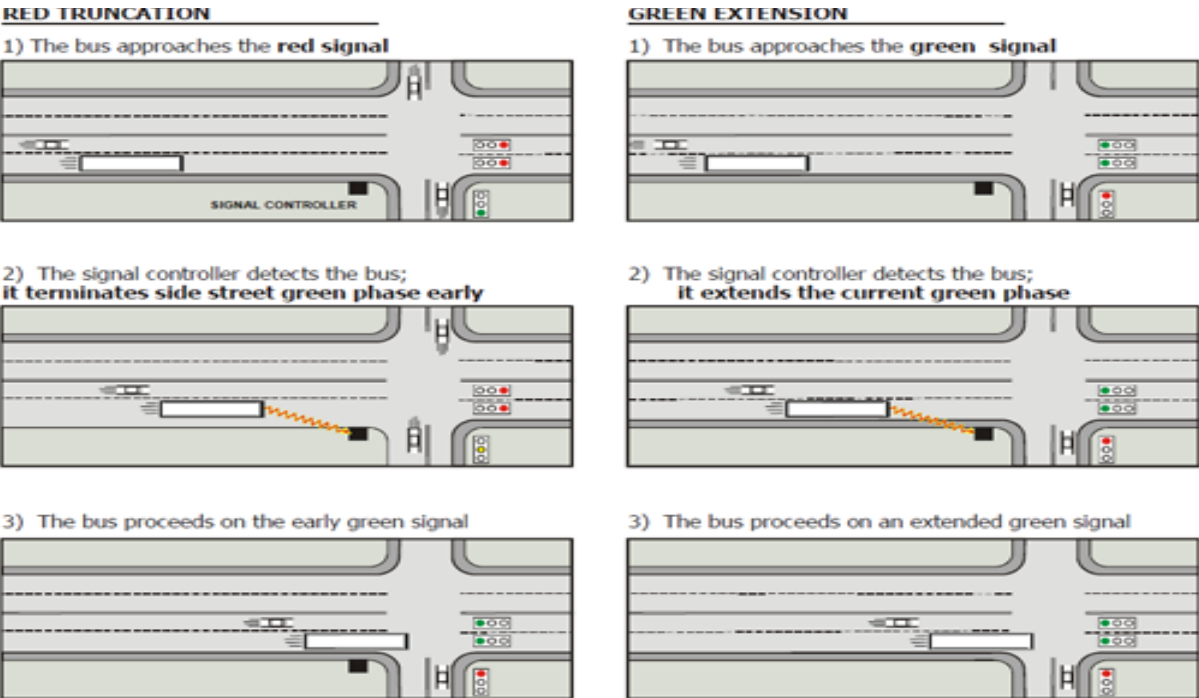


Figure 2-3 Traffic Pre-emption design. Source: [https://ops.fhwa.dot.gov/publications/fhwahop08024/images/9\\_2.png](https://ops.fhwa.dot.gov/publications/fhwahop08024/images/9_2.png)

- *Bus Advances*- Bus advances use the same principle as the bicycle boxes. Bus advance areas allow buses/public transport vehicles to move to the front of the queue at traffic lights. An extra set of traffic lights with special bus signals would have been installed about 50metres

from the main intersection, which is used to hold back other traffic but allows buses/public transport vehicles to move to the front.



Figure 2-4 Bus advance at an intersection. Source:Auckland city

- **Queue Jumps-** A queue jump is a special type of roadway geometry, which is used to provide priority especially for public transport or non-motorised transport at an intersection. The set up comprises of an additional lane, which is restricted to be used public transport vehicles only on the approach to a signalised intersection. The queue jump lane is often accompanied by a traffic signal designed with an initial phase specifically for the vehicles on the queue jump lane, which allows them to head-start and move over the queued traffic on the normal lanes and merge back into the normal travel lanes immediately after moving beyond the traffic signal. The main reason for a queue jump lane at an intersection is to allow public transport vehicles with higher capacity to jump the traffic queue and cut to the front thereby reducing delay caused by traffic signals and improving the overall efficiency of a public transport system.



Figure 2-5 Queue jump at an intersection. Source: <https://nacto.org/publication/transit-street-design-guide/intersections/intersection-design/queue-jump-lanes/>

### 2.4.1.3 Bus Stops

Priority can be given to paratransit vehicles on the road space through the design of bus stops. The most common bus stops for paratransit vehicles are embayment and bus boarders

- *Embayment*- This is a common off-street type of bus stops design for public transport vehicles. Embayment should be designed in such a way that will provide easy access for public transport vehicles to join back the traffic stream on the main travel lanes.



despite improvements, vehicles still struggle to re-enter the traffic stream in congested conditions

Figure 2-6 Embayment for public transport vehicles.

Source: END5035Z Lecture notes by Roger Behrens(2015)

- *Bus Boarders*- This is an on-street type of bus stops design for public transport vehicles, which intrudes on to a traffic lane making it easier for buses to stop and easily move back into the traffic stream.

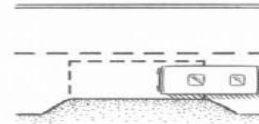


Figure 2-7 Bus Boarders for public transport vehicles. Source: Auckland city

## 2.5 INTRODUCTION TO TRANSPORT MODELLING

Transportation models are defined as set or series of mathematical equations, which are used to represent how people make their choice when they want to travel. Travellers making decisions about how, when and where to travel are the reasons why travel demand occur. Many factors, such as characteristics of the traveller, his or her family situation, socio-economic group of the traveller, the destination, route and the mode of travel available for the trips are the basis on which travel decisions are made upon. Mathematical relationships are used to represent human behaviour when making choices about their travel patterns. These models are derived based on assumptions and are limited to previous data collated over time and which are available to make future travel demand forecast. The coefficient used in the model equations are calibrated based on these existing data.

Transportation models are important because transportation plans and investments are made base on the forecast of people's future travel pattern, and are also used to estimate the number of trips that will be made at some future dates usually between 15 to 25 years from now into a given land use and transportation system alternatives.

There are basically two theoretical methods used in transport modelling, and it is essential to understand the two methods especially when one of the approaches that best suit the problem-context to be solved needs to be chosen. The two approaches in transport modelling are trip-base models and activity-based models.

**Trip-based models-** Trip-based models are currently the most universally used models, it is the classic transport model that used the conventional four-step modelling process. It uses individual trips as the unit of its analysis. Time-of-day trips factors are used when modelling time-of-day trips or 24 hours total trips are used or the time factors are not even included in the model. The parameter trip is used as the base of analysis and separate models are made for home-based trips and non-based trips. The organisation of trips is not considered because there is no distinction between home-based trips that are made directly from origin to destination or home-based trips that have multiple stops along the way from its origin to its destination i.e. trip chaining is not considered. The impact of such multiple stops during the trips are considered to be significant in the local environment.

**Activity-based models-** Activity-based models were developed to understand travel behaviour responses which focus on a set of activity patterns rather an aggregated trip rate per household. The model tries to model a comprehensive daily travel-activity pattern for individuals. This allows the transport planner/modeller to respond to spatial constraint, allowing activity rescheduling, trip chaining and destination substitution. One good example is micro-simulation models, which, when they are used as input into a dynamic assignment model, replace the trip generation, distribution and modal split of the conventional trip-based models to produce a dynamically trip tables.

Activity-based models require time, survey data and decision-making criteria for forecasting and analysis. This requires the collection of data about individual's activities during the day. It is similar to making household survey because data for in-home and out-of-home activity data need to be collected. The information need to develop an activity-based model is quite extensive but the afterwards results are quite worth it as they provide a much comprehensive understanding of travel patterns and trip making.

### **2.5.1 INTRODUCTION TO TRAFFIC FLOW MODELS**

Traffic flow models can be used to simulate traffic. For example, to predict or estimate the effect of using a new part of an infrastructure on the general traffic conditions in the network. Traffic flow model can be used to provide answers to general traffic questions, such as: What causes traffic jam and when do they emerge? How does traffic jam propagate in space and time? And how long

does it take for congestion caused by traffic jam to be resolved? Furthermore, traffic models can be used to improve road safety.

*Table 2-1 Overview of traffic flow model classifications*

Representation	Behavioural rules	
	Microscopic	Macroscopic
Vehicle based	Microscopic flow models	Particle models
Flow based	Gas-kinetic models	Macroscopic models

Source: Hoogendoorn and Knoop (2001)

Traffic flows models can be categorised using various dimensions such as continuous or discrete, deterministic or stochastic, analytical or simulation etc. But the distinction between microscopic and macroscopic traffic flow modelling approaches is the most common classification of traffic flow models.

Traffic flow models are categorised based on two major aspects: firstly, is the **representation of the traffic flow** in terms of flows (macroscopic), group of drivers(macroscopic) or individual drivers (microscopic). Secondly, is the **underlying behavioural theory** which can be based on the characteristics of the flow (macroscopic) or individual driver (microscopic behaviour).

Based on observation, driver’s behaviour such as headways, driving speeds and driving lane are all as a result of different factors such as the driver-vehicle combination (vehicle characteristics, driver experience, age, gender etc.), the traffic conditions (average speeds and densities), infrastructure conditions (road condition) and external influences (weather condition and driving regulations and law). Different theories have been proposed over the years to dynamically relate the observed driving behaviours to the parameters describing these conditions (Hoogendoorn and Knoop, 2001)

According to Hoogendoorn and Knoop, (2001), a microscopic model provides a description of the movements of individual vehicles that are considered to be a result of the characteristics of drivers and vehicles, the interactions between driver–vehicle elements, the interactions between driver–vehicle elements and the road characteristics, external conditions and the traffic

regulations and control. Most microscopic simulation models assume that a driver will only respond to the one vehicle that is driving in the same lane directly in front of him (the leader).

Depending on the driver's preferences and abilities coupled with other factors, such as the roadway conditions, curvature, the road speed limits etc., the driver can freely choose his speed especially when the number of driver-vehicle units on the road is small. The driver's target speed is called the free speed. The free speed varies from one driver to another, but the free speed of a single is not constant and thus changes over time. However, most microscopic models assume that the value of the free speeds is constant and it is driver-specific. The drivers can no longer drive at the free speed when the traffic condition deteriorate. The driver will have to adapt his speed to the prevailing traffic conditions i.e. the driver is following as he won't be able to overtake or pass the slower vehicles.

### **2.5.2 SAFE - DISTANCE MODELS**

Pipe (1953) is the first person to develop the first car- following model, which was based on the assumption that drivers maintain a safe distance. The rule for safe-distance is that for following vehicle  $i$  at a safe distance  $s_i$  is to allow at least the length  $S_o$  of a car between vehicle  $i$  and a part which is linear with the speed  $v_i$  at which  $i$  is travelling:

$$s_i = S(v_i) = S_0 + T_r v_i$$

Where,  $S_o$  is the effective length of a stopped vehicle (additional distance in front inclusive), and  $T_r$  represent a parameter, which is synonymous to the reaction time. Forbes et al. (1958) also proposed a similar approach. However, both Pipes's and Forbes's theories was compared to field measurements and it was concluded that the minimum headways are slightly lesser at low and high velocities than the observed in empirical data according to Pipes's theory.

### **2.5.3 STIMULUS-RESPONSE MODELS**

Phenomena such as hysteresis, traffic instabilities etc. which are observed in real life traffic flows do not seem to be captured effectively by safe-distance model. These phenomena are incorporated into stimulus-response models, which are dynamic models that illustrate more realistically the reaction of drivers to things like changes in distance, speeds etc. relative to the vehicle in front by considering a finite reaction time. Stimulus-response models are applicable to quite busy traffic

flows where the possibilities of overtaking are quite low and therefore, drivers are forced to follow the vehicle in front of them.

The assumption that drivers control their acceleration( $a$ ) is used in stimulus-response models.

The popular model of Chandler et al. (1958) is also based on the inherent hypothesis that a driver's acceleration is proportional to the relative speed  $v_{i-1} - v_i$ :

$$a_i(t) = \frac{d}{dt} v_i(t) = \alpha(v_{i-1}(t - T_r) - v_i(t - T_r))$$

Where  $T_r$  represent the overall reaction time and  $\alpha$  represent sensitivity. Some field experiments were carried out to quantify the parameter values for the reaction  $T_r$  and sensitivity  $\alpha$ , and it was concluded that  $\alpha$  depends on the distance between the vehicles i.e. the closer the vehicles are together, the higher will be the sensitivity and vice versa.

Stimulus-response models have been applied mainly to single traffic lane and in traffic stability analysis. There has been no general applicable set of parameters estimates that has been established so far, estimates for parameters are specific to each site.

## **2.6 MICROSIMULATION AND ITS ROLE IN MODERN-DAY TRANSPORT PLANNING**

Since the introduction of microsimulation in the 1990s, it has literally changed the way traffic engineers approach transport modelling and test transport and traffic scenarios. It represents a significant improvement in transport modelling. Its ability to test scenarios and immediately see results through a reality-virtual display or saved externally and its focus on vehicle behaviours and interactions on the network make it a ground-breaking revolution. Since its inception, microsimulation has advanced immensely and has been used in wide variety of applications globally. Microsimulations are used to investigate the following

- Bus priority,
- Signalised roundabouts,
- Ramp metering,
- Wide area traffic management,
- Urban traffic control,

- Traffic calming,
- Roadworks design,
- Parking location and control,
- Pedestrian and Cyclist Interaction,
- Traffic impact,
- Incident management,
- Traffic emissions and many more.

Microsimulation has been used in many circumstances where other modelling systems could not thrive. It is undeniable about the fact that microsimulation has transfigured traffic modelling and the way modelling results are being presented to the world.

Microsimulation differs from the traditional static modelling methods in two unique ways. Firstly, microsimulation models the action and interactions between various mode of transport in a simulated time step, which is typically less than 1s, as they travel through a road network. The classic modelling methods on the other hands tend to calculate the average trip times across a time frame, maybe of one hour or more by assigning matrix of trips to a network using the empirical relationship between traffic flow and capacity. Microsimulation's ability to simulate individual vehicles or people makes it possible to provide a real-time visual display which represents the second unique difference from the classic modelling methods.

Microsimulation works on a simple principle, which is the moving component of the system (the moving vehicles) execute base on their physical properties, constraint and the behavioural attributes of their driver i.e. aggressiveness and awareness of the drivers. Vehicle following, gap acceptance and lane changing are the three interacting models that governed the movement of individual vehicles in microsimulation. The result of these moving vehicles depends on their physical and behavioural characteristics.

Microsimulation has provided a coalesce approach to traffic modelling, which has allowed modellers to handle problems where the traditional modelling could not tackle by directly modelling the components of traffic flow instead of their mathematical proxy. Many applications have been applying microsimulation to tackle conventional and more challenging problems. For instance, microsimulation is the ideal methods to model the characteristics of traffic flow in a

congested network, as this depends on a deep comprehension of vehicles interactions and behaviour as to be able to replicate crucial flow characteristics, such as shock waves (disturbances that occur in a traffic line in response to changing conditions at the front of the line) and flow breakdown. Furthermore, microsimulation is able to illustrate the circumstances that lead to congestion in all types and sizes of road network.

The ability of microsimulation to present and display results by providing real-time display and high-resolution 3D graphics has provided a substantial means to converse the benefits of a scheme to stakeholders and the public in general. This negates the output from a traditional modelling method which consumes time to be interpreted and sometimes confusing especially to people outside of transport modelling profession. Also, the interactive nature of microsimulation makes it an ideal method to quickly test scenarios and make decisions. It enables the effect of proposed design changes to be tested and easy visualisation of these impacts which allows informed decision making to be made with ease.

## **2.7 PUBLIC TRANSPORT PERFORMANCE MEASURES**

TRB (2003) described transit performance measure as “a quantitative or qualitative factor used to evaluate a particular aspect of transit service”. Kelley (1982) further said that these measures are usually quantifiable and can be expressed as a whole number, a percentage or as a ratio.

In 2005, Gleave et al. categorised the criteria for measuring the performance of a transport system into seven in their study. It consists; affordability, safety, quality of service, journey times, impact on the environment, the working condition of people employed in the transport industry and sustainability over a number of years.

Ryus (2003) also uses eight criteria for assessment of Public transport performance, they are; availability, service delivery, economic, safety and security, maintenance and construction, capacity, travel time and community.

Public transport system performance evaluation was classified into four categories by Vuchic (1981). They are categorised as below.

- 1) **System Performance-** This describes the entire set of the performance elements
  - *Service Frequency-* The number of Transits Unit that pass a point on a transit line in one direction in one hour (or some other time interval)
  - *Operating Speed -* This is the average speed that Transit Unit travels on a transit line.
  - *Reliability-* Described as the percentage of transit unit arrivals with less than a fixed time deviation from normal time schedule. It depicts the average waiting time for passengers at public transit stops.
  - *Safety-* This is expressed as the number of fatalities, injuries, and property damages that occurred per 100 million passenger-km.
  - *Line or offered capacity-* This is the maximum number of spaces in public transport vehicles that can be transported past a fixed point in one direction in one hour.
  - *Productive capacity-* This is the product of line capacity with its operating speed. This is one of the most important quantitative performance indicators as it incorporates capacity that affects operators with operating speed, which affect the passengers.
  - *Work-* Transportation work performed on a transit line represents its output i.e. the quantity of offered or utilized service. Offered work is the product of line capacity and the length of line travelled while utilized work is the product of the passenger volume by the length of the line travelled expressed as passenger-km.
  - *Work utilization coefficient –* This is the ratio of utilised to offered work.
- 2) **Level of service(LOS)-** This tends to measure the overall general service characteristics that affect public transport users. The factors that affect LOS can be categorised into three:
  - Performance elements that affect passengers which simply are operating speed, reliability and safety.
  - Qualitative elements which are also part of the quality of service rendered by the public transport system. Examples are convenience, comfort, system simplicity, aesthetics, cleanliness and passenger's behaviour.
  - Price paid by the passengers for the service.
  - Impact- The overall level of impact the public transport system has on the environment and the area its serving.
- 3) **Costs-** The actual cost of building and running public transport service. It is divided into two categories, which are: investment cost and operating cost.

### **2.7.1 KEY PERFORMANCE INDICATORS TO EVALUATE THE EFFECT OF INFRASTRUCTURAL IMPROVEMENT ON PARATRANSIT FEEDER'S SERVICE**

This section will briefly discuss some KPIs which are directly part of the output results generated after successful model simulation by the agent-based modelling tool used in this study, coupled with some other KPIs which are formulated from the output results but will be useful indicators to evaluate the effect of different scenarios considered in this study on the overall operation efficiency of paratransit feeder's service. The KPIs that will be used to evaluate and assess the effect of each scenario are as follows.

- **Load factor-** This depicts the capacity utilisation of the paratransit vehicles. It is the ratio of in-vehicle passengers to the total capacity of the paratransit vehicles expressed in percentage.
- **Dwelling time-** This is the fraction of the total trip time used at the stops for passengers to get in and off the paratransit vehicles expressed in minutes.
- **Crawling time-** This is the total time spent by the paratransit vehicles waiting at signalised intersections and in traffic congestion expressed in minutes.
- **Number of boarded waiting passengers-** This is the ratio of the number of passengers that boarded to the number of waiting passengers at the stands expressed in percentage.
- **Total distance covered by the paratransit vehicles-** This is the summation of the distance covered by all the paratransit vehicles considered in the model during the simulation period expressed in kilometres. The higher the distance the higher will be the impact of the testing scenario.
- **Total time used by paratransit vehicles-** This is the summation of the total trip time by each paratransit vehicle used in the model during the simulation period expressed in minutes. The smaller the overall time used by all the vehicles, the higher the impact of the testing scenario.
- **Reliability-** Reliability affects the overall passenger's travel time. It is measured in affiliation to the duration of time passengers uses at the public transport stops while waiting for the arrival of public transport vehicles and in terms of consistency of passenger's arrival time at the stops on a daily basis. It can also be measured in terms of regularity of headways between successive public transport vehicles and on-time performance (TRB, 2003). It is referred in this study as the feeder's waiting time.

There some factors that affect reliability which can be controlled by the operator and some that cannot be controlled by the operator. Examples are unevenness in passenger

demand, construction work, vehicle breakdown, traffic condition etc. (TRB, 2003).

- *Travel Time-* In Public transport, the majority of the indicators used to measure the performance of public transport circumscribe around trip travel time. Litman (2014) said time and how it's being spent is one the most valuable possession to human beings. Travel time is the primary justification for trying to improve transport system.

Travel time can be defined as the time required to complete a trip. In Public transport, according to (TRB, 2003), total trip time consist of travel time from the passenger's place of origin to the public transport stop, waiting time at the stops for public transport vehicles, in-vehicle trip time, waiting time at the transfer station, and in-vehicle trip time to the passenger's final destination. Some trips might require more than one transfer to complete the trip.

Armstrong-Wright, (1993) suggested that passengers should not spend more than 3hours daily to travel to and from work and the yardstick for average speed should not be less than 10km/hr in a dense urban area with mixed traffic and 25km/hr in a medium to low dense area.

<b>Variables</b>	<b>Description</b>
Distance	Segment length
Intersections	Number of signalized intersections
Bus stops	Number of bus stops
Boarding	Number of passenger boardings
Alighting	Number of passenger alightings
Time	Time period
Driver	Driver experience
Period of service	How long the driver has been on service in the study period
Departure delay	Observed departure time minus scheduled
Stop delay time	Time lost in stops based on bus configuration (low floor, etc.)
Nonrecurring events	Lift usage, bridge opening, etc.
Direction	Inbound or outbound service
Weather	Weather-related conditions
Road	Road characteristics

*Figure 2-8 Factors that affect travel time in public transport*

*Source: (El-Geneidy et al., 2009).*

## **2.8 RESUME**

The chapter started with the role of the transport system in a society which is to convey people and their goods from their current location to wherever they want to be. It later moves on to discuss public transport system, types of public transport service which are formal service and paratransit.

The chapter later discussed paratransit in depth, starting with its definition and brief history of paratransit in South Africa and later gives overview of paratransit status quo in South Africa, its role in public transport system and strategies that can be implemented to improve its current operation and how it can be fully integrated with schedule trunk services.

The chapter also moved on to discuss transport modelling, its role in modern urban transportation planning process. Differences between trip and activity base model were also highlighted and later proceed to the definition of microsimulation and its role in modern-day transport planning.

Lastly, the chapter discusses some the key performance indicators used to assess the performance or efficiency of a public transport system.

### **3.0 STUDY AREA AND DATA.**

The study area chosen for this study is Mitchells Plain which is a suburb in the Western Province of South Africa. It is located about 20km from the Cape Town city business district centre. Mitchel Plain has a total area of about 43.76km<sup>2</sup>. According to 2011 national census, the population of Mitchel plain is 310,000 whereby 91% of the population are coloured, 30% of the residents are unemployed, 42% of the resident earn less than R1600 monthly, 75% of the adult doesn't have matric certificate and 40% of the people between the age of 4 and 24 years do not attend school, because they must work (Statistics South Africa, 2011).

Mitchells Plain is a township created to offer housing for coloured people who were victims of implementing Group Areas Act, whereby people were forcefully removed and segregated based on their racial background according to 1970s Apartheid legislation. (Urban Landmark,2009).

Mitchells Plain is well connected to other major areas in the city of Cape Town in terms of public transport services available. The Mitchells Plain Public transport interchange which is the main reason why this area was chosen for this research is located about 27km south-east of Cape Town City Business District. It consists of a rail station, My-Citi line-haul Bus services, Bus termini for Golden Arrow Buses and three minibus-taxi ranks which are located to the north, south, and west of the rail station. The interchange is considered as the third busiest in Cape town with approximately 75,000 passengers using the interchange on each weekday (City of Cape Town, 2009)

The lack of employment opportunities in this area warrants the reason why most of the working population residing in the area have to travel a considerable distance every day to their various work destinations. The mini-bus taxi rank in the area are Hazeldene, Promenade mall and Westgate mall. However, this research will consider the feeder route used by the mini-bus taxis from Westgate mall to the western side of the interchange, which is the Hazeldene taxi-rank and also Promenade mall to Hazeldene taxi rank.

Figure 3-1 below shows the map of Mitchells Plain in Google map and the Google Earth map shows the location of the Mitchells Plain interchange, Promenade mall and West-gate mall.

Figure 3-2 shows the route used by the Paratransit from Westgate mall to Promenade mall and the Hazeldene Taxi rank, which is the route used for this research.



Figure 3-1 Map of Mitchel Plain on Google map

Source: Birungi 2017

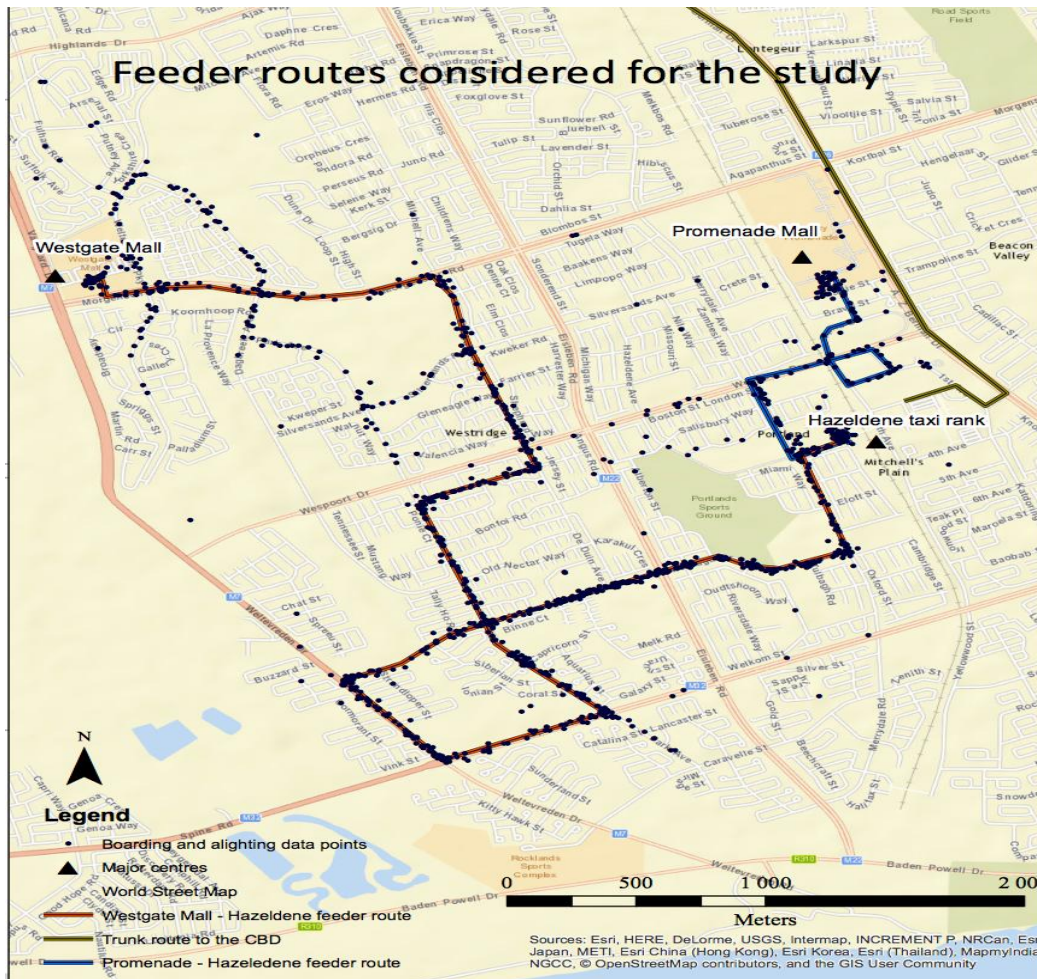


Figure3-2 Feeder's route used for this research

Source: Birungi(2017)

### 3.1 DATA REQUIRED TO SET UP THE MODEL

This research was conducted based on the data and model already developed by Birungi (2017) but nevertheless, this section will briefly discuss about data that are required to set up a model and also how the data was collected, collated and the final data that were used to set up the model used in this research.

The data required to set up a model are briefly discussed below:

- Road network data: Road network is essential to be built first in the model. The road network must replicate the existing traffic system in reality. Google Earth maps can be used to achieve this. The road network data required consist of the road geometry, road network, Public

transport stops, the distance between public transport stations, stations data, traffic control settings, speed limits on roads, vehicle transfer zones and passengers transfer areas.

- **Vehicle data:** Vehicle data is required to replicate the normal flow of private and public transport vehicles and their interactions on the road network. Data require include traffic counts, fleet of buses to operate on the trunk, fleet of taxis to operate on the feeder, vehicle capacity and vehicle speeds.
- **Passenger data:** Passenger travel data is required to estimate their trip origin and destination. This is essential as passenger travel data is required to set up a transportation model. The data required will be the number of passengers moving from their trip origin to their trip destination which will be represented as an origin-destination matrix.

### **3.2 DATA COLLECTION**

Data collection process was done by Birungi (2017) but this section will briefly discuss the categories of data that was collected and analysed by Birungi to set up the model used for this research.

- *Boarding and Alighting:* This data is required to be captured to have the number of passengers getting off and on in the paratransit vehicles at every point along the feeder's route. This survey required a data capturer (field worker) to be present in the vehicle to be able to monitor and record the number of passengers that board and alight at every point the vehicle stops along the feeder's route.

The onboard survey was conducted using an Open Data Kit (ODK) technology, which is an open-source set of tools, which was developed by the University of Washington and allow users to develop and manage collections of data using smart mobile devices. ODK form hub was a better alternative method of data collection as it enables all data collected to be sent to an online server in XLS or KML format which can be further visualized and analyse on google or Geographic Information System (GIS). According to Birungi (2017), the ODK form hub provides three sequential solutions toward data collection and output process:

- Build a data collection form; using excel and the ODK coding format.
- Collect data using the mobile phone and send it to the server.
- Agglomerate the collected data. This can be saved in MS Excel format for further analysis or sent the server which can be exported and analysed in GIS.

The Survey form was designed to be able to capture location information of every point where the taxi stops to pick or drop off passengers, the vehicle information, the number of passenger boarding and alighting at every stop and the time and date of capturing the data. Figure 3-3 below shows the ODK form at the start of the survey on an android mobile phones used for data collection while Figure 3-4 shows the positons of the data collected during the survey along the feeder’s route.

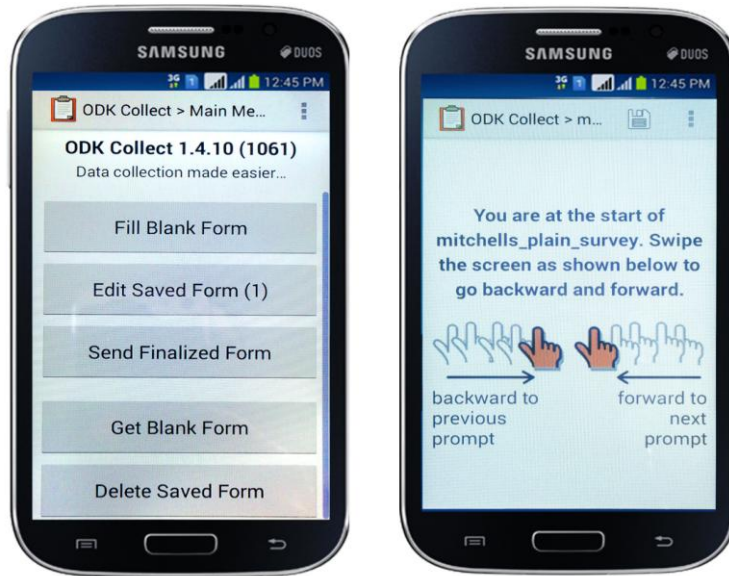


Figure 3-3 ODK form on the mobile phones at the start of the survey.

Source: Birungi (2017)

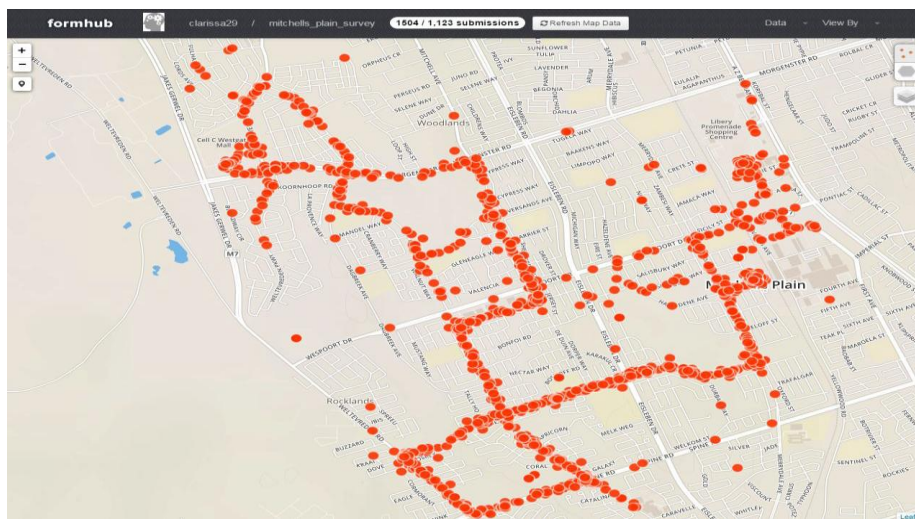


Figure 3-4 The final data points along the feeder's route captured during the survey.

Source: Birungi (2017)

- *Modal Split Survey*- This survey was conducted to be able to collect data on the number of passengers that are transferring from the paratransit vehicles to other modes of transport at the interchange to reach their final destination. At the end of the survey, it was able to capture the number of passengers that connect to trunk service (train, MyCiTi, Golden arrow bus) and those that end their trips at the interchange (passengers working or trading at the interchange).
- *Traffic count*- To build a realistic model, which incorporate paratransit delays, due to varying traffic condition during the intended period of the simulation, traffic count is very essential and the data have to be accurate to give a reflection of the traffic situation on the routes that are used by the paratransit feeder's service to the interchange. Three points along the main routes were selected by Birungi, which depict the daily traffic situation along those routes. The traffic count data collected was validated with City of Cape town's traffic count data that has been collected in the past.
- *Trunk Service data*- This data was collected to replicate transfer behaviour of passengers and to have data on the schedule of connecting trunk services. Metro-rail and MyCiTi already have a fixed timetable for their schedule but it was observed that their arrival and departure time doesn't correspond with the timetable, so therefore survey to collect the actual arrival and departure time for the period of time under study was essential.

## 4.0 METHODOLOGY.

### 4.1 INTRODUCTION

This section will give a brief description of the methodology used in this research, and the chapter will give an overall overview in details of the methodology.

- Optimisation of an already built model by Birungi (2017) to suit the objectives and aim of this research.
- Development of road prioritisation/infrastructural improvements scenarios that will enhance the operational efficiency of paratransit feeder's service.
- Development of Key Performance Indicators (KPIs) to assess and evaluate the effect of the scenarios developed.
- Testing of each scenario developed at varying traffic levels.
- Assessment and evaluation of each scenario tested using the KPIs developed.
- Use Multi-Criteria Analysis (MCA) to evaluate and rank scenarios tested based on the level of improvement added to the operational efficiency of the paratransit feeder's service.
- Determine at which traffic level each of the scenarios tested are to be implemented on the feeder's route.

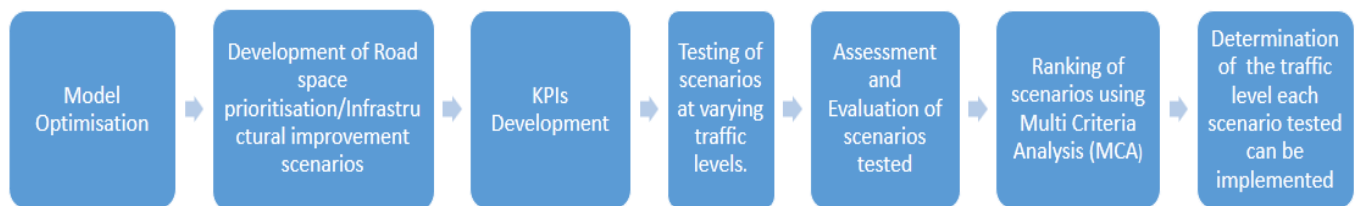


Figure 4-1 Methodology flow chart

Majority of data processing required to build the model used for this research has been done by Birungi (2017), but this chapter will briefly discuss the commuter software used to build the model including the data and the process required to build a realistic model.

### 4.2 MODEL DEVELOPMENT

Data required to build a public transport model include:

- *Network Infrastructure and facilities:* - This depicts the model's layout, which comprises of the roads, walkways, stairs, intersections (signalised and non-signalised), vehicle parking

zones along the roads and stands or platform for waiting passengers. The origin and destinations of passengers and vehicles are also incorporated at this stage. Figure 4-1 below shows an overview of the road network used in the model on Google earth and Commuter software.



Figure 4-2 Overview of the network used in the model in google earth and Commuter software

- *Public transport Service and timetables-* inputting timetables and public transport services in the model is a way of providing direction for the flow of public transport services within the network. Trails must be created within the network for all the public transport services in the model. Each trail is then associated with a timetable for the public transport service. Figure 4-2 below shows the Westgate mall to Hazeldene interchange trail in yellow with its associated timetable for paratransit feeder's service.

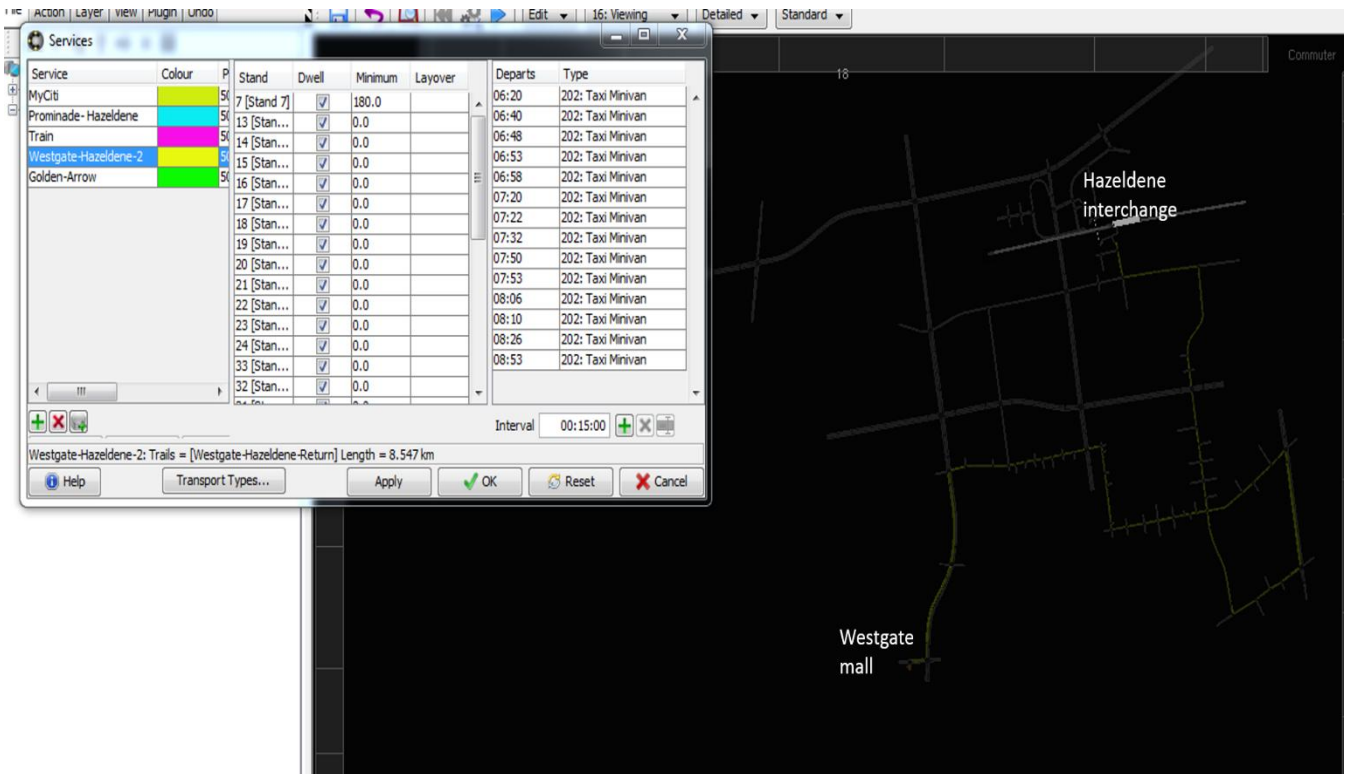


Figure 4-3 Westgate to Hazeldene trail with the associated timetable for the paratransit service in Commuter.

- Demand Data:** - This refers to the Origin-Destination matrix that is inserted into the model which depict the volumes of passengers moving between areas and volumes of vehicles moving from one zone to the other. In commuter, areas stand for point of origin and destination for passengers while zones stand for the origin and destination for vehicles. Time profile is another demand input that is required in model development, it depicts the rate/proportion of agents that are released into the model over time. Figure 4-3 below shows the passenger's O-D matrix used in the model and Figure 4-4 shows the O-D matrix for Cars, Bus and Trucks used in the model used for this research.

Stop No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	Sum Boarding	
1	0	15	45	0	0	0	0	5	7	0	25	0	0	0	3	2	2	0	5	0	4	2	5	4	1	9	0	0	18	9	3	0	32	195	
2		0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
3			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	2	3	0	10	0	0	0	1	1	1	0	2	0	1	1	2	2	0	4	0	0	7	3	1	0	13	52	
5					0	0	0	1	2	0	6	0	0	0	1	0	0	0	1	0	1	0	1	1	0	2	0	0	4	2	1	0	8	33	
6						0	0	1	1	0	4	0	0	0	0	0	0	0	1	0	1	0	1	1	0	1	0	0	3	1	1	0	5	20	
7							0	1	2	0	6	0	0	0	1	0	0	0	1	0	1	0	1	1	0	2	0	0	4	2	1	0	7	31	
8								0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	2	9	
9									0	0	3	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	2	1	0	0	3	13	
10										0	5	0	0	0	1	0	0	0	1	0	1	0	1	1	0	2	0	0	4	2	1	0	7	26	
11											0	0	0	0	13	5	7	0	15	0	8	5	8	6	1	11	0	0	11	1	0	0	0	88	
12												0	0	0	2	1	1	0	5	0	3	2	4	4	1	8	0	0	15	8	3	0	28	85	
13													0	0	7	3	4	0	8	0	4	3	4	3	0	6	0	0	6	1	0	0	0	46	
14														0	1	1	1	0	2	0	2	1	2	2	0	4	0	0	7	4	1	0	13	39	
15															0	1	1	0	3	0	1	1	1	1	0	2	0	0	2	0	0	0	0	13	
16																0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2	7		
17																	0	0	11	0	6	4	6	4	1	8	0	0	8	1	0	0	0	48	
18																		0	3	0	2	1	2	1	0	2	0	0	2	0	0	0	0	13	
19																			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20																				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21																					0	1	3	3	0	6	0	0	11	6	2	0	20	52	
22																						0	6	4	1	8	0	0	8	1	0	0	0	0	27
23																						0	1	0	2	0	0	4	2	1	0	0	7	17	
24																							0	0	4	0	0	7	4	1	0	14	30		
25																							0	4	0	0	8	4	2	0	14	31			
26																								0	0	0	7	4	1	0	14	26			
27																								0	0	0	11	6	2	0	20	39			
28																									0	7	4	1	0	14	26				
29																										0	0	0	0	0	0	0	0	0	0
30																												0	19	0	171	191			
31																												0	0	65	65				
32																													0	13	13	13			
33																																			0
Sum Alighting	0	15	59	0	0	0	0	10	15	0	59	0	0	0	29	15	18	0	59	0	37	22	49	39	6	88	0	0	162	59	44	0	479	1261	

Figure 4-4 Passenger O-D matrix used in the model.

Source: Birungi (2017)

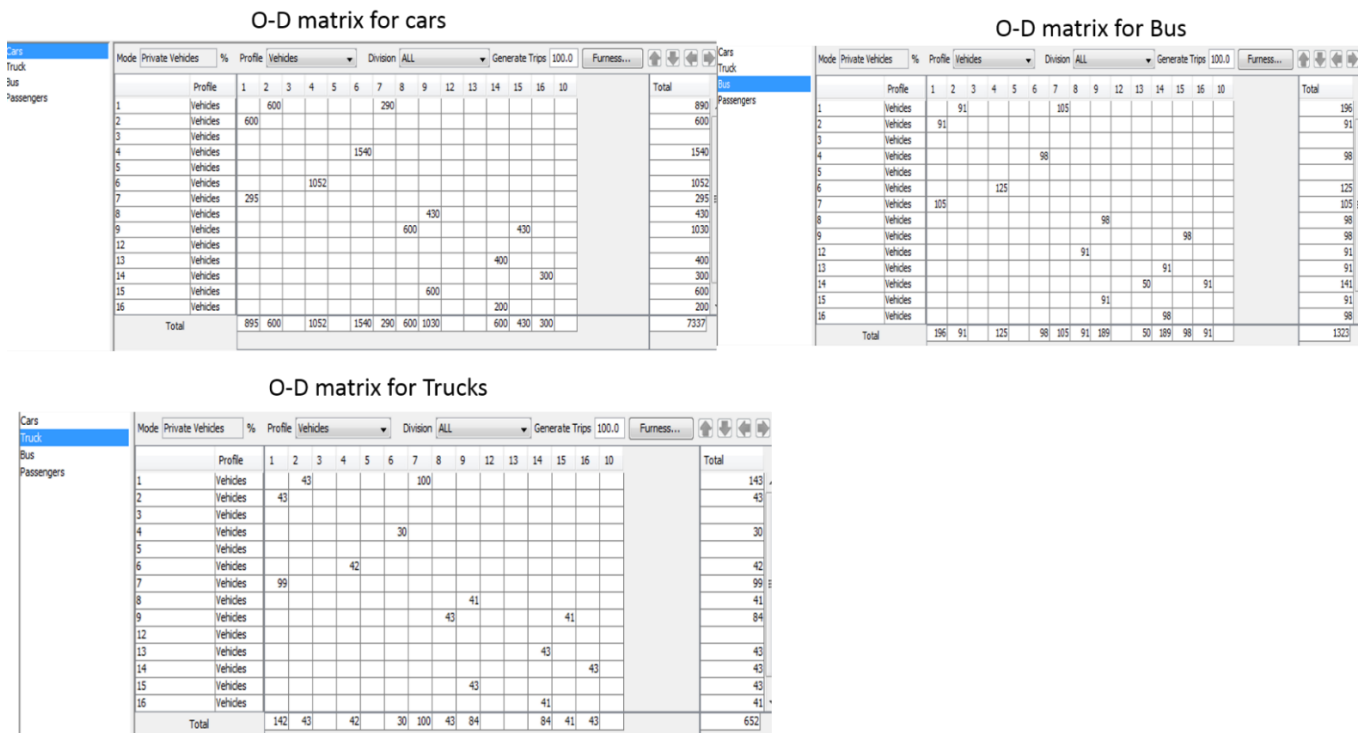


Figure 4-5 O-D matrix for cars, bus and trucks.

- Parameters: - These contain variables that control both trip generation and model behaviour. It is used to refine the operation of the model. For example, behaviour contains parameters that control agent's decision in the model, the decisions include mode and route choices, lane and parking selection. Behaviour also contains parameters that define weights which describe the value of time, distance and price, controlling temperament and driving style of drivers.

### **4.3 ABOUT COMMUTER**

Commuter is an Agent-based simulation modelling software, which can be used in modelling people, vehicles or freights moving in the transport network as an autonomous entity. Commuter can model people driving, walking, cycling or passengers on a bus or train. Commuter is a very useful software as in a typical modern-day transport analysis, it is important to study all mode of transport and not just private cars. Being able to model each person-origin to each person-destination will give transport planners and transport economist much clearer insight in to the total cost of each trip, if the cost can be determined, then the potential benefit can be assessed.

According to Birungi (2017), Commuter was the chosen tool for this research as it is the only simulation software that meets the requirement to achieve the objectives of the research. The required simulation software package for the research must be able to analyse and visualise the effect of the operation of trunk and feeder services on passenger flows. Departure and arrival patterns of the feeder's service, which are based on the paratransit timetables and general interaction of passengers with the public transport system are all part of the operation required to be analysed. Boarding and Alighting, transfer time from feeder to trunk and passenger's waiting along the feeder's route are all KPIs that needs to be analysed in the research. Table 4-1 below shows various simulation software that was considered with their capabilities before commuter was chosen.

Table 4-1 Capabilities of different software packages considered.

Capabilities \ Tool	Paramics	PTV - Vissim/Viswalk	Commuter	MS Excel
Arrival/departure patterns (Scheduling)	✓	✓	✓	✓
Passenger transfers	X	Requires combination of 2 software packages	✓	X
Boarding and alighting	X	X	✓	X
Capacity analysis	✓	✓	✓	✓
Informal bus stop route adherence	✓	✓	✓	✓
End to end journeys	✓	✓	✓	X
Visualization	✓	✓	✓	X

Source: Birungi (2017)

Commuter is a multi-agent simulation or agent-based modelling software. An agent in commuter is a person or a vehicle.

Agents in commuter can be classified into several groups

- People walking are referred to as pedestrian,
- People cycling are referred to as cyclists,
- People using public transport are referred to as passengers,
- People in private vehicles are referred to as driver or passenger(s),
- Private vehicles,
- Public transport vehicles,
- Unit of freight.

#### 4.3.1 MODEL PARAMETERS IN COMMUTER

Parameters component within Commuter contain variables that control trip generation and model behaviour.

- *Terms*- This refers to the defined period of the simulation. A term is a multi-purpose window in time. One can create as many terms as possible and they can even overlap. A Day can be split into a period using terms. A term must have a start time, end time and day of operation.

- *Behaviours*- Behaviour in commuter contain parameters that control agent's decision in the model, the decisions include mode and route choices, lane and parking selection. Behaviour also contains parameters that define weights that describe the value of time, distance and price, controlling temperament and driving style of drivers.
- *Restriction*- Restriction contains parameters that are used to limit the use of lanes or walkways. Restriction can be set up on a walkway or lane to operate at all time or during some period i.e. during a term. Restrictions are based on mobs (group of behaviour).
- *People (Person types)*- This defines the physical appearance and ability of a person such as size and speed. Each person type is assigned with a single behaviour but there can be multiple person types with the same behaviour. For example, one can define a child, adult and elder and later define child as being smaller than adult and elder being slower than adult.
- *Vehicles (Vehicle types)*- This defines the physical characteristic of the car such as size, shape, capacity, fuel type, engine type etc. For instance, one can define car as "small car", "medium car", "Truck" etc. A behaviour can be assigned to each vehicle type describing how the driver behaves.
- *Crossing times*- These are used for pedestrian crossing to define the walk, flash and Don't walk times.
- *Time Distributions*- These are used for dwelling time on public transport i.e. the boarding and alighting times. It is also used for delay times at entry and exit of boom gates, or at toll plazas.

#### **4.3.2 ZONING PLAN**

This is the first step to take to build a model in commuter after collecting all the necessary input data. Zoning plan is a spatial mapping plan that shows the origin and destination of all trips that need to be modelled. In commuter, Areas are used as the trip-end location for person trips while zones are used as the trip-end location for vehicular trips.

The following data are required to create a zoning plan;

- A scale map of the area to be modelled.
- A set of trip-end locations, to use as trips origin and destination. (areas for person trips and zones for vehicle trips).
- Demand Data- This can be in form of an origin-destination matrix or just as origin volumes for simpler models.

- Behavioural data such as the value of time information from stated preference surveys.
- Population data such as the physical sizes of vehicle, number of children, adult and elders etc.
- Details of the network layout for both roads and walkway.
- Public transport routes and timetables.
- Validation data such as traffic counts, travel times, queue lengths etc.

### **4.3.3 NETWORK**

The network is a combination of roads, walkways, crossings and intersections. It is set for vehicles and pedestrian movement.

- *Walkway*- Walkways are paths created for pedestrian movement. They are generally bi-directional i.e. they allow pedestrian flow in both directions.
- *Crossing*- A crossing is a specialised walkway that crosses a road. It is always straight.
- *Road*- A road supplies traffic capacity for vehicles. In commuter, road consists of link and lanes. A link is the routing component that joins two nodes and holds travel time, distance and price information used for calculating routes while Lane is the drivable surface of a road. Each lane has its own set of parameters such as speed limit, width and restrictions.
- *Intersection*- An intersection is an area on the road network where traffic streams conflict or merge. It contains one or more nodes. An intersection might be signalised or unsignalised, a signalised intersection has a controller which is a device that hold and retain information such as Turns, Groups, Phases, Plans and Rules for an intersection while unsignalised intersection is an intersection without any device controlling traffic stream but instead assigned a fixed priority such as free flow, give way, Stop etc.

### **4.3.4 PUBLIC TRANSPORT SERVICE AND TIMETABLE**

To include public transport service in the model using commuter, then facilities that will connect passengers to public transport vehicles needs to be created.

- *Stands*- A stand depicts a location along the public transport route where public transport vehicles stop to pick up and drop off passengers. It is a mode change location where passengers change mode from walking to public transport and vice versa.
- *Trails*- A trail is a sequence of route elements such as links and walkways which are used in controlling routing. In commuter, trails are used to define the route of each public transport

service. In commuter, creating a public transport route is a two-level exercise, the first is to create a trail made up of two or more roads and the second is to create a service route made up of one or more trails.

- *Service*- A service in commuter defines the route used by public transport vehicles such as a bus, tram or train. It also defines stands where public transport vehicles drop and pick up passengers.

#### **4.3.5 DEFINING DEMAND**

Demand can be defined in simple term as the number of people that want to travel. The network of road and walkways are the supply for these travel demands. Congestion occurs when the demand is more the supply.

Commuter is basically a tool to model person-trips but can also be used to model and analyse vehicle-trips. There are two levels of demand in commuter, the first is the “upper level” where person-trips are defined between areas whereby each trip is defined as a door to door journey for a person which use one or more modes of transport. The second is the “Lower level” where vehicle-trips are defined between zones. Vehicle trips can be created to carry people on trips that were defined in the upper level or to act as background traffic or to study vehicle traffic only.

Based on the two-level hierarchy mentioned above, demand can be defined in three ways as illustrated below

- *Directed demand*- This type of demand has a definite number of trips with each trip having an explicit origin and destination. Directed demand is applicable to both person and vehicle trips.
- *Undirected demand*- This type of demand has a definite number of trips from an origin but with no explicit destination. It always co-exists with turn counts(splits) at each intersection. The turn counts define the probability of any trip taking any of the exits at an intersection. It's also applicable to both person and vehicle trips.
- *Public transport (Fixed route) demand*- This type of demand is used to define public transport vehicle trip on the road network. This is applicable to vehicle-trips alone.

#### **4.3.6 GENERATING TRIPS**

Trip generation in commuter is the process whereby individual trips are separated and produced from the combine demand specification. Commuter makes use of pseudo-random number generators to choose values from within parameter distributions.

In commuter, trips generation is separated from simulation as trips are generated once before simulation begins. The trip table is saved as input data which means that simulation can be repeated with the same pattern of trips several times even if the model changes. Trips generated can be saved within the model or externally. External is recommended when the model is large and the number of trips is also large.

#### **4.3.7 COLLATING RESULT**

Numerical results are usually required after running a simulation model to give a summary of the findings from the study, and visualization alone during the simulation is not sufficient to give an in-depth interpretation of what goes on during the simulation of the model.

After accurately running the simulation, Commuter can save the result internally or externally as XLS file. Results generated by commuter at the end of each simulation include person-trips, vehicle-trips, environmental effect report, level of service report and economic evaluation reports. Creating a model using commuter involves the following summarised process:

- Collation of data to use as an input parameter to run the model and to validate the model.
- Creation of zoning plans (i.e. identifying areas for person-trip and zones for vehicle-trips as origin and destination)
- Building network of roads and walkways.
- Addition of public transport service and timetables
- Addition of demand data (O-D matrices)
- Defining people and vehicle behavioural parameters
- Trip Generations
- Validation by running models and adjustment of parameters
- Simulation of model
- Simulation of different scenarios
- Collection and analysis of results

#### **4.4 SIMULATION**

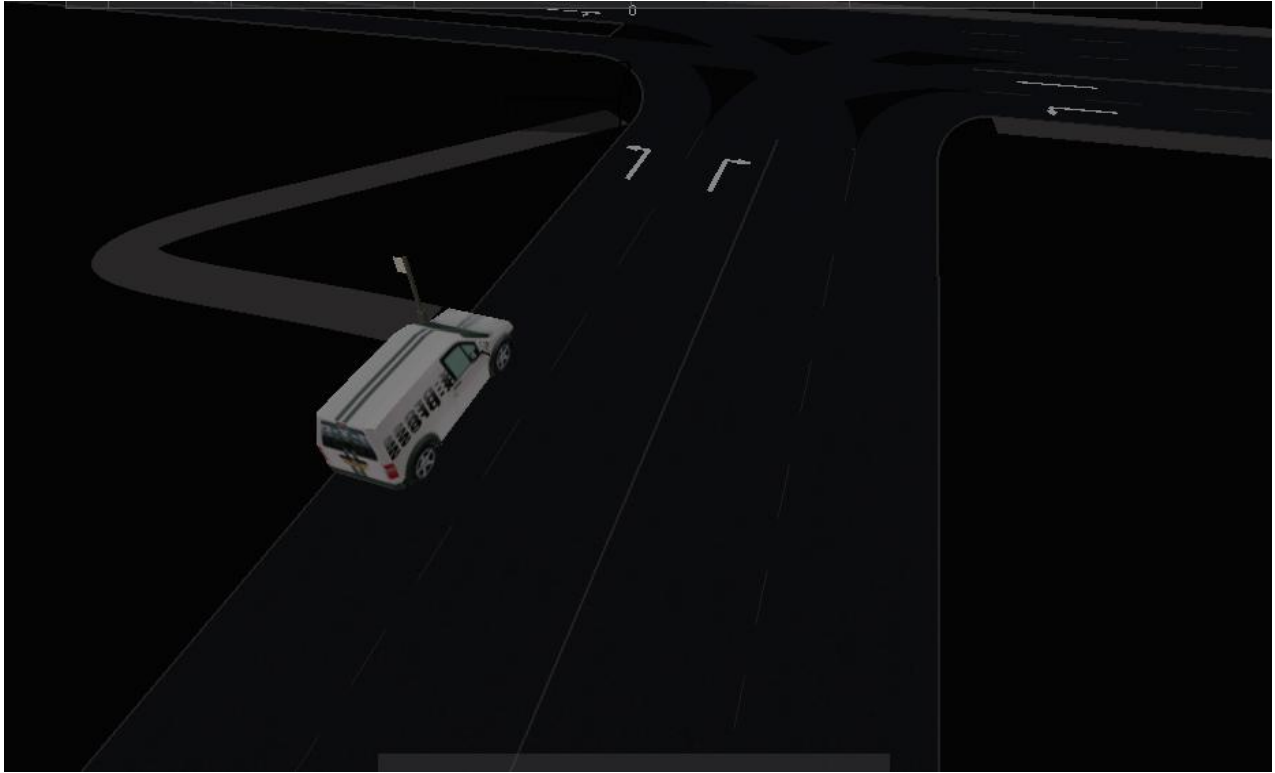
Immediately the play button in commuter is clicked, the simulation will start initially with an empty network, but after few seconds, Commuter will start to generate traffic into the network. Pedestrian are generated in areas designed as the trip-origin which are usually the entry node of a walkway, while vehicles are generated at zones designated as the trip-origin usually at the entry nodes of the road network.

The network becomes built up of passengers walking on the walkway to board, waiting at the stands, and those that have alighted from a paratransit vehicle; paratransit vehicles moving from one stand to another along the route picking and dropping off passengers; and also, private vehicles consisting of cars, trucks and buses moving from their origin-zones to their destination-zones.

The paratransit vehicles move from the beginning of the trip to the end without any break in the trip. They operated exactly like they do in reality in the model except for the competitive behaviour they do exhibit which will be discussed later as part of the limitation of using commuter to model paratransit services. The paratransit vehicles are only allowed to stop at the designated stands along the route either where passengers are waiting to board or where passengers want to alight.

The vehicle will not stop at any stand if its full regardless if passengers are waiting at the stands or not, but will stop immediately there are empty seats to accommodate more passengers.

The paratransit will keep picking and dropping off passengers along the route as long as there are empty seats till it gets to its final destination which is the Hazeldene interchange where all passengers remaining in the vehicle will have to alight and move through the interchange walkways to connect to the trunk service or end their trip at the interchange. The screenshots below were taken during the simulation to illustrate how paratransit vehicles operate in the model.



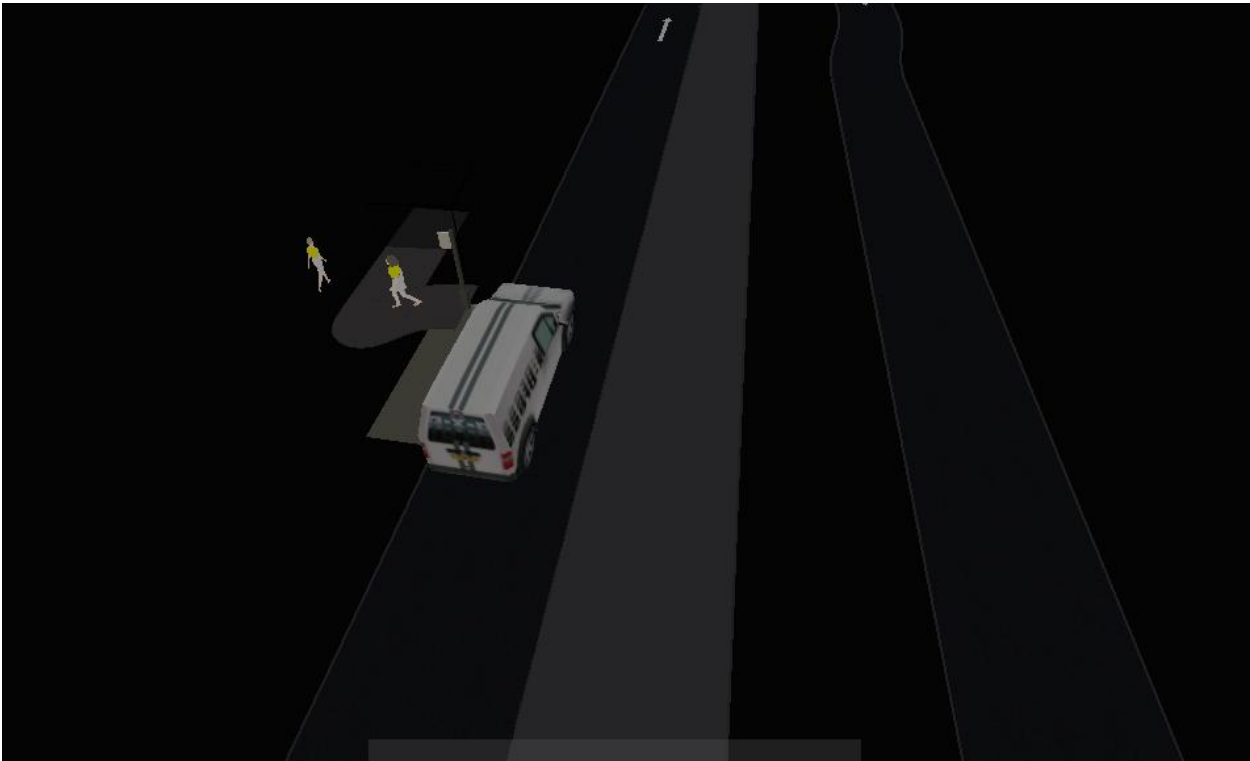
*Figure 4-6 Paratransit vehicle waiting for passengers at Westgate mall before starting its trip*



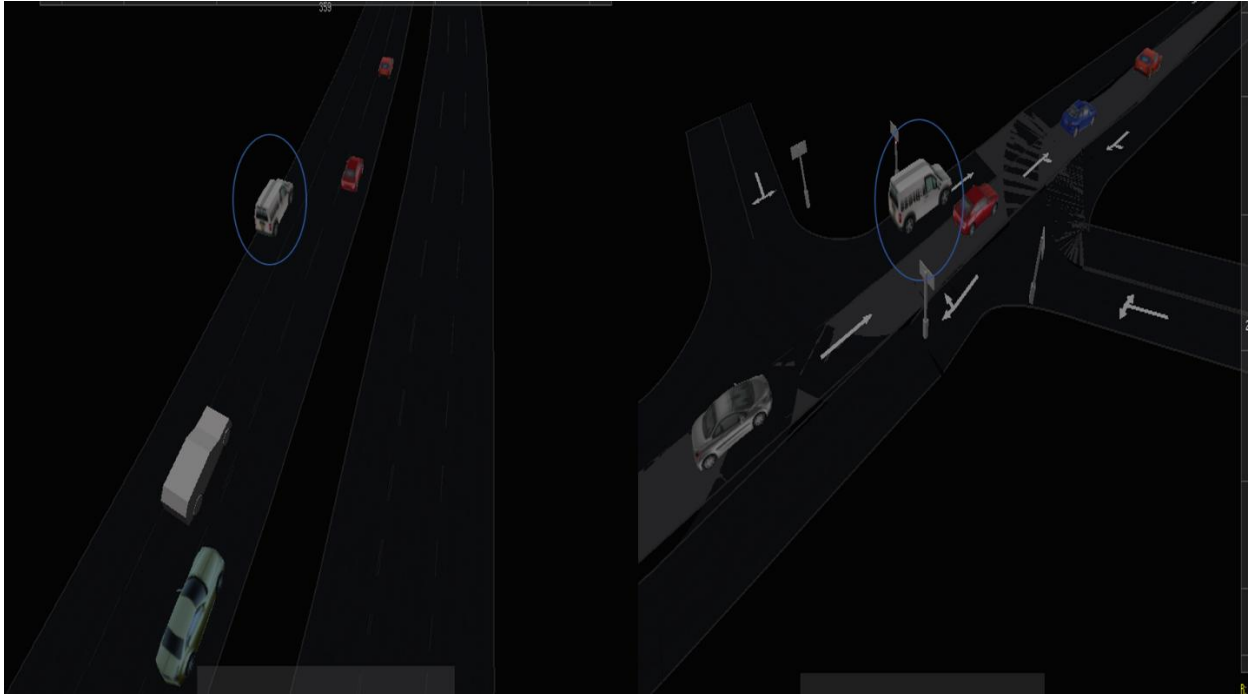
*Figure 4-7 Passengers waiting for Paratransit vehicle at a stand along the feeder's route*



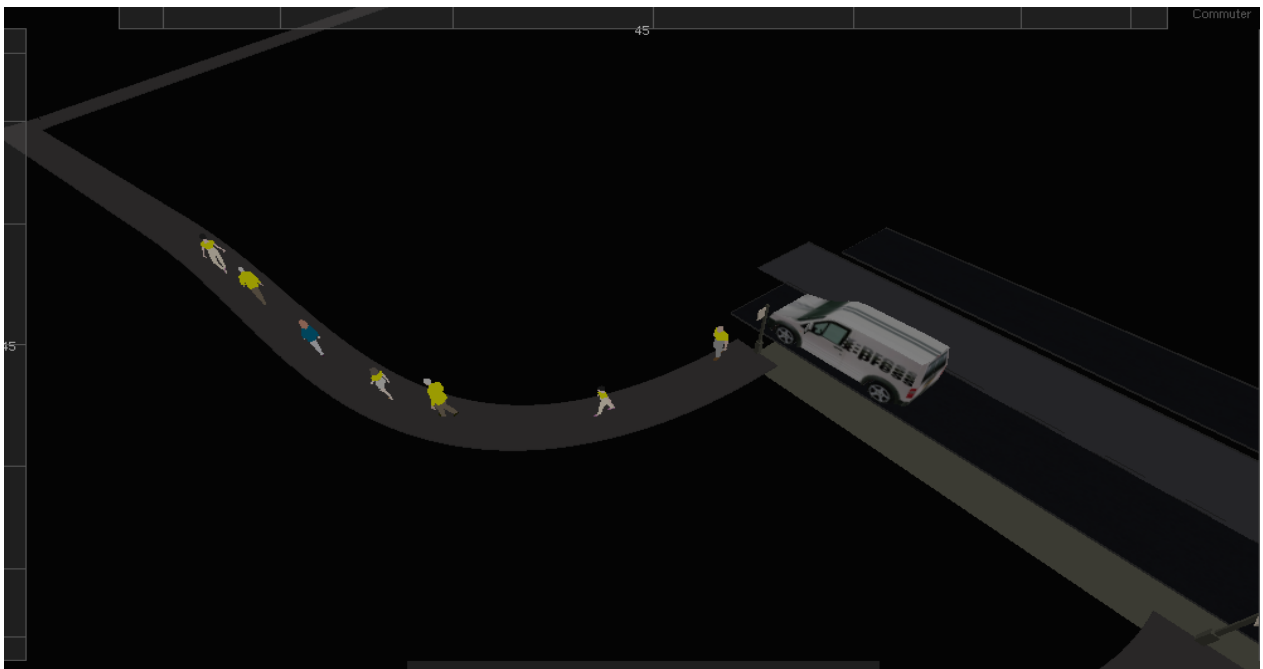
*Figure 4-8 Paratransit vehicle in its dedicated lane with vehicular traffic at a signalised intersection*



*Figure 4-9 Paratransit vehicle alighting passengers at a stand on the feeder's route*



*Figure 4-10 Paratransit vehicle travelling on its dedicated lane*



*Figure 4-11 Paratransit vehicle alighting passengers at the Hazeldene interchange and passenger walking through the walkway to either connect to a trunk service or end their trip at the interchange*

#### **4.5 LIMITATION OF USING COMMUTER AS THE MODELLING TOOL TO MODEL PARATRANSIT FEEDER'S SERVICE**

In terms of model validation, commuter only allowed validation using passenger and vehicle counts. The passenger demand O-D matrix used for the model was acquired using boarding and alighting counts, which according to Birungi (2017) could not be validated due to the fact that obtaining similar data to validate is time-consuming and expensive. Therefore, the passenger counts could not be validated.

At the time of undergoing this research, Commuter was the best available modelling tools that meet the aim of the research. However, the model didn't wholesomely depict how paratransit operates in reality. In reality, passengers will leave their origin and walk towards the nearest public transport network that can take them to their destination i.e. passengers don't always walk to the public transport stands, they walk to the nearest point on the paratransit route and can board a paratransit vehicle at any point along the route and they also alight at any point along the route that is closest to their destinations. Moreover, paratransit vehicle doesn't really have a fixed route, because they tend to use any route with highest passenger's demand at that particular time that can lead to their destination. But commuter makes use of trail, which is a fixed public transport route to model public transport service. Therefore, route deviation is not possible in the model which is a major characteristic of paratransit services in South Africa.

Realistic paratransit service in South Africa can be modelled if there is a modelling tool that can incorporate route deviation in the model and the fact that passengers can be picked up and dropped off any point along the public transport route and not necessarily at a public transport stand/stops.

Another limitation of using Commuter to model how paratransit operates is the fact that, it cannot produce the level of service on the paratransit route, as Commuter only produce the level of service at an intersection or pedestrian walkway only. This hinders the possibility of using level of service to analyse the level of service at which each road prioritisation strategy for paratransit vehicles is warranted, which is the main objective of this research. As the level of service on the paratransit route cannot be used for analysis, increase in general traffic condition along the paratransit route was therefore adopted instead for analysis purpose.

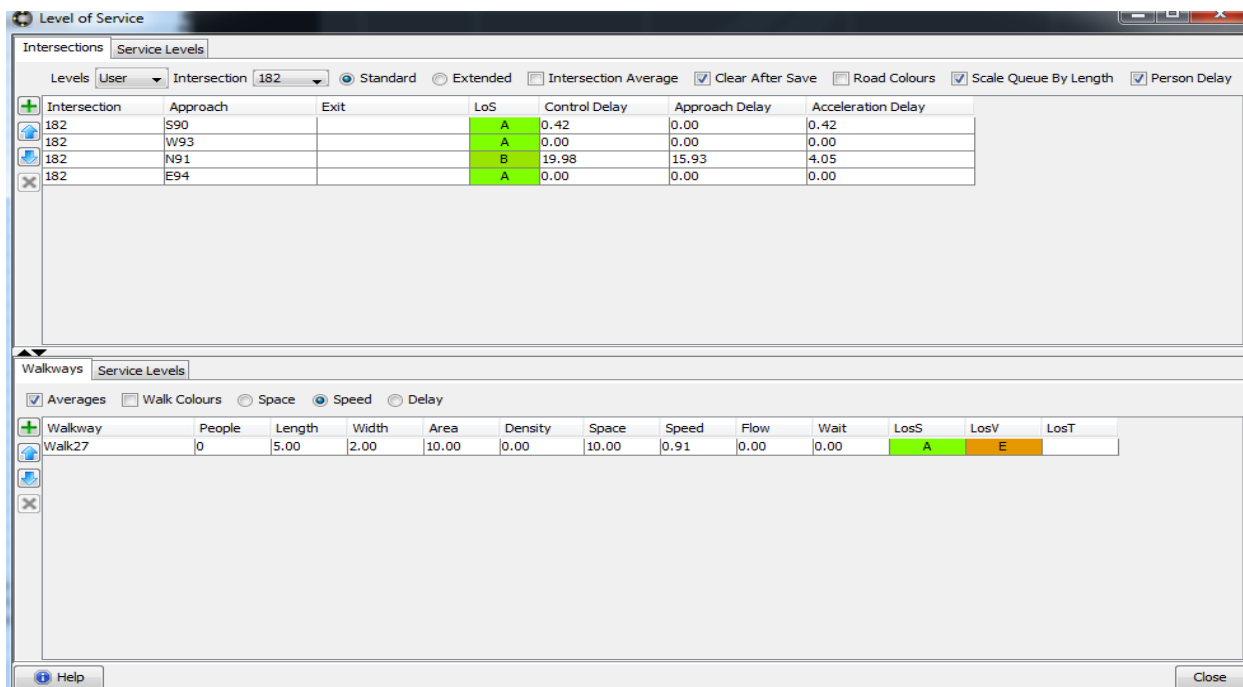


Figure 4-12 Commuter producing the level of service at Intersections and at pedestrian walkway only

#### 4.6 MODEL VERIFICATION, CALIBRATION AND VALIDATION

The model verification, calibration and validation process was already done by Birungi (2017).

- *Model Verification*- The model was verified by making sure that all the input component such as the timetables for the trains, bus and paratransit are all inputted correctly. The road network was also checked to make sure that all the roads are connected as any obstruction on the road will affect trip generation. The behaviour of the model was also assessed to make sure all the paratransit vehicles didn't deviate from the trail to get to their destination and lastly the passenger volume in the O-D matrix was verified to be equal to the number of completed and uncompleted passenger trips.
- *Model Calibration*- Calibration is the process of adjusting the parameters and demand input into a model. Important input component such as O-D matrix was calibrated outside the model and imported into the model. Parameters such as phase times, vehicle mixing and vehicle counts were all amended to exhibit data from City of Cape Town (2015).
- *Model Validation*- Validation is the subsequent process after calibration, by checking that the set of observed values matches the observed values on-site/field. Travel time data were used

to validate this model, the modelled total trip time was plotted against observed total trip time when collating the data on the field. The goodness of fit ( $R^2$ ) was found to be 0.96. The goodness of fit ( $R^2$ ) is a statistical parameter that is used to measure how data fits into each other. Therefore, a value of 0.96 shows that the modelled and observed travel time data correlate with each other.

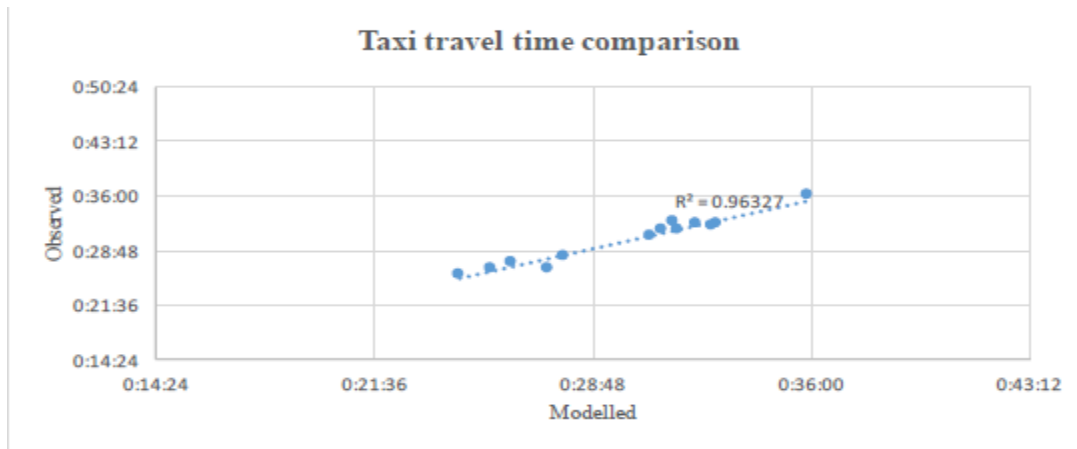


Figure 4-13 observed travel time vs modelled travel time.

Source: Birungi (2017)

#### 4.7 INFRASTRUCTURE IMPROVEMENT SCENARIOS MODELLED

Apart from the base model which show the status quo of the transport infrastructure currently present at the study area, the infrastructural improvement scenarios modelled are ;

- 1) Introduction of traffic signals at some strategic intersections.
- 2) Introduction of queue jumper at all intersections
- 3) Combination of queue jumper and traffic signal
- 4) Introduction of dedicated lanes on the feeder's route for paratransit vehicles only.

The above scenarios are discussed below.

##### 4.7.1 INTRODUCTION OF TRAFFIC SIGNAL AT SOME STRATEGIC INTERSECTIONS

This scenario was modelled to investigate the effect of introducing traffic signal control at some strategic intersection with priority given to the paratransit vehicles on the overall trip time and passengers waiting time. The strategic intersections chosen are nodes where it is not possible to give free flow to vehicles travelling on the feeder's route and in the direction of the paratransit

vehicles. The traffic condition was increased by 10%,15%,20%,25% and 30% to investigate the effect of the traffic signals on the operation efficiency of the paratransit feeders service as traffic condition increases.

There are some intersections along the feeder's route that are already signalised but it was discovered that they were not properly designed and priority was not given to vehicles flowing in the direction of the paratransit vehicles offering feeder's service to the interchange. All the incumbent intersections were optimised to give priority to vehicles flowing in the paratransit vehicle's direction and were designed to eliminate any conflict points for turning vehicles using the intersections. Results were collated for each of the increased traffic conditions and were analysed. Figure 4-13 below illustrates the positions along the feeder's route of the new and existing signalised intersections and Figure 4-14 shows a redesigned traffic signal at the intersection giving priority to the vehicles travelling in the direction of the paratransit vehicles.



Figure 4-14 The feeders route with new and existing signalised intersections

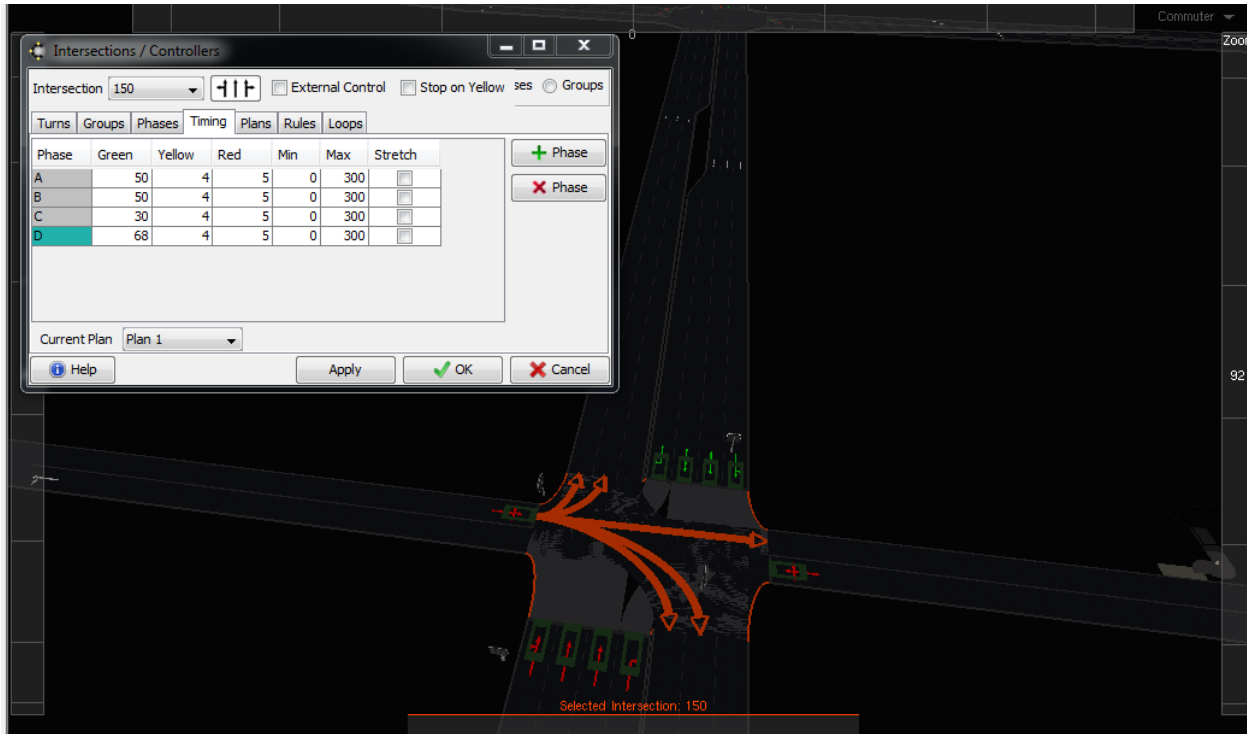


Figure 4-15 A redesigned intersection along the feeder's route where priority was given to vehicles flowing in the direction of the paratransit vehicles by giving them more green time

#### 4.7.2 INTRODUCTION OF QUEUE JUMPERS ONLY AT ALL INTERSECTIONS ALONG THE FEEDER'S ROUTE

Queue jumper is a traffic management facility such as elevated ramps or additional lanes that can be used to bypass queueing vehicles at an intersection. It is used globally as a traffic management tools to manage congestion and improve the operation efficiency of public transport system by giving priority to public transport vehicles mostly at a signalised intersection. For the purpose of this research and due to the fact that major proportion of the feeder's route are single lanes, queue jumpers were introduced to all intersections but not to prioritise paratransit vehicles but any turning vehicles that would have caused queues of vehicles while looking for space to turn within vehicle flowing in the reverse direction on the opposite lane. Queue jumper was also introduced at signalised intersections along the feeder's route without additional lane for turning vehicles while the ones already with dedicated lanes for turning vehicles were left like that. The effects of these queue jumpers added to the intersections on the overall operation efficiency of the paratransit feeder's service were investigated at varying traffic conditions. The traffic conditions were increased by 10%,15%,20%,25% and 30%, and results were collated for each of the increased

traffic conditions and analysed. Figure 4-15 below shows some intersections before and after queue jumpers were introduced to them.



*Figure 4-16 Part of the feeder's route showing before and after the introduction of queue jumpers*

#### **4.7.3 COMBINATION OF TRAFFIC SIGNAL AND QUEUE JUMPER**

This scenario was formulated to see the impact of introducing traffic signal control on some strategic intersections coupled with queue jumpers on the overall performance of the paratransit feeder's service. Most of the traffic signals had to be redesigned to incorporate the new lane added at the intersection for the queue jumper. This scenario was simulated at varying traffic conditions. The scenario was simulated at 10%,15%,20%,25% and 30% increase in general traffic conditions and the result was collated and analysed. Figure 4-16 below shows an intersection where queue jumper and traffic signal control measures was combined.



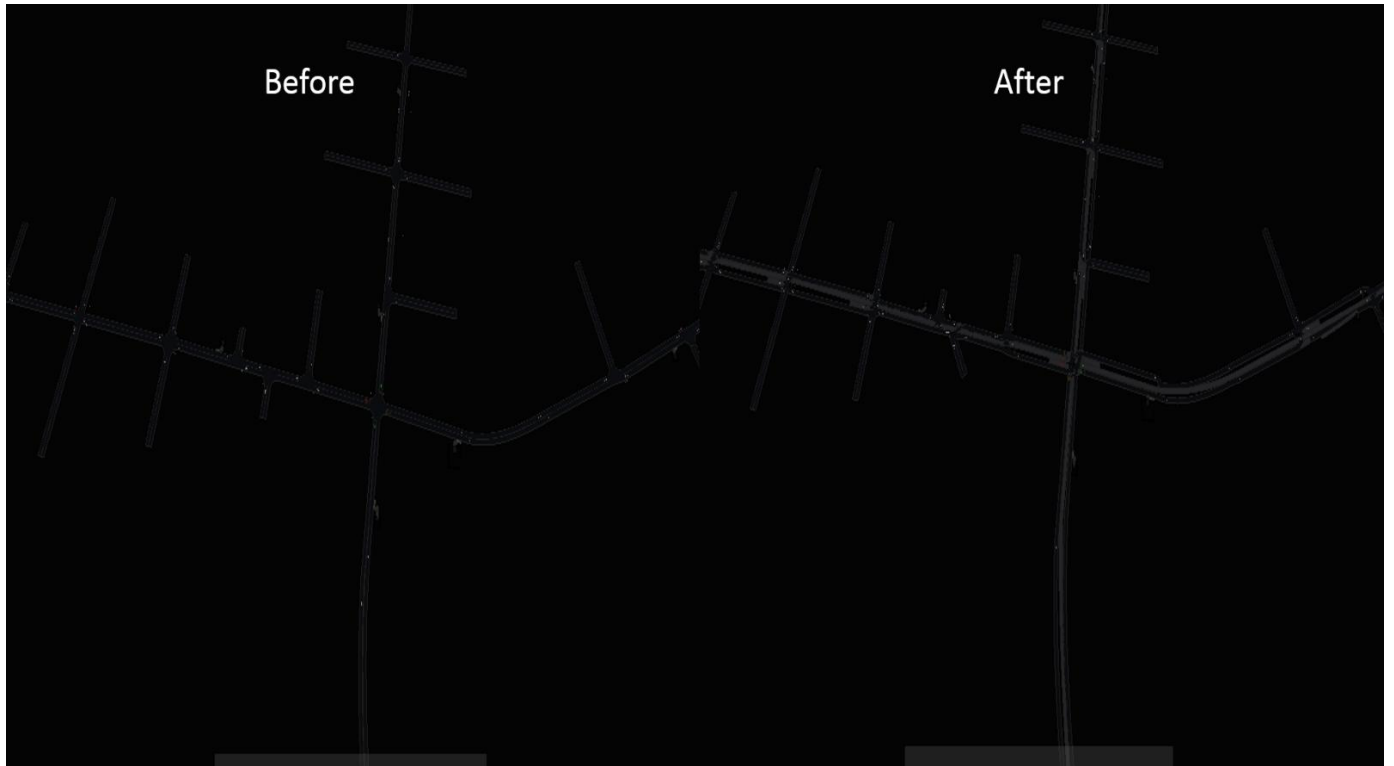
*Figure 4-17 An intersection before and after the introduction of queue jumper and traffic signal along the feeder's route*

#### **4.7.4 INTRODUCTION OF DEDICATED LANES FOR PARATRANSIT VEHICLES ALONG THE FEEDER'S ROUTE**

Dedicated Lanes are lanes on the road that are created to be exclusively used by public transport vehicles. It is a traffic management strategy to prioritise public transport vehicles on the roadway, its main objective is to increase the use of sustainable modes of transport and to encourage the use of public transport. It is also a strategy that can be used to improve the reliability of public transport by improving the overall travel time of public transport vehicles and reduce the waiting time of passengers at public transport stops especially in a congested traffic condition.

Dedicated lanes were introduced throughout the length of the feeder's route in the model to investigate the impact it will have on the overall efficiency of the paratransit feeder's service to the interchange. The paratransit vehicles were forced to use the dedicated lanes created in commuter by using the rule for lane options and to restrict other private vehicles from it.

The model was simulated for varying traffic conditions by subjecting the model to 10%,15%,20%,25% and 30% increase in general traffic conditions. Figure 4-17 below shows a portion of the feeder's route before and after dedicated lanes were introduced.



*Figure 4-18 Portion of the feeder's route showing before and after the introduction of the dedicated lanes*

## 5.0 RESULTS AND ANALYSIS

The previous chapter described the various process involved to build a working model using commuter software and also some specific attributes of Commuter software. The chapter also described the various key parameter indicators (KPIs) that will be used to assess the impact of the various infrastructural improvements investigated using the model, and lastly, the chapter described each of the infrastructural improvements investigated in this study.

The current chapter will present the results of each scenario investigated in the model and discuss the impact each of the infrastructural improvement has on the overall efficiency of the feeder's service to the Mitchells Plain interchange in Cape Town. Each of the scenarios will be assessed based on each of the KPIs discussed in the previous chapter.

### 5.1 CRAWLING TIME

Crawling time is the total time spent by the public transport vehicles waiting at signalised intersections and in traffic congestion expressed in minutes. It forms part of the overall trip time used by public transport vehicles from their origin to their destination. The lower the crawling time used by the public transport vehicles the better the impact it will have on the overall efficiency of the public transport service and the lesser will be the overall trip time used as crawling time is directly proportional to the overall trip time used by public transport vehicles.

*Table 5-1 Crawling times of each of the infrastructural improvements with different level of traffic conditions*

Percentage increase in traffic condition	Base model (min)	Traffic signal only (min)	Queue jumper only (min)	Traffic signal + Queue jumper (min)	Dedicated lane (min)
0	0:21:10	0:17:08	0:17:18	0:16:58	0:13:23
10%	0:22:08	0:19:27	0:14:58	0:15:23	0:13:30
15%	0:19:24	0:16:31	0:11:23	0:12:19	0:12:13
20%	0:24:48	0:17:08	0:14:44	0:14:11	0:13:35
25%	0:26:57	0:16:32	0:20:00	0:18:30	0:17:50
30%	0:29:38	0:21:44	0:19:51	0:19:10	0:18:37
Average	0:24:01	0:18:05	0:16:22	0:16:05	0:14:51

From table 5-1 above, the base model performs worst in terms of crawling time with an aggregated average crawling time of 24 minutes, which means all the infrastructural improvements considered reduces the crawling time used by the paratransit vehicles. Crawling time is expected to increase as the general traffic conditions increases which are evident from the results obtained from all the scenarios tested.

The best performing scenario in terms of crawling time is the dedicated lane, which is expected as the paratransit vehicles were travelling on their own lane without any obstruction from other vehicles, the crawling time for this scenario is only as a result of time spent at the signalised intersections. The aggregated average crawling time of 14 minutes 51 seconds was obtained for the introduction of dedicated lanes, which is the least compared to other infrastructural improvements tested.

The second best performing scenario is the combination of queue jumper and signalised intersection at some strategic intersections along the feeder's route. It can be seen from table 5-1 above, that combining queue jumper with redesigned signalised traffic signals performs better than the other scenarios excluding dedicated lanes, as the traffic conditions increased. It has an aggregated average crawling time of 16 minutes 5 seconds.

The third best performing scenario is the introduction of queue jumper at all the intersections along the feeder's route. It has an aggregated average crawling time of 16 minutes 22 seconds, which makes it be the third best out of the four scenarios tested in the model.

The least performing infrastructural improvements scenarios in terms of crawling time among the four scenarios tested is the introduction of traffic signal control at some strategic intersections along the feeder's route. An aggregated average crawling time of 18 minutes and 5 seconds was obtained after this scenario was tested which makes it the worst scenario in terms of crawling time but it's still better than the base model with an aggregated average crawling time of 24 minutes.

## 5.2 NUMBER OF BOARDED PASSENGERS

The number of boarded passengers is the KPI used to assess the number of passengers that could board and make use of the feeder’s service to the interchange during the period of the simulation. Infrastructural improvements on the feeder’s route focus mainly on reducing the overall trip time and passengers waiting time, but it was observed that some of the infrastructural improvements scenarios tested actually have some significant improvement on the number of passengers served on the feeder’s route. The higher the number of passengers that board, the better the impact on the overall efficiency of the paratransit feeder’s service.

*Table 5-2 Number of passengers boarded with each scenario as the traffic condition increases*

Percentage increase in traffic condition	Base model	Traffic signal only	Queue jumper only	Traffic signal + queue jumper	Dedicated lanes
0	425	429	432	431	436
10%	421	428	414	430	432
15%	414	422	428	426	427
20%	420	429	424	429	430
25%	414	436	417	435	439
30%	360	417	427	429	432
Average	409	427	424	430	433

From table 5-2 above, it can be deduced that the best performing scenario whereby many passengers were able to board, is when dedicated lanes were introduced to be exclusively used by the feeder’s paratransit vehicles. An aggregate average of 433 passengers were able to use the paratransit feeder’s service during the simulation period. Changes in traffic condition don’t really have any significant impact on the number of boarded passengers in all the scenarios tested.

The second best performing scenario is the combination of queue jumpers and traffic signal control along some strategic intersections along the feeder’s route. An aggregate average of 430 passengers were able to board during the simulation period as the traffic condition increases.

The third best performing scenario is when traffic signal controls were introduced to some strategic intersections, and the existing ones on the feeder’s route were redesigned to give priority to vehicles travelling in the direction of the paratransit vehicles. An aggregated average of 427

passengers were able to use paratransit feeder's service as traffic condition increases during the simulation period.

The worst performing scenario for this KPI is when queue jumpers were introduced at all the intersections present along the feeder's route. An aggregated average of 424 passengers were able to use the feeder's route service during the simulation period, when this scenario was tested. The number of passengers that was able to use the feeder's service was pretty close (427 and 424), when "traffic signal controls only" and "queue jumpers only" were introduced respectively.

The base model depicts the status-quo of the paratransit operation along the feeder's route, the number of passengers boarded decreases as the traffic condition increases with the base model which translate to the fact that the current infrastructure present won't be able to serve the passenger's demand as the traffic condition increases. An aggregated average of 409 passengers were able to use the feeder's service with the current infrastructure condition on the feeder's route. The difference between the number of passengers boarded during the simulation period in the base model and the worst performing scenario tested is about 15 passengers, which depicts that, to serve more passengers on the feeder's route and be able to transfer more passengers in to the trunk route, infrastructure improvement needs to be considered.

### **5.3 TOTAL DISTANCE COVERED**

This KPI was formulated to get the total distance covered collectively by all the 14 paratransit vehicles that were modelled during the simulation period. It is a KPI developed to have an idea of the collective performance of the paratransit feeder's service during the simulation. The more the distance covered collectively, the more will be the passengers served by the service and the better will be the overall efficiency of the paratransit feeder's service. This KPI is relatively similar with the number of boarded passengers(KPI) because the more distance covered the more passengers will be served.

Table 5-3 Total distance covered against each infrastructural improvement at varying traffic conditions

Percentage increase in traffic condition	Base model(km)	Traffic signal only (km)	Queue jumper only (km)	Traffic signal + queue jumper (km)	Dedicated lane (km)
0	104.77	108.67	108.09	108.74	109.25
10%	103.73	107.79	102.26	107.49	109.81
15%	105.53	109.53	108.78	107.25	109.74
20%	102.71	107.67	106.14	107.17	108.27
25%	99.63	106.38	101.27	106.40	108.15
30%	78.83	99.34	103.90	105.39	106.79
Average	99.20	106.56	105.07	107.07	108.67

From table 5-3 above, the best performing scenario is the introduction of dedicated lanes with an aggregate average of 108.67 km covered collectively by the 14 paratransit vehicles at the end of the simulation period as traffic conditions were varied. It shows that more completed trips were made during the simulation period. Increase in traffic condition doesn't have any significant effect on the total distance covered collectively when dedicated lanes were introduced for the paratransit vehicles.

Combination of queue jumpers and traffic signal controls at some strategic intersections along the paratransit feeder's route is the second best performing scenario tested with an aggregate average of 107.07 km covered collectively by all the 14 paratransit vehicles modelled as the traffic conditions were varied.

The third best performing based on the total distance covered collectively during the simulation period is when traffic signal control system was introduced to some strategic intersection and the existing traffic signals were optimised to prioritise traffic flowing in the direction of the paratransit vehicles. An aggregate average of 106.56 km was covered collectively by all the 14 paratransit vehicles during the model simulation period when traffic signals controls were introduced to some strategic intersections along the paratransit feeder's route.

The least performing scenario tested is when queue jumpers was introduced at all the intersections along the feeder’s route. An aggregate average of 105.07km was collectively covered by all the 14 paratransit vehicles modelled during the simulation period. In the base model, an aggregated average of 99.20km was collectively covered by all the paratransit vehicles in the model.

The scenarios performed the same way as they were tested for the number of passengers boarded (KPI), which is an evidence that the more distance covered collectively, the more will be the number of passengers that use the paratransit feeder’s service i.e. the total distance covered collectively is directly proportional to the number of passengers served by the paratransit feeder’s service.

#### 5.4 FEEDER’S WAITING TIME

Waiting time is the estimate of the average time used by passengers at public transport stops/stands while waiting for public transport vehicles to board expressed in minutes. Waiting time is dependent on service frequency/headway. It’s a very important KPI in assessing the overall efficiency of a public transport system as the majority of passengers don’t like spending lots of time waiting for public transport vehicles. The lesser the waiting time spent at the stops by passengers, the higher they will rate the performance of the public transport system. Waiting time is part of the overall travel time used by passengers.

*Table 5-4 Waiting time by each infrastructural improvement scenario at varying traffic conditions*

Percentage increase in traffic condition	Base model (min)	Traffic signal only (min)	Queue jumper only (min)	Traffic signal + Queue jumper (min)	Dedicated lanes (min)
0	0:08:54	0:07:38	0:05:55	0:05:21	0:05:26
10%	0:08:13	0:07:14	0:05:58	0:05:25	0:05:06
15%	0:09:27	0:06:43	0:06:11	0:06:12	0:05:53
20%	0:08:57	0:07:36	0:06:53	0:06:20	0:05:18
25%	0:08:38	0:07:55	0:06:01	0:06:29	0:05:57
30%	0:09:18	0:08:18	0:07:21	0:07:01	0:06:03
Average	0:08:54	0:07:34	0:06:23	0:06:08	0:05:37

From table 5-4, all the scenarios tested perform better than the base model i.e. the passenger’s waiting time reduced when each of the infrastructural improvement scenarios was tested. The aggregate average waiting time for the base model is 8minutes 54 seconds.

The best performing infrastructural improvement scenario is when dedicated lanes are introduced on the feeder's route to be used exclusively by the feeder's paratransit vehicles. The waiting time is almost constant as the traffic condition increases and has an aggregated average waiting time of 5 minutes 37 seconds.

The second best performing scenario is when queue jumpers and traffic signals control measures were combined at some strategic intersections along the feeder's route. The aggregate average waiting time got reduced by 2 minutes 46 seconds from the base model when this scenario was tested. The aggregated average waiting time at varying traffic conditions was calculated to be 6 minutes 08 seconds.

The third best performing scenario is when queue jumpers were introduced at all the intersections along the feeder's route. The aggregate average passenger's waiting time got reduced by 2 minutes 31 seconds as compared to the base model. The aggregated average passenger waiting time of 6 minutes 23 seconds was calculated at varying traffic conditions.

The least performing scenario is when traffic signal controls only were introduced at some strategic intersections along the feeder's route and the existing intersections were re-designed to give priority to traffic flowing in the direction paratransit feeder's vehicles. The aggregate average passenger's waiting time reduced by 1 minute 20 seconds from the base model. The aggregated average waiting time of 7 minutes 34 seconds was obtained when this scenario was tested.

## **5.5 OVERALL TRIP TIME**

This is the overall in-vehicle time taken by paratransit vehicles from their origin to their destination, which includes the dwelling, cruising and crawling time expressed in minutes. Dwelling time is time used by paratransit vehicles at the stand to pick up and drop off passengers expressed in minutes, cruising time is the time used when the paratransit vehicles are moving without interruption normally at speed above 8 km/hr while crawling time is the time used by the paratransit vehicles waiting at the signalised intersections or in traffic congestion expressed in minutes.

Overall trip time(min)= Dwelling time (min) + crawling time (min) + cruising time (min).

Any alteration or delay in any of the times mentioned above will have an effect on the overall trip time. The overall in-vehicle trip time is one of the most important KPI used in assessing the overall efficiency of a public transport system. Most passengers desire trips with minimum in-vehicle travel time when deciding the mode of transport to use for the trip. The lesser the overall trip time, the better the overall efficiency of the public transport system.

*Table 5-5 In-vehicle trip time of each infrastructural improvement scenario as traffic condition increases.*

Percentage increase in traffic condition	Base model (min)	Traffic signal only (min)	Queue jumper only (min)	Traffic signal + Queue jumper (min)	Dedicated lanes (min)
0	00:36:57	00:35:38	00:31:20	00:32:11	00:33:31
10%	00:39:05	00:34:45	00:35:01	00:34:12	00:33:20
15%	00:41:47	00:37:39	00:34:47	00:34:32	00:34:27
20%	00:43:45	00:35:48	00:37:12	00:34:11	00:33:16
25%	00:46:13	00:39:47	00:34:15	00:35:30	00:35:18
30%	00:47:24	00:37:23	00:36:10	00:35:54	00:34:30
Average	00:42:32	00:36:50	00:34:47	00:34:25	00:34:04

It is evident from table 5-5 above that all the infrastructural improvement scenarios tested in the model performed better than the base model in terms of the in-vehicle overall trip time. The base model has an aggregated average overall trip time of 42 minutes 32 seconds as traffic condition varied which makes it the worst scenario tested.

Introduction of exclusive dedicated lanes along the feeder’s route for the paratransit vehicles is the best performing infrastructural improvement scenario tested in the model. The traffic condition was varied to have a view of how the scenario will perform at various levels of traffic condition and aggregated average overall trip time of 34 minutes 4 seconds was obtained, which makes it the best performing scenario.

The second performing scenario is when queue jumpers and traffic signal controls were combined and introduced at some strategic intersections at all the intersections along the paratransit feeder’s route at varying level of traffic conditions. The aggregated average overall in-vehicle travel time of 34 minutes 25 seconds was obtained, which makes it the second-best performing infrastructural improvement scenario tested.

The third best performing scenario when queue jumpers were introduced at all the intersections along the feeder's route. The scenario was tested as traffic level kept increasing and an aggregate average in-vehicle overall trip time of 34 minutes 47 seconds was obtained, which is lesser than what was obtained when traffic signal only was introduced along the feeder's route and in the base model.

The least performing scenario out of the four scenarios tested was when traffic signal only was introduced to some strategic intersections along the feeder's route and the existing intersection were re-designed to give more green time to traffic flowing in the direction of the feeder's paratransit vehicles which was tested at different level of traffic along the route. An aggregated average in-vehicle overall trip time of 36minutes 50seconds was obtained which makes the least performing scenario but still perform better than the base model.

## **5.6 ANALYSIS OF SIMULATION RESULT**

From the results discussed above for each KPI, it is evident that introduction of dedicated lane is the best performing scenario tested in the model. However, the performances of other scenarios tested cannot be phantom against each other, as one scenario performs well with a KPI but performs worse in other KPIs or scenarios having a very close result for some of the KPIs. In a situation like this, where multiple criteria (KPIs in this context) are involved, confusion can arise if a well-structured decision making process is not adopted. Hence, there is a need for a technique that can help to rank the infrastructural improvement scenarios against each other from best performing scenario to the least performing scenario. Multi-Criteria Analysis (MCA) evaluation is chosen to help in ranking the tested scenarios as the mechanism is able to compare a diverse range of information, in which for this case, it will be able to use each of the KPIs analysed in section 5.1 to 5.5 above to produce its result.

According to Madurika, HKGM, & Hemakumara, GPTS. (2015), MCA is a sub-discipline of operation research that explicitly evaluates multiple conflicting criteria in decision making both in daily life and in settings such as business, government and medicine. MCA unifies different dimension, both qualitative and quantitative. Social, economic and environmental evaluations are

all takes into account when MCA is used which makes the techniques attractive to different stakeholders.

### 5.6.1 MCA PERFORMANCE MATRIX

The performance matrix shows how each of the infrastructure improvement scenarios tested perform against each KPI. The KPIs will represent the criteria for the evaluation, while the aggregated average values obtained from varying traffic levels were also used for the evaluation. The KPIs are the criteria while the infrastructural improvement scenarios tested will be the alternatives.

*Table 5-6 Performance matrix table of infrastructure improvement scenarios tested against each KPI*

KPI/Criteria	Units	Base model	Traffic signal only	Queue jumper only	Traffic signal + Queue jumper	Dedicated lanes
Overall trip time	minutes	00:42:32	00:36:50	00:34:47	00:34:25	00:34:04
Passenger's waiting time	minutes	00:08:54	00:07:34	00:06:23	00:06:08	00:05:37
crawling time	minutes	00:24:01	00:18:05	00:16:22	00:16:05	00:14:51
Number of boarded passengers	number	409	427	424	430	433
Total distance travelled	km	99.20	106.56	105.07	107.07	108.67

### 5.6.2 SCORING AND WEIGHTING OF KPI/CRITERIA

Scoring and weighting is the next step when using MCA evaluation technique, this is the aspect where each KPI/criteria are given weight base on their level of significance to the stakeholder involves. The most significant criteria are given bigger weight than the less significant ones. The main aim of this research is to investigate the effect of some infrastructural improvement scenarios on the overall trip time and passenger's waiting time on the feeder's route. Therefore, overall trip time and passengers waiting time are the most significant criteria here, hence they were allocated the highest score and weight.

The score is always on the numerical scale of 0-10, while the weight of each criterion is derived by dividing its score with the total sum of scores of all criteria considered. The sum of all the weight must be equal to 1.0

$$criterion\ weight = \frac{criterion\ score}{\sum(scores\ of\ all\ the\ criteria\ considered)}$$

For example, the weight of overall trip time =  $\frac{9}{41} = 0.220$

Table 5-7 Score and weight of each criterion

KPI/Criteria	Units	Score	Weight
Overall trip time	minutes	9	0.220
Passenger's waiting time	minutes	9	0.220
crawling time	minutes	7	0.171
Number of boarded passengers	number	8	0.195
Total distance travelled	km	8	0.195
	<b>Total</b>	41	1.000

### 5.6.3 CRITERIA STANDARDISATION

The next step using MCA evaluation is to standardised the values obtained for each of the criterion/KPI considered. This is done using the performance matrix to obtain a uniform measure of the criteria which makes them to be comparable to one another. Standardisation is done for each criterion by dividing all the values with the highest value of the criterion. For instance, considering the criterion passenger's waiting time, it was standardised by dividing all its values by 8:54 minutes, which is its highest value.

Furthermore, the value of each criterion can either be negative or positive depending if the criterion is a constraint or benefit. For instance, a criterion can be considered a constraint if higher values are undesired, i.e. the lower the value, the higher it will be desired. A good example is overall trip time; lower trip times are always desired by passengers while higher trip times are not desirable. Criteria such as overall trip time, crawling time and passenger's waiting time in this research are all constraint and therefore, will carry negative signs.

On the other hand, a criterion can be considered a benefit if its higher values give more desirability i.e. the higher the value, the higher is its positive impact and the higher is its desirability. For the purpose of this research, criteria such as the number of boarded passengers and the total distance travelled are all benefit and therefore, will carry positive signs.

Table 5-8 Standardised Performance Matrix

KPI/Criteria	Units	Base model	Traffic signal only	Queue jumper only	Traffic signal + queue jumper	Dedicated lanes
Overall trip time	minutes	1.000	0.866	0.818	0.833	0.801
Passenger's waiting time	minutes	1.000	0.851	0.717	0.689	0.631
crawling time	minutes	1.000	0.753	0.682	0.670	0.618
Number of boarded passengers	number	0.945	0.986	0.979	0.993	1.000
Total distance travelled	km	0.913	0.981	0.967	0.985	1.000

#### 5.6.4 EVALUATION USING WEIGHTED SUM METHOD

There are quite some other methods, such as Score card, Evamix and Coordinance methods that are used in Multi-criteria analysis, but for the purpose of this research, Weighted sum method has been employed because of its less complexity, easy steps involved and the fact that it allows public transport stakeholders to be fully involved in the decision making. It gives the stakeholders the opportunity to give higher weight to criteria that will positively impact them and lesser weight to criteria that will negatively impact them.

The next step is to multiply the standardised values by the weight allocated to each criterion and the summing up all the values for each of the scenario tested. The scenario/alternative is ranked based on the sum of the value obtained. The alternative or scenario with the highest value is the best and the other scenarios are then ranked base on their value.

Table 5-9 Weighted sum method

KPI/Criteria	Units	Base model	Traffic signal only	Queue jumper only	Traffic signal + queue jumper	Dedicated lanes
Overall trip time	minutes	-0.220	-0.190	-0.180	-0.183	-0.176
Passenger's waiting time	minutes	-0.220	-0.187	-0.157	-0.151	-0.139
crawling time	minutes	-0.171	-0.129	-0.116	-0.114	-0.106
Number of boarded passengers	number	0.184	0.192	0.191	0.194	0.195
Total distance travelled	km	0.178	0.191	0.189	0.192	0.195
	Sum	-0.247	-0.122	-0.074	-0.062	-0.030

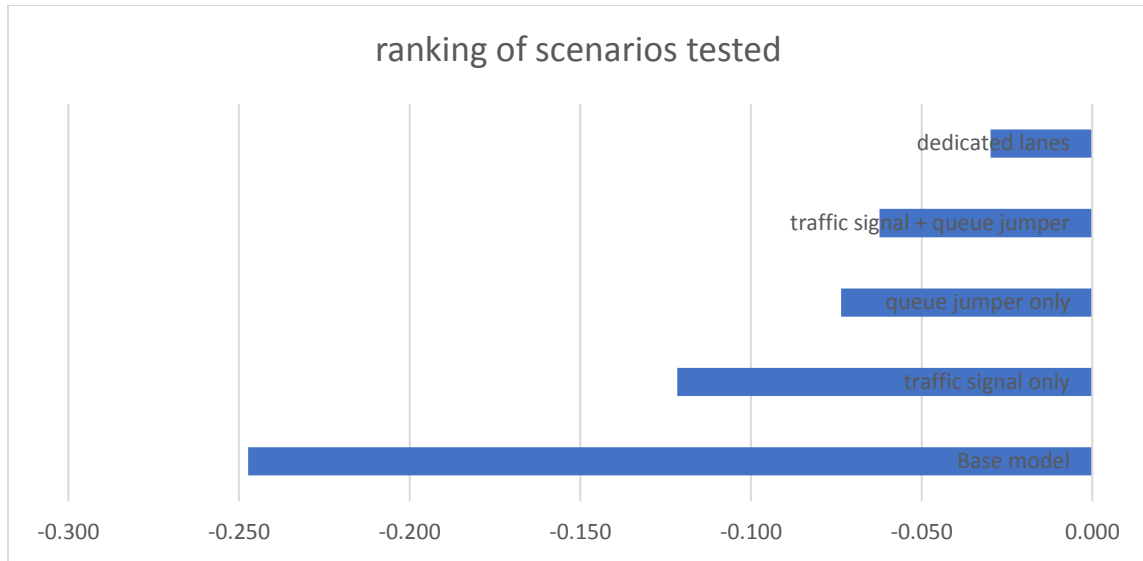


Figure 5-6 Chart showing the ranking of tested scenarios using weighted sum method

From table 5-9 and Figure 5-6 above, it is evident that all the scenarios tested performed better than the base model. The base model is the least performing scenario as it has the lowest value of -0.247. The overall best performing scenario is the introduction of dedicated lanes on the feeder's route which has the highest value of -0.030.

Table 5-10 Ranking of the infrastructural improvements scenario based on their performance at varying level of traffic

Scenario	Ranking
Dedicated lane	1st
traffic signal + queue jumper	2nd
Queue jumper	3rd
traffic signal only	4th
Base model	5th

Table 5-10 above simply indicated that if any of the above infrastructural improvement strategies is implemented, it will improve the overall efficiency of the paratransit feeder's service to the Mitchells Plain interchange. The overall trip time and the passengers waiting time on the feeder's route will be reduced. As traffic increase with time in the future, any of the above infrastructure improvement strategies from the 1st position to 4th position can be implemented, which will all increase the overall efficiency of the paratransit feeder's service and also improve ridership at the long run.

## 6.0 CONCLUSION AND RECOMMENDATION

### 6.1 CONCLUSION

This study focused on the current operations of the paratransit feeders service to initiate and understand its informal way of operations, which pose an integration problem with trunk service.

The study later goes on to explore possible operational improvements strategies to improve paratransit feeders service to the interchange. These operational improvement strategies were then narrowed down to the types of infrastructural improvements that can be implemented to improve the operational efficiency of the paratransit feeder's service and then to determine the impact of these infrastructural improvements on the overall efficiency of the paratransit feeders service at varying level of traffic conditions.

An agent-based micro-simulation software called Commuter was used to model the operation of the paratransit feeders service using the feeders service from Westgate mall to Hazeldene public transport interchange in Mitchells Plain, Cape Town, South Africa as the case study. The model was subjected to various scenarios to investigate the impact each of the scenario modelled will have on the overall efficiency of the paratransit feeders service. In each scenario modelled, an infrastructural improvement through road prioritisation was implemented in the model and the results which consist of various parameters were then used to evaluate the impact of each implemented scenario on the efficiency of the paratransit feeders service.

The remainder of the chapter will provide possible answers to the research questions that guided this research, which was raised in chapter one of this dissertation.

➤ **What are the infrastructural improvements that can be implemented to enhance the operational efficiency of the paratransit feeder's service?**

There are quite few numbers of infrastructural improvement strategies that can be implemented to enhance the operational efficiency of the paratransit feeder's service. These strategies have already been explained in Chapter 2; section 2.4.1.1 to section 2.4.1.2 of this dissertation. These strategies ranges from prioritisation at the intersection, introduction of dedicated Bus ways/lanes to provision of adequate and comfortable Bus stops along the feeder's route.

For the purpose of this research, only four infrastructural improvements scenarios excluding the base model were investigated, which are part of the possible infrastructural improvements that can be implemented to enhance the operational efficiency of the paratransit feeders service. The scenario tested in the model include the following.

- **Introduction of traffic signals at some strategic intersections-** The first scenario tested, after the base model, was the introduction of traffic signal control at some strategic intersections along the paratransit feeders route, which would not have been possible to give traffic flowing in the direction of the paratransit feeders vehicles free flow at the intersections. The existing traffic signals at the intersections along the route were also redesigned to give priority to traffic flowing in the direction of paratransit feeder's vehicles. This scenario was tested under varying traffic conditions to have an idea of how the scenario will perform under normal and increased traffic conditions.
  - **Introduction of queue jumper at all intersections-** This scenario was tested to investigate the impact of introducing queue jumpers at all the intersections along the feeder's route. Queue jumpers were introduced at all the intersections along the feeder's route and its impacts on the efficiency of paratransit feeder's service at varying traffic levels were investigated.
  - **Combination of queue jumper and traffic signal-** This scenario was tested to investigate what the combination of both queue jumpers and traffic signal control at some strategic intersections along the feeder's route at varying traffic levels will have on the overall performance of the paratransit feeder's service.
  - **Introduction of dedicated lanes on the feeder's route for paratransit vehicles only-** Dedicated lane was introduced throughout the length of the paratransit feeders route from Westgate Mall to Hazeldene interchange. The dedicated lanes are to be exclusively used by the paratransit feeder's vehicle alone and its impact on the efficiency of the paratransit feeder's service is being investigated at varying traffic levels.
- **What are the effects of these infrastructural developments on the overall performance of the paratransit feeder's service?**

From the analysed result in the previous chapter, it is evident that all the scenario tested has a positive impact on the overall efficiency of the paratransit feeder's service. The tested scenarios all performed better than the current way of operation of the feeder's paratransit

service. Each scenario was tested against some KPIs that are used to assess the performance of a public transport system. The KPIs used are as follow

- Overall trip time(minutes),
- Passenger's waiting time(minutes),
- Number of boarded passengers(numbers),
- Crawling time (minutes),
- Total distance collectively covered by the Paratransit vehicles during the simulation period.

Each scenario was tested against the above KPIs at varying level of traffic conditions. The aggregate average values for each KPI from varying traffic conditions were then used to formulate a performance matrix where Multi-Criteria Analysis (MCA) technique was later used to rank the scenarios based on their performance on the overall efficiency of the paratransit feeder's service.

Table 5-6 and Figure 5-6 from Chapter 5 of this dissertation has clearly shown how the infrastructural improvements scenario tested ranked against one another after using weighted sum analysis method to rank them. The best performing scenario is when dedicated lanes were introduced throughout the length of the paratransit feeder's route which is to be used only by the paratransit feeder's vehicle.

The worst performed scenario when the model was subjected to varying levels of traffic is the base model which depict the current operations pattern of the feeder's paratransit service. It can be inferred that the current mode of operations of the paratransit feeders service will not be able to perform at its current level as traffic conditions increase until one of the infrastructural improvements strategies are implemented.

➤ **At what level of traffic can each of these infrastructural improvements enhance the operational efficiency of paratransit feeder's service?**

The base model seems to be performing well with the current traffic condition and passenger demand on the feeder's route. But as the base model was subjected to an increase in general traffic condition along the route, the KPI results got deteriorating which depict that the current operation pattern of the paratransit feeder's service will not be desirable in the future as population and traffic condition increases.

Using the origin-destination matrices for cars, Buses and Trucks from the base model which depict the current traffic level on the feeder's route as illustrated in Figure 4-4 in Chapter 4 of this dissertation as the base traffic. From the results obtained and analysed in the previous chapter, it is advisable that in the future, as the general traffic conditions increases by 10%, traffic signal controls can be introduced to some of the strategic intersections highlighted in the methodology and the existing intersections along the route can be optimised to favour traffic flowing in the direction of the paratransit feeder's vehicles. This will take the KPIs result back and even better than the KPIs results obtained at the current traffic level and paratransit feeder's service operational pattern.

As the traffic condition increases to 15%, it is advisable to implement the introduction of queue jumpers at all the intersections along the feeder's route, this will bring back the KPIs result back to the KPIs obtained at the current traffic condition and operational pattern.

As the traffic condition increase up to 20% from the base traffic conditions, combination of traffic signal control and queue jumper will be able to sustain the operational requirement of the paratransit feeder's service and still produce better KPIs than what is been produced currently at the normal traffic conditions. No need for any implementation as this stage as traffic signal controls and queue jumpers would have already been implemented when traffic conditions has increased by 10% and 15% respectively.

When the traffic conditions increased to about 25% of the current traffic condition along the feeder's route, it is advisable to make a shift to implement introducing dedicated lanes throughout the length of the feeder's route which will be exclusively used by the paratransit feeder's vehicles. Introduction of dedicated lanes has been the best performing infrastructural improvement scenario tested as it has produced the best KPIs result which is better than the other scenarios at any level of traffic condition. The KPIs result obtained at all level of traffic condition was almost constant as the results differ by few minutes and numbers, which indicate that as traffic conditions increases, the KPIs results are expected to almost be the same.

Table 6-2 Traffic level each infrastructural improvement scenario needs to be implemented and the expected KPIs result

Traffic level	Suggested infrastructural improvements scenario to implement	Expected KPI results				
		Overall trip time(min)	Waiting time (min)	Crawling time (min)	Number of boarded passengers	Total distance covered (km)
0%	base model	00:36:57	00:08:54	00:21:10	425	104.77
10%	traffic signal only	00:34:45	00:07:14	00:19:27	428	107.79
15%	Queue jumper	00:34:47	00:06:11	00:11:23	428	108.78
20%	traffic signal + queue jumper	00:35:30	00:06:20	00:14:11	429	108.27
25%	dedicated lane	00:35:18	00:05:57	00:17:50	439	108.15

➤ **At what level of traffic congestion are each of these infrastructural improvements required?**

Table 6-2 above has clearly given the necessary answers to this research question.

The above result is not necessarily applicable to paratransit feeder's only but its applicable to all paratransit service within the urban area. The model used for this research depicts the current operational pattern of a feeder's service but paratransit service in South Africa exhibit the same operational pattern either as a feeder service or general paratransit services within the urban area.

Therefore, the result of this research is also applicable to general paratransit services operating within an urban setting in South African cities.

## 6.2 RECOMMENDATION

### 6.2.1 Incorporation of Route deviation option

As already discussed in Chapter Four of this dissertation, where the limitations of using commuter as the modelling tool to model a trunk-feeder public transport system were highlighted. Commuter was the best available tool that can model and give the expected result for this research. However, it was not able to model a realistic operation pattern of paratransit service in South Africa. A passenger doesn't go straight to a stop from his/her point of origin, but rather go to the nearest point on the public transport route, which is heading to his/her destination. Also, the paratransit drivers don't follow a fixed route when moving from their origin to their destination, they tend to use the route with the highest passenger demand to get to their destination. Unfortunately,

commuter doesn't have the capability to incorporate route deviation and the driver's competitive behaviour for the paratransit vehicles in the model. Instead, it uses a fixed trail for the paratransit vehicles which they cannot deviate from.

To improve the model and have a realistic model that will showcase the real operational pattern of the paratransit vehicles in South Africa, a function with a dynamic route choice decision and competitive nature of the paratransit drivers must be incorporated into the model.

A modelling tool called Multi-Agent Transport Simulation (MATSim) has the capability of incorporating the competitive nature of the paratransit drivers and also provide some degree of freedom to deviate from planned routes into the model. It is, therefore, recommended that the data used in this research to be improved and use a modelling tool that can incorporate both the competitive nature and route deviation options in the model and then re-test all the scenarios.

### **6.2.2 Incorporating cost of implementing the infrastructural improvements scenario tested**

The monetary cost of implementing the infrastructural improvement scenarios tested was not incorporated during analysis of the results obtained using the Multi-Criteria Analysis (MCA) technique. MCA was done based only on the KPIs/Criteria that relay the benefits to be derived from the implementation of the scenarios to the passengers and community as a whole but the cost implication to the government/policy makers was not considered.

It is, therefore, recommended that data that can be used to get the cost estimates of the infrastructural improvement scenario tested above should be collected and the cost implication should also be a criterion used during the multi-criteria analysis. This will give the policy makers clearer picture of what it will cost for a scenario to be implemented at the required traffic level.

### **6.2.3 Incessant update of traffic counts record**

As the agent-based simulation tool used to carry out this research could not produce the level of service on the paratransit feeder's route used as the study route. Instead, increase in traffic general condition on the paratransit feeder's route was used to analyse when each of the road space prioritisation scenario investigated in this research is warranted. It is, therefore, required to always keep constant updates of the traffic count records on major paratransit routes in South African

cities so as to know which road prioritisation strategy for paratransit vehicles to implement depending on the percentage increase in general traffic condition on those routes.

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