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EFFECTS OF FEEDER NETWORK OPERATIONS ON TRUNK-FEEDER NETWORK PERFORMANCE: A CASE STUDY OF MITCHELLS PLAIN, CAPE TOWN

A Master's Research Dissertation Submitted to the Department of Civil Engineering at the University of Cape Town [120 Credit Dissertation]

Complied by: Claire Birungi

Supervisor: A/Prof. Mark Zuidgeest

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I dedicate this research to my father P.K. Mutabwire who instilled in me the qualities that I have now. Your continued belief in me has been great inspiration to work harder.

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Abstract

In South Africa, more than 65% of commuters use public transport every day. However, the public transport system which commonly takes the form of a trunk-feeder network is not structured to meet the needs of the different users. Taxis which are informal serve as feeders to an interchange while the trunk services depart the interchange in a scheduled formal manner. Because of this difference in the nature in which the two public transport services operate, it renders the intermodal system uncoordinated. It thus makes it difficult for transport planners to coordinate unscheduled feeder services to the scheduled trunk services. This study investigated how the feeder public transport service configurations and operations on trunk bus services can be integrated and coordinated.

The research employed an agent-based simulation tool to model and simulate trunk-feeder operations and further investigate how the configuration and operational characteristics of the trunk-feeder public transport system impact the passenger travel performance. The modelled intermodal operations mimicked typical trunk-feeder operations as follows: passenger arrival at stops to wait for taxis; passengers boarding and alighting along the feeder route; transferring passengers alighting from taxis; and walking through the interchange to connect to their respective trunk services so as to reach their destinations. The output of the validated base simulation model i.e. system characteristics, configurations and parameters were utilized to determine the Key Performance Indicators (KPI) in the system. The analysis of the KPIs showed that there is indeed no co-ordination between feeder arrivals and trunk departures, and that this is mostly a result of inefficiencies in current operations in the feeder system. Scenarios were then developed to improve the trunk-feeder model where they focused on improving the efficiency of taxi feeder operations along the feeder route, as well as integrating and co-ordinating the feeder services to the trunk services.

The results of the model analysis showed that integration of trunk and feeder services can be achieved through timed transfers; whereby taxi arrivals at the interchange are co-ordinated to bus departures from the interchange. This must of course be supplemented with other improvements tested in the scenarios on the feeder network. However, the operational behaviour of taxi feeder services is not predictable as a result of route non-compliance. This makes it difficult to plan timed transfers between them and formal bus and train services in

order to achieve integration. It is therefore key that the transport authority and the taxi association's work closely to ensure that the regulations set about taxi operations and route compliance are followed. Without monitoring, the taxis will tend to operate in areas with high demand as operators are profit seeking as opposed to servicing the community and this will limit the success of this objective.

Key words: Trunk-feeder, Taxi, simulation modelling, co-ordination, boarding & alighting, public transport integration, passengers

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List of Abbreviations

ABM: Agent Based Modelling

BRT: Bus Rapid Transit

CBD: Central Business Districts

CITP: Comprehensive Integrated Transport

DoT: Department of Transport

FSM: Four Step Model

GIS: Geographic Information System

GTZ: German Technical Corporation

ITDP: Institute for Transportation and Development Policy

KPI: Key Performance indicator

NHTS: National Household Travel Survey

OD: Origin Destination

ODK: Open Data Kit

SA: South Africa

SABOA: South African Bus Operators Association

TMB: Trip Based Modelling

TCRP: The Transit Cooperative Research Program

1. Introduction

1.1 Background

Public transport, if well planned and managed, plays an important role in meeting passengers' mobility needs (Roux, 2013). However, the quality of public transport services offered in most developing countries are inefficient and they thus need improvement (Nyarirangwe & Mbara, 2007). Recent studies have suggested transformational processes to deal with the deficiencies in public transport systems. In South Africa, the current processes are aimed towards the integration of, and complementarity between formal and paratransit services (Ferro et al., 2012; Behrens & Ferro, 2015, Del Mistro & Behrens, 2015; Wilkinson, 2010; Jennings & Behrens (2017).

Most of South Africa's urban public transport system is highly reliant on paratransit and it is often the only possibility for mobility for low-income citizens (Behrens et al., 2012; Neumann et al., 2015). These services deliver high frequencies that are flexible, affordable and demand responsive (Schalekamp et al., 2009). Despite their great importance, the Neumann & Nagel (2011) study concluded that the paratransit system is viewed as a nuisance due to the lack of structure in the way they operate. Much of this resulting from the fact that they are poorly managed – which is a result of weak public sector regulations, and they operate as an informal business as operators are primarily profit seeking as opposed to servicing their communities (Behrens and Ferro, 2015).

To this day, paratransit continues to provide a vital service for the vast majority of South Africans, and is anticipated to continue doing so in the coming decades (Fobosi, 2013). In order to plan a feasible and effective public transport system, it is imperative that the upcoming public transport reform strategies recognize the continued presence of paratransit services. Jennings & Behrens (2017) have argued that public transport reform strategies that recognize the continued presence of paratransit services are more likely to produce an effective transport systems than those strategies that ignore their continued existence.

In support of the continued existence of paratransit services, the City of Cape Town has explicitly recognized hybrid public transport systems in their public transport reform strategy. The hybrid public transport system comprises of paratransit services and formal scheduled services. A hybrid public transport system in which paratransit services complements the formal scheduled services can be achieved through feeder- trunk distributer public transport system.

The hybrid trunk-feeder public transport system is such that; taxis serve as feeders - providing services from local neighbourhoods to a public transport interchange while the large buses provide trunk-line services from the interchange to the central business centres. In some areas, however, taxis also operate as trunk services (City of Cape Town, 2013). The trunk-feeder system typically allows smaller capacity vehicles to operate on routes with lower and dispersed passenger volumes while high volume routes can operate more efficiently with large trunk-line vehicles (ITDP, 2007).

The obvious advantage of this hybrid public transport structure is the division of two components; the feeder and the trunk services. Each of these services are designed to carry different volumes of passengers with different public transport modes which are appropriate and efficient (Del Mistro and Bruun, 2015). On account of such advantages, the Department of Transport (2007), has envisioned that the upgrading of these service networks to an integrated public transport network is the mobility wave for the future and is the only viable option that can ensure sustainable mobility in liveable cities.

However, as it stands, these two public transport services are not integrated or coordinated. They co-exist but operate independently under different authorities (Ferro et al., 2012), they exhibit different operational service structures; feeder services exhibit an informal-unscheduled structure while trunk line services exhibit a formal-scheduled structure, and there is no co-ordination of transfers from one service to another. Because of this difference in the nature in which the two public transport services operate, it is difficult to coordinate them to obtain an efficient public transport system where the taxi feeder services complement the trunk services to provide a quality level of service for its users (Wilkinson, 2008).

The issue presented above is a serious cause of concern as it translates to inefficiencies in the public transport system. As such, pragmatic integrated public transport strategies need to be put in place to provide an efficient public transport system. In the past, many attempts have been made to solve this public transport problem by looking into road network designs, routing and other non-traditional optimization techniques. However, little work has been done in simulation modelling of coordinated and integrated operations involving vehicles and pedestrians as well as their transfers from one mode of transport to another (O’Mahony & Shrivastava, 2006).

Very little researches have been done to help understand this problem, with majority of the studies carried out in the Global North i.e., Europe and the United States (Eboli et al., 2007). For example, 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) 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.

In contrast, there is relatively limited research on paratransit quality and its integration to the existing trunk services particularly in Africa. It is only recently that studies are stirring up to try understand paratransit. Behrens (2015); Schalekamp (2015); Wilkinson (2008); Ferro et al. (2012), and many others have conducted studies to understand paratransit quality and the need to integrate it. Yet none of these studies have looked into simulation modelling of paratransit and its integration to the trunk services. In essence, there is still a lack of understanding on actual operations in view of paratransit – trunk service complementarity.

This study will therefore set-up a multi-agent based simulation model to understand the status quo of paratransit feeder service operations. The model will delve into investigating possible operational improvements that focus on coordinating paratransit services with existing trunk-line services. This will be used to analyse how the integration impacts the overall trunk-feeder network performance.

1.2 Motivation for the study

When developing cities experience economic growth, the middle class tends to free itself from public transport services because of the inefficiencies experienced in the public transport system. This translates to higher expectations in terms of mobility and better quality of service. In that regard, debate about the role of informal public transport services have become highlighted as it faces pressure to upgrade its services or/and to integrate with formal services. This will ensure the provision of competitive services to meet the city's demand in a sustainable manner (Transport Policy Advisory Services, 2010).

Recent improvements such as reducing time spent transferring between vehicles and the scheduled coordination of intermodal public transit systems, saving travel time and the reduction of emissions, made to trunk and feeder systems have proven to be a power tool to support an integrated urban transit system. These have been realized by understanding passenger flows, vehicle schedules and, vehicle and passenger coordination. Understanding these aspects that play important roles in the operation of trunk feeder systems aid to reduce the costs that a transit impacts on the user (Karthikgeyan et al., 2010). Eventually, this can bring broader benefits to South Africa by inducing greater transit ridership and better competition with private cars.

With such benefits, the City of Cape Town (2013) has recognized the need to invest and move towards integrated intermodal public transport systems. As such, it has developed an integrated public transport network operational plan (IPTN) to investigate and address issues affecting public transport. The strategic approach is intended to improve the level of service by; restructuring the feeder network to ensure that users do not encounter long waiting times, complementing interventions to improve capacity and travel time based on the extent of the need, designing new vehicle sizes for sufficient capacity, and network integration through integration of schedules. This restructured public transport system should provide users with an efficient intermodal network such that they are able to use public transport services to optimally move from their origins to their destinations.

1.3 Research objective

1.3.1 Main objective

The objective of this study to investigate the operational coordination of paratransit feeder services and formal trunk service. The research will develop a model to investigate the status quo of paratransit services to generate an understanding of its operations and subsequently explore possible operational improvements – with a focus towards coordinating paratransit services to bus and rail trunk-line service, whose operations remain constant. The outcome will evaluate how the coordination impacts the overall trunk-feeder network performance.

1.3.2 Sub-objectives

The following specific objectives will be addressed in this research:

- To give an overview of public transport operations focusing on taxi operations, their travel patterns, transfers and elements of public transport structure.
- To identify trunk-feeder system configurations and their respective input parameters.
- To select an appropriate software package that suits the particular needs of the model.
- To identify a case study area in Cape Town with sufficient information to demonstrate trunk-feeder network operations.

- To collect data required to set up a trunk feeder public transport model.
- To build a trunk-feeder public transport model using a simulation software.
- To simulate the operations of taxis and trunk services.
- To identify key performance indicators (KPIs) on service operations from the simulation model output.
- To develop scenarios to improve feeder network operations.
- To use the obtained KPI and scenarios to evaluate the trunk-feeder system.
- To perform a multi-criteria analysis to guide the decision making in evaluation of the system.
- To identify the potential for the research to influence policy and practice.

1.4 Research questions

The following sub-questions will be addressed in order to achieve the research goal.

- **To give an overview of public transport operations focusing on paratransit operations.**

  What is the main challenge of trunk and feeder operation in academic literature?

  What is the modelling concept of trunk-feeder in terms of design and operations?

- **To select an appropriate software package that suits the particular needs of the model.**

  What are the criteria to select a tool for to build the model?

- **To identify a case study area in Cape Town with sufficient information to demonstrate trunk-feeder network operations.**

  What is the appropriate public transport interchange with a feeder catchment area that has a high percentage of commuters using public transport and can demonstrate trunk-feeder network operations?

- **To collect data required to set up a model**

  What data is required for developing a micro simulation model?

- **To build and simulate trunk-feeder network operations in the selected software.**

  How was the trunk-feeder simulation model developed?

- **To define the KPIs from the simulation model**

Which KPIs were derived to analyse a trunk-feeder system?

- **To develop scenarios to improve feeder network operations**

  Which scenarios were developed to improve public transport performance?

- **To use the derived KPI and Scenarios to evaluate the trunk-feeder system**

  How did scenarios perform for each KPI?

- **To perform a multi-criteria analysis to guide the decision making in evaluation of the system**

  What is the best solution for all considered scenarios?

- **To identify the potential for the research to influence policy and practice.**

  What are the potential practice and policy implications?

1.5 Research framework

Figure 1-1 illustrates the process that will be followed in order to develop the model. This conceptual framework will offer an organization of the process for the research.

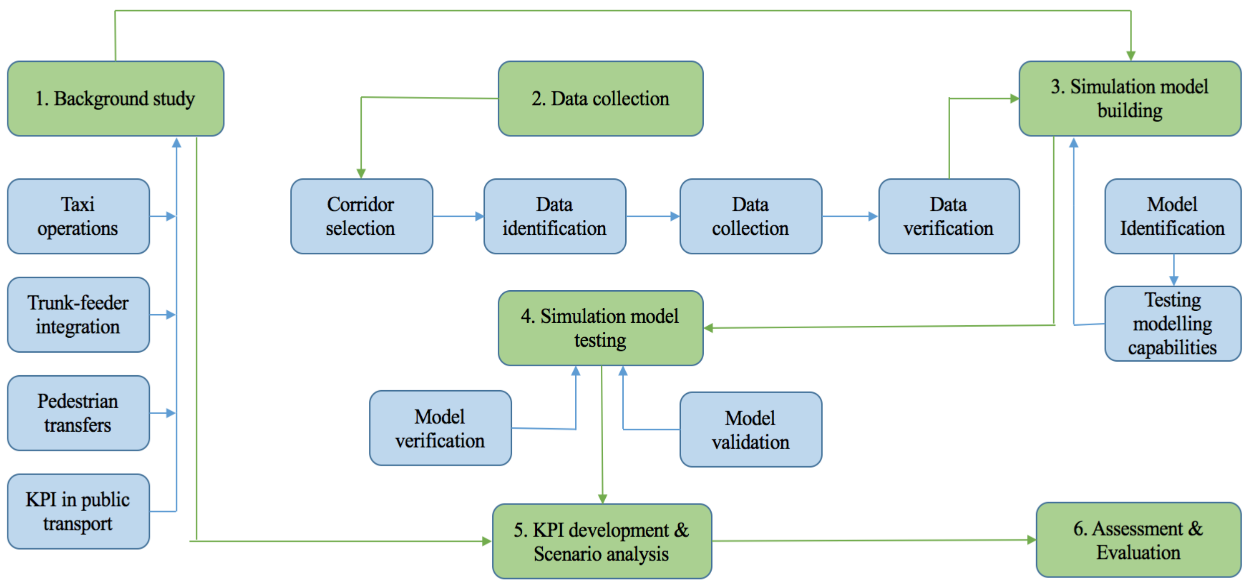

Figure 1-1: Co-ordination of the trunk-feeder model

1.6 Structure of the research

The present chapter provides the background and objective of the study. The remainder of the research is structured in six chapters as outlined below:

Chapter 2: Literature review

The public transport structure, operations and configurations are reviewed in this chapter. This chapter also presents steps to approaching the objectives of the research. These include studies into the status quo of public transport, model concepts of trunk-feeder services, development of KPIs to evaluate the performance of public transport systems and finally, economic implications of implementing trunk feeder systems.

Chapter 3: Study area and data collection

The background of Mitchells Plain in terms of public transport is presented. It further discusses the dependence of most commuters to public transport. In addition, the chapter discusses planning of the survey, data collection process, and the tools developed to collect data. It also presents the results of the survey.

Chapter 4: Methodology

This chapter describes the methodology used in this study. It gives an overview of the data processing techniques used to obtain OD matrices and other data inputs for the model. The chapter also builds on the development and simulation trunk-feeder public transport model in Commuter to replicate the situation in the study area.

Chapter 5: Results and case study discussion

The results of the simulation model in terms of KPIs as well as the scenarios are presented in this chapter. This is followed by the economic analysis performed using KPIs. The benefits and costs of each scenario on stake holders are also presented.

Chapter 6: Conclusion and recommendation

The chapter gives a summary of the results and further provides the answers to the research questions. Finally, recommendations based on the conclusion about the study are presented.

2. Literature review

The public transport system of most South African cities is dominated by paratransit services – an important component of its overall transport services. These services are, however; poorly managed as a result of weak public sector regulations, and operate as an informal business as operators are primarily profit seeking as opposed to servicing their communities. Consequently, they provide a poor quality of service. This points to an indisputable need to improve these services. As an initiative to improve these services, some city authorities are exploring prospects of a hybrid transport system in which paratransit complements the formal services (Behrens and Ferro, 2015).

Accordingly, this literature review presents the theoretical basis for understanding and improving public transport operations with a focus on trunk-feeder network operations. It begins by developing literature on the characteristics of the two forms of public transport service structures with a deeper focus on paratransit services – their status quo and quality of service in South Africa. This unfolds into literature investigating the prospects of incorporating paratransit in the trunk public transport services. This is then followed by further discussions on operational characteristics of trunk-feeder public transport systems, modelling concepts of the systems and concludes with a discussion about KPIs for public transport systems.

2.1 Public transport service structures in South Africa

This section presents the types of public transport services in the public transport system, as well as the the characteristics of each of these services. The service types that will be explored are; formal and paratransit (also known as informal public transport). The services will be explored by investigating their operational characteristics. Understanding the characteristics of each of the public transport services is important to understanding the disparities that make operational compatibility a challenge while exploring their integration.

To distinguish between the two types of public transport services, their characteristics are outlined following sub-sections.

2.1.1 Formal services

The formal public transport is comprised of rail and road-based transport. 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). Central to the road-based public transport services are the scheduled buses; Golden Arrow buses and the Bus Rapid Transit (BRT); MyCiti buses. Formal services exhibit the following characteristics:

- Fixed routes and bus stops
- Do observe fixed schedules and timetables
- Usually (but not always) subsidized in some form or other with buses.
- Use a ticketing system, which incorporates some form of proof of payment for example paper ticket or card.
- Drivers have rosters, which stipulate the routes to be followed and impose limits on hours of work.

2.1.2 Paratransit services

Paratransit is a central component of the public transport system in South Africa and other Sub-Saharan African countries. It is, therefore, necessary to develop an understanding of its background, provide insight into its ways of operation, as well as its quality of service ranging from service planning, vehicles and organization frameworks.

2.1.2.1 Defining paratransit

Paratransit takes different forms and can be defined differently based on the city's context. 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).

It can be defined based on; its regulatory frameworks. Behrens et al. (2012) who studied paratransit in sub-Saharan Africa defines paratransit as informal and unregulated, while Cervero (2000), defines paratransit systems' functionality in a "laissez faire" context in which authorities allow for a very flexible regulatory framework.

Similarly, based on analyses in Africa, Wilkinson et al. (2012) based his definition on flexibility of services. The study defines paratransit as a flexible mode of transport that lacks schedules or frequencies, with features of a small to medium sized vehicles – often ageing minibuses. Figure 2-1 depicts typical examples of the nature of paratransit in some Sub-Saharan African cities.

Based on observations in Mexico, Chapain (2005) proposed a definition that is centred round the subject of vehicle capacity. The capacity of vehicles vary from minibuses (10-15 seater) to midibuses (intermediate capacity of a 20-40 seater) to that of a large bus of 50 or passengers.

Figure 2-2 shows where Cape Town fits in this definition. Averagely, the capacity of paratransit in South Africa is 15 passengers. This actually leaves leverage in managing paratransit capacity issues in case of the need to increase capacity.

Figure 2-1: Paratransit in Sub-Saharan African cities
Source: (Bruun & Behrens, 2016)

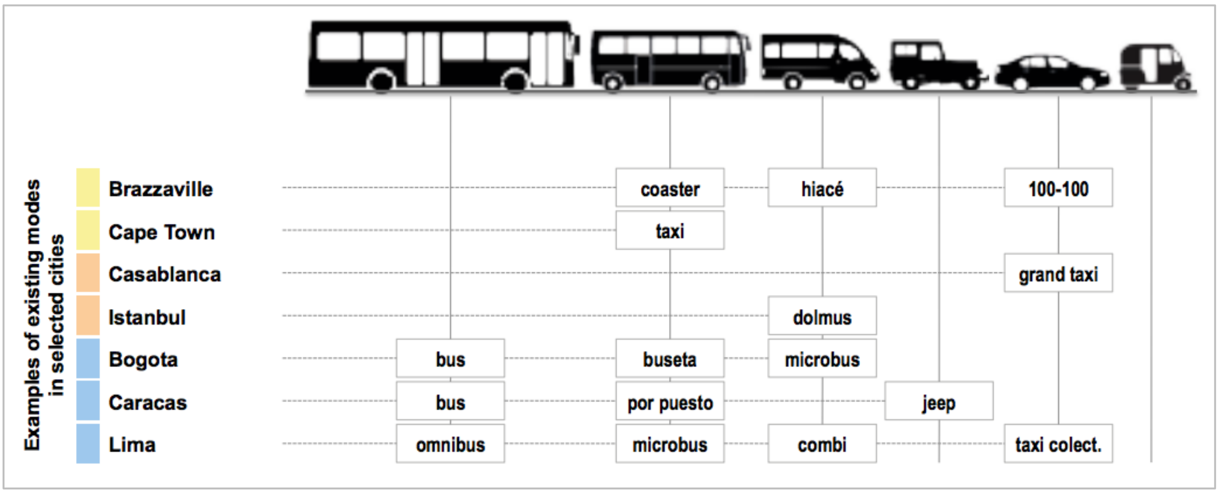

Figure 2-2: Types of paratransit vehicles in cities
Source: (Ferro, 2015)

2.1.2.2 Paratransit market share in Africa

Paratransit is notable for its role as "gap-fillers" – existing mainly to fill gaps left by formal public transport (Nwaogbe, 2012). However, in many African cities, they are not just gap-fillers; these services are in fact the primary form of public transport (Ferro, 2015). Figure 2-3 shows the passenger market share distribution of paratransit modes across cities in Africa. This goes to show the strong presence and reliance of these fragmented and unregulated services which accentuates that transport needs are not met sufficiently by the government through formal services alone (Transport Policy Advisory Services, 2010).

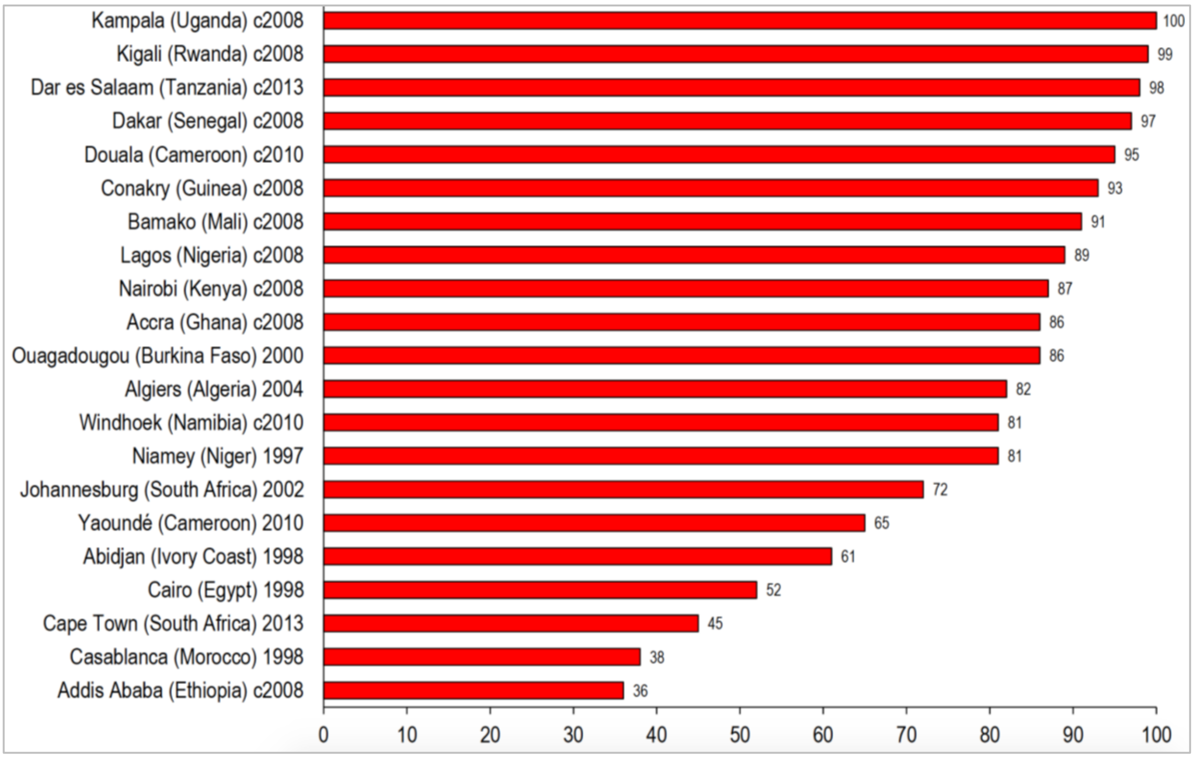

Figure 2-3: Paratransit market share in Africa

Source: (Bruun & Behrens, 2016)

2.1.2.3 The South African context

South Africa is one of the many African developing countries that lacks sufficient public transport to meet transport needs of citizens. Instead, informal public transport serves the transport needs, more specifically, taxis. Paratransit in different cities around the world is known by various local names such as Matatu, Dalla Dalla, Jeepney etc. – in South Africa it is called Minibus taxi which in short is referred to as taxi (GTZ, 2010).

The government of South Africa does not provide an organized form of public transport in most areas, specifically in local neighbourhoods. This started during apartheid – the the Group Areas Act 41 of 1950 was the legislation which created residential segregation in Cape Town, where by black and coloured people were settled in areas far from the economic centres with limited access to transit services (Ahmed, 2004; Walters, 2012). As a result, taxi operators organized themselves to meet the demands of a growing urban African workforce. The operators legally or illegally formed associations to serve areas without public transport or those that were poorly served by formal operators.

Initially when the taxis started operating in the late 1970's, the government was against it. But since democracy in 1994, it became more acceptable. However, there have been state efforts to formalise or regulate the industry (Fobosi, 2013). To date, regulation of the industry has not been attained, which has caused many questions to rise with regards to the the role of the taxi industry. Many researchers have done studies on this industry in order to understand it. Many studies have been economic and political in nature, but recent studies are pointing to retaining the industry and trying to formalize it. This is a challenging attempt as the industry has shown resistance to this directive. Schalekamp (2015) found that the industry shows resistance from the operators because not much effort has been to understand their views, attitudes and practices on public transport and how it can be reformed.

2.1.2.4 Paratransit's quality of service

Literature on paratransit generally presents itself as a service that does not fit in the idea of a modern urban public transport system (Gauthier & Weinstock, 2010). The quality of paratransit can best be understood based on indicators such as service frequency, coverage, level of regularity, service hours and comfort.

In South Africa, the quality of service of taxis is steadily declining (Wilkinson et al., 2012). This has resulted from the fact that taxi operations are not directly subsidized. They therefore cannot bear the significant increases in operating costs and this has resulted into limited expectations of improving frequency.

Moreover, it is difficult to manage service regularity in a public transport system that does not always follow fixed routes. Browning (2001) indicates that paratransit services can be operated at optimal intervals that are more advantageous to users if routes were assigned to each taxi.

Also, critical to an understanding of paratransit is the fact that it is dynamic, very complicated and dangerous (Fobosi, 2013). Drivers of taxis board and alight passengers anywhere, they often over speed, they don't follow traffic regulations sometimes, and they normally do not depart until the taxi is full (Bruun and Behrens, 2016). These services also lack structure – the taxi drivers work is considerably less structured compared to that of workers within formalized public transport. In terms of the taxi's modus operandi, a taxi driver makes decisions on a daily basis as to where he is going to operate in order to make the most money.

Even though, the nature of service delivery by taxis is not desirable, there is still strong reliance on these services because they provide affordable, accessible and flexible transport solutions for the users. For that reason, the taxi industry remains the critical pillar of the country's transport sector accounting for 65% of all public transport commuter trips to the public (Fobosi, 2013).

In conclusion, the market for both formal and paratransit public transport systems can be desirable in areas where they is a better alternative. This divides the users into those that support paratransit services and those that support formal services. Despite being unregulated and the ambivalent characteristics of paratransit services, users may argue the following reasons to support their system:

- Higher travel speed in combination with high frequencies that are manoeuvrable
- In small towns and low density areas, paratransit services are the only means of public transport available
- Transport fares are normally lower than formal services

While formal services users argue the following:

- The certainty and reliability of the services particularly in small towns and low density areas where paratransit services are not frequent.
- Scheduled services are more desirable.
- They are more likely to be less crowded because of the well organised structure.

2.2 Approaches to public transport integration

As previously mentioned in chapter one, there are two public transport services. Taxis which serve as feeders and large buses which provide the trunk-line services. These services co-exist, operate independently under different authorities and exhibit different operational service structures (Ferro et al., 2012). While in the process of planning for appropriate strategies to integrate and coordinate the two services, it is critical to consider and investigate possible public transport structure arrangements that could possibly achieve an efficient public transport system. The two mostly implemented systems are considered here; the direct system and trunk-feeder systems. The two service structures are compared to provide insight into their configurations and to point out some of the characteristics of the system that are desirable and those that are not.

A “trunk- feeder” system is described as a system that allows smaller vehicles (paratransit) to be utilized in low density areas while main corridors can be better served with large - sized vehicles (rail and bus services). The smaller vehicles feed passengers to the large trunk buses and passengers using this system must transfer from one mode to another ITDP, 2007). In this arrangement, paratransit transport network is linked to the trunk transport network through a transfer terminal/interchange.

On the other hand, direct services will utilize a single vehicle to connect residential areas to central business centres without the need to transfer (ITDP, 2007). Figure 2-4 is an illustration between the two systems.

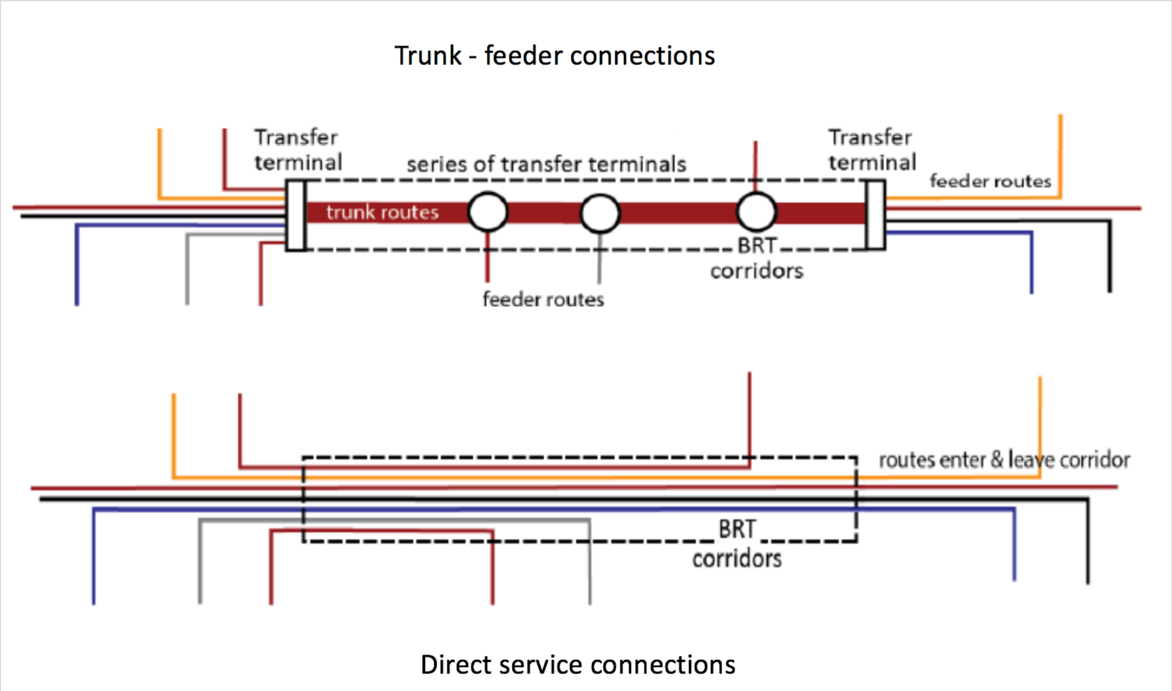

Figure 2-4: Illustrative comparison between direct system and trunk-feeder services

Source: (Cervero, 2015)

The two service structures are compared by presenting the advantages and disadvantages of each service structure. The comparison is presented in the following sub-section.

2.2.1 Advantages of trunk-feeder services

- **Operational efficiency**: This is one of the major advantages of trunk-feeder services. In optimizing public transport, demand and supply are matched in the most efficient way. Trunk-feeder systems are greatly based on this concept to increase ridership. In so doing, the system increases the load factor (passengers carried in a vehicle relative to the capacity of the vehicle) which is the measure of effectiveness and profitability. The improved load factor leads to a reduction in the fleet size required in a certain location hence reducing the wider traffic congestion in cities.

- **Vehicle utilization**: Trunk feeder systems utilise small vehicles in low density areas and bigger buses in high density area. This is less costly and more effective. It can allow for frequent service delivery and wider coverage into residential areas.
- **Service quality**: The service quality offered by these systems is high since there is reduced generalised costs of travelling like waiting time.

2.2.2 Disadvantages of trunk-feeder services

- **Time loss due to transfers:** The trunk-feeder system involves passengers transferring from the feeders to the buses on the trunk. This process can be undesirable mostly for passengers travelling with luggage or children. The time loss during transfers is also undesirable and some passengers may opt out of using the system because of such inconveniences. Moreover, passengers would trade travelling longer distances in one vehicle over the time used in waiting. Waiting time has a relatively bad perception towards passengers because it makes the process of travelling seem longer even if it is not.
- **Infrastructural costs**: There are infrastructural costs associated with construction and maintenance of transfer station. These include platforms, and facilities for pedestrian access.

It should be noted that in trunk-feeder systems not all passengers use both the feeder and trunk services. In Bogota, Columbia for example, there is a portion of people that only need the feeder or a trunk bus service to get to their destination. In that case, the disadvantage of time loss at transfers is not incurred (ITDP, 2007).

2.2.3 Advantages of direct services

- **Time saving:** This is the main advantage of the direct system. Most direct systems employ one vehicle from an origin to a destination. There is no time loss at transfers.
- **Low operation costs**: This is due to shorter direct routes hence less fuel consumption and secondly, there is no need for construction of intermediate transfer stations.

2.2.4 Disadvantages of direct services

- **Operational efficiency**: The major drawback of direct system is the use of a single vehicle size through the entire route given that the demand profiles along routes are ever-changing. Employing one large vehicle mostly in low density areas implies that the frequency is low, waiting time for the bus to get full is more, and if it operates with fewer passengers, their cost of travel will be higher. This makes the overall operation expensive and inefficient.

- **Slow operating speed and increased travel time**: The vehicles operate at low speeds due to congestion. This leads to increased travel time. The time thought to be saved by using the direct route can be negated through traffic congestion.

The section has presented the advantages and disadvantages of direct and trunk-feeder public transport services. An appropriate and effective public transport system for any city must be selected on a stand point of efficiency and cost effectiveness (ITDP, 2007). However, both trunk-feeder and direct services can be efficient depending on the circumstances. An optimal and appropriate choice must consider the service's ability to connect origins and destinations as well as match the demographic characteristics or any other conditions of the area. In the South Africa, the consequence of the Settlement Act during Apartheid forced most black people and the coloureds – who also constitute a large proportion of the urban poor to settle in areas far from the economic centres with limited access to transit services. On account of such reasons where distance between the CBD and feeder services is far apart, ITDP (2007) recommends trunk-feeder services as the better option to achieve an effective public transport.

Furthermore, with the implementation of BRT services in Johannesburg and Cape Town, public transport improvement initiatives now typically propose the transformation of paratransit-based direct services into trunk-feeder service models so as to maintain paratransit services which provide flexible and demand responsive services to the rapidly growing transport demand (Ferro & Behrens, 2015).

In order to understand the degree of impact of trunk – feeder systems, scenarios of cities that have transformed from direct to trunk-feeder systems are reviewed. Colombia and Brazil are some of the notable countries that has experienced success in their public transport systems through introduction of BRT together with restructuring to scheduled feeders. Brazil had one of the first BRT implementation in 1974 in Curitiba and has since grown in other cities of the country. The restructuring methods included forming associations of vehicle owners. The vehicle owners are reshuffled and organized to operate in specific assigned corridors (Hook, 2005).

Although moving to restructured and formal transit systems is recommended, the extent to which the impacts are perceived is highly dependent on the region in which the transformation is executed. In Bogota, the implementation of the trunk-feeder system has resulted in various positive outcomes;

- Traffic accidents have reduced by approximately 50% in most operational corridors and injuries reduced by 56% in 2008 (Rodriguez, 2010)
- There has been time saving of at least 40 min per trip
- Predictable schedules and routes offering traveller confidence in the system
- Improved comfort, safety and so forth.

Many benefits have been achieved by these services except for coverage. It has been reviewed that trunk-feeder services mostly cover city centres (Hook, 2005). Most importantly, time saving which is the primary objective of restructuring the public transport is achieved by eliminating the loop circulation of direct systems, thereby allowing the services to operate more frequently (Charlottesville Area Transit, 2011). According to Ferro and Behrens (2015), the significance of the trunk-feeder services is notable although it is rigid and still limited in coverage.

2.3 Incorporating paratransit in the formal public transport system

The previous sub-chapters have discussed the two forms of public transport systems, provided more insight in the operations of paratransit. This was followed by comparing possible connectivity options for achieving integration. This chapter presents a summary of the processes that have tried to achieve improved public transport services, it further discusses the alternative and realistic option to achieve integration and finally describes what public transport integration means and the issues hindering its realization.

As explained in chapter 2.2, paratransit's quality of services is poor – drivers of taxis board and alight passengers anywhere, they often over speed, and don't follow traffic regulations sometimes. The strong presence of these poor quality services is a consequence of the public sector's failure to regulate them (Bruun and Behrens, 2016). Initially, authorities in cities which are dependent on paratransit were inclined towards formalisation of the paratransit public transport operations as a way of providing better quality of public transport services whilst bringing control within the public transport sector (Shittu, 2014). The plan was to phase-out paratransit by incorporating their services into the formal service and consolidate operations or forced withdrawal of their services with compensation. That meant that paratransit services would become redundant and that the whole city would fall within formal trunk and feeder network services – assuming that implementation of all planned BRT networks would be completed by then (Schalekamp et al., 2010). This strategy, however, faced a lot of resistance from paratransit business owners and proved to be costly for the government (Department of Transport, 2007).

City authorities then embarked on exploring alternative ways of improving the quality of public transport services. An alternative approach that attracted attention of many city governments is the incorporation of paratransit services in to the formal services (Bruun and Behrens, 2016). Paratransit services and trunk-line services; bus, BRT services and rail services would then maintain their operations.

The arrangement of trunk-feeder- distribution services is a possible means of integrating paratransit and formal services that are scheduled. In that case, city authorities in charge of transport planning would concentrate on providing trunk services using large high capacity vehicles on trunk networks. On the other hand, taxi operators would provide feeder and distribution services using small lower capacity in local neighbourhoods to transport passengers close to where they can board trunk services to their final destinations (Del Mistro and Behrens, 2015).

The possibility of attaining integration of paratransit services and formal services also depends on how well the two sectors work together to have a coordinated transport system. Three ways can be considered to achieve a successful coordination. They are; cooperation, joint-use agreements and integration. In the cooperation arrangement, the two public transport systems operate separately but agree to work together with a purpose of improving the services. In the joint-use agreement alternative, the public transport services share resources but operate separately under separate management. Under the integration arrangement, the two public transport systems are consolidated and managed under one lead agency. A good administrative co-ordination is vital to achieve a practical physical integration of paratransit and formal operations (TCRP, 1999).

Physical integration implies a well-designed multi-modal system where trunk services depart in a scheduled manner and in turn, feeders are connected to the trunk services in a timed transfer system (Department of Transport, 2007). However, this is currently not easy to achieve in South Africa. The status quo of trunk services is that they are regular and reliable. During peak periods, headways can be approximately 15 minutes and can increase to 30 or 60 minutes during off peak periods. That way, users depend on a reliable schedule with buses arriving at the interchange with small deviations from the timetable. By contrast, the status quo of informal operations is the total opposite of formal services. Drivers of informal services typically like to wait till the vehicle is full or almost full before they can depart, they don't follow fixed routes meaning that there is a great variation in their arrival times at the interchange, and these drivers can start and withdraw from service at any time they wish to depending on whether they have made enough money for the day (Bruun and Behrens, 2016). This leaves the would-be passengers without connection. The operational behaviour of informal services is not predictable and it makes it difficult to plan timed transfers between them and formal services in order to achieve integration.

2.4 Review of analytical approaches in modelling trunk-feeder operations

The review of the trunk and feeder systems shows that passengers may need one or more transfers in order to get to their destinations. As such, the analysis of scheduling and co-ordination in vehicle operations is important as it helps to understand transfer operations – how to synchronize schedules in intermodal public transport systems most especially in feeder vehicles that have stochastic arrivals in (Chowdhury & Chien, 2010).

Hsu (2010) formulated a model to determine the transfer waiting time for a connecting service at multi-modal stations where waiting time is dependent on the characteristics of both connecting service (Trunk line services) and the feeder services. The results of the simulation model showed that transfer waiting time is largely affected by variables such as capacities and headways of trunk and feeder services. The results of the simulation also showed that compared to the effects of feeder services variables, the corresponding variables of the feeder services have more influence on the waiting times. Based on the analysis and evaluation of the simulation model, the study was concluded that in multi-modal operations, transfer waiting time at stations cannot be improved without operational coordination and scheduling with the feeder services.

Time loss in transfers at stations is influenced by the nature of transit scheduling and operations – particularly arrival of feeder vehicles and departure of trunk vehicles at a designated transfer location. Obkowitz et al. (1987) 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 strategies that were simulated for analysis were; (1) Unscheduled transfers, (2) Schedules transfers; without vehicle waiting, (3) Scheduled transfers; where low frequency bus is held until high frequency bus arrives, and lastly (4) Scheduled transfers; always holding the early arriving vehicles and the next until all transfers are made. The factors affecting transfers are evaluated based on the analysis of the microsimulation results.

Several other studies have been conducted to look into the impact of probabilistic vehicle arrivals to the intermodal transportation coordination problem (Chowdhury & Chien, 2002). Hall (1985) developed and evaluated a simulation model for scheduling vehicle arrivals at transportation stations or terminals. Equations were developed to optimize the time between scheduled vehicle arrivals for the feeders and schedule departure for the trunk line. The equations depend on the headway on the trunk line. Throughout the study, Hall demonstrated that coordinating vehicle arrivals and departures when the headway is large enough is important for solving transfer problems. Knoppers & Muller (1995) investigated the possibilities and limitations of coordinated transfers in public transit systems. The major aim of their research was to minimise transfer time at stations. It was shown that optimum transfer times can be obtained if the probabilistic arrivals of feeder services at the boarding station can be contained within certain limits. The results of the analysis revealed that coordination was worthwhile when the standard deviation of the feeder service at a transfer point is less than 40% of the headway on the trunk line.

Sivakumaran et al. (2012) explored how the coordination of vehicle schedules in public transit can affect user and operator costs. An idealised trunk-feeder system that delivers passengers to their destination by requiring them to transfer from a feeder vehicle to trunk vehicle at a transfer station was considered. A model was developed that first analysed the trunk vehicle schedules. It was found that when feeder vehicles are dispatched in coordination with the trunk vehicles, the cost reduction incurred by the users outweighs the operator cost. In cases where the frequency of the trunk-feeder service can be jointly incorporated in the model, it shows that this type of coordination can diminish both user and operator costs.

2.5 The modelling concept of trunk - feeder services

Providing public transport in urban areas where populations are varying can be challenging. Most commercial areas have high population densities while residential areas can have scattered densities but they all need to be accessible to public transport (ITDP, 2007). The challenge posed is mainly how to provide the public transport in the most effective and efficient way whilst covering all areas. In order to overcome such challenges, high density parts of the cities are served with high capacity vehicles and likewise low capacity taxis in low density areas. Serving with low capacity vehicles in the low density areas such as residential areas can be economical. This allows for possibilities to expand the public transport coverage compared to the direct transit systems which use same vehicles of same capacity from low density areas to high density areas. Using high capacity vehicles in low density areas is not considered to be of high economic sense.

The model operates in such a way that passengers wait for feeder vehicles at a stop closest to their origin. These vehicles operate in an unscheduled manner, that is, they wait for passengers until they are fully occupied and then they can move. Passengers board the low capacity vehicles which operate on mixed traffic lanes and travel to a bus stop. At the bus stop, the passengers alight from the mini bus taxi and wait at the transfer station to board on to a high capacity bus operating on the trunk. The trunk on which the high capacity buses are operating is exclusively for buses, normally dedicated bus lanes (ITDP, 2007). Unlike the feeders, most buses on dedicated lanes move based on a schedule.

2.5.1 Trunk- feeder operational structure and characteristics

i) Network layout

Figure 2-2 depicts an idealised system of a trunk-feeder operational structure on which Sivakumaran (2012) used to describe the environment of trunk-feeder systems. The system consists of a vertical line in the Y direction which operates with buses at a certain head way. The headway which determines the arrival and departure patterns can be at even or uneven time intervals. The trunk-line heads to the direction of central business districts (CBD) showing origin at the interchange and destination of passengers (CBD). The horizontal lines are routes feeding into the trunk at certain headway. The position of the feeder line along the trunk and its length are also important for modelling. The rectangular region bound by L and L_r is the service area from which the travel demand that uses the trunk-feeder services is derived.

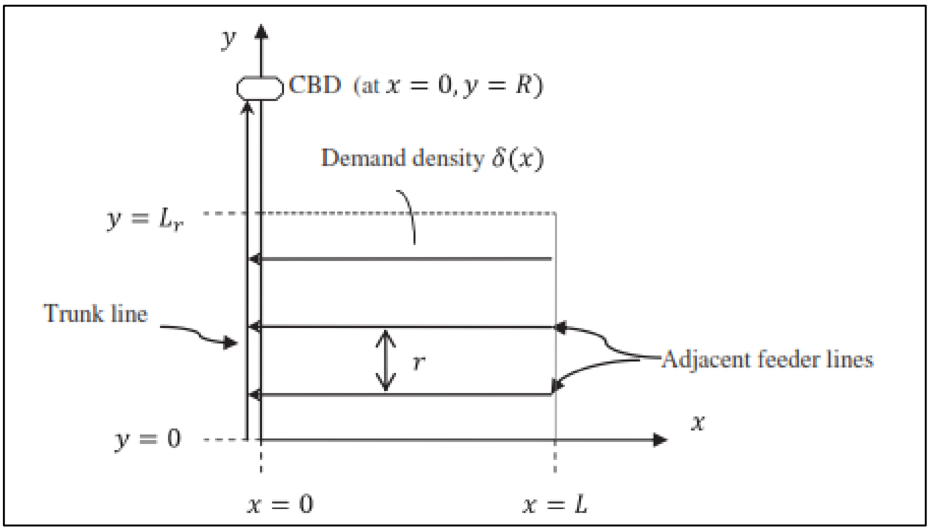

Figure 2-5: Trunk-feeder network structure

Source: (Sivakumaran et al., 2012)

ii) Station/interchange

Stations are an instrumental element for efficient and effective transfers. The design of the stations influences the time taken by passengers as they move through the station. The distance between alighting a feeder vehicle and boarding a trunk vehicle should be very short preferably not more than 10 metres (Nielson et al, 2005). In trunk-feeder systems, two kinds of stations are used; closed and open systems. Trunk stations utilise closed system while feeder stations utilise an open system. An example of closed system is illustrated in Figure 2-3 below. Closed systems have restricted access where access into the trunk station is only by passengers that have paid. They normally enter through access controlled gates or turnstiles. On the other hand, feeder stations are like normal stations. It is a shelter where passengers sit and wait for feeder vehicles. Unlike trunk stations, at feeder stations, passengers do not pay for tickets (City of Cape Town, 2009).

Figure 2-6: Transfer at a station

Source: (BRT planning guide, 2007)

2.5.2 Operational characteristics

i) Speed and reliability

Trunk-feeder systems should aim at travel speeds that are quite faster than the direct public transport services, and comparable or faster to the travel speed of private vehicles in order to make the system a competitive public transport system. This requires vehicles to travel uninterrupted for reliability of the service. The trunk services ideally operate on dedicated lanes but this is not the case for feeder services that travels in mixed traffic (Dodson et al., 2011). More detailed discussion on these characteristics are presented in Chapter 2.11.

ii) Transfers

The impact of the environment of transfers on ridership cannot be underrated. Users evaluate whether to use the system or not depending on the time they will spend transferring between vehicles. Also, if the transfer station involves hardships in transferring like walking long distances, use of staircases or exposure to rain, cold or heat, then the systems acceptability is compromised (ITDP, 2007). Most transit users would find the intermodal system desirable if there were no transfers at all. In order to get the best out of the transfers, the transfer stations should be designed in the most optimum way to avoid time loss.

iii) Capacity

Capacity is defined as the number of persons who can be carried by a mode of transport. In trunk-feeder systems, capacity can be categorised into two; the station/interchange capacity and the route/line capacity.

i) Route/line capacity

Janic (2015) defines the capacity of the route line as the maximum number of vehicles or the number of passenger spaces passing through a certain point at a specific time under conditions of a constant demand density of passengers. The capacity is expressed as a frequency of the route line from one origin (k) to one destination (l). The frequency at time (T) – in minutes is given by equation 2-1.

$$f(T) = \frac{T}{\max(H_{kl/w}{}^{(min)}; H_{kl/s}{}^{(min)})} \qquad \text{Equation 2-1}$$

Where;

kl is the route line distance

min is time in minutes

w is the vehicle

s is the station

and;

$H_{kl/w}{}^{(min)}$ is the minimum headway between successive vehicles along a route line (kl) in [min] and,

$H_{kl/s}{}^{(min)}$ is the minimum station headway defined as the inter-arrival time of successive vehicles at a specific station along a route line (kl) in [min].

Also if $H_{kl/w}{}^{(min)} > H_{kl/s}{}^{(min)}$ the station headways determine the capacity of the particular route.

In the case where the demand is satisfied by a specific load factor of a vehicle, the frequency at a time (T) is estimated as in equation 2-2.

$$f_{kl}(T) = \frac{q_{kl}(T)}{\lambda_{kl}(T)\, N_{kl}}$$ Equation 2-2

Where;

q_{kl} (T) is the passenger demand at a particular route line (kl) at a specified time T measured in [passengers].

λ_{kl} (T) is the average load factor at a specific time along a route line (kl) in [passenger/vehicle] and,

N_{kl} is the vehicle capacity along a particular route line (kl) in [spaces/vehicle].

ii) Station capacity

The capacity of a station is dependent on the platform size on which passengers stand or the stopping place where vehicles park and the average time they spend occupying the spaces (Janic, 2015).

iv) Travel time

One of the most valuable possession of people is time – how they spend their valuable limited time (Litman, 2014). In public transport, almost all index to measure the efficiency of transport systems are encompassed around travel time. It is one of the largest cost of transportation and in addition, it is the primary justification for transportation performance improvements.

Travel time is defined as the amount of time a bus takes along a road network over a specified period. The average travel time is affected by the transfers in intermodal systems, route length, traffic conditions, road blocks, passenger activity such as boarding and alighting, the number of signalised intersections and other variables depicted in Figure 2-4 (El-Geneidy et al., 2009).

Variables	Description
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 2-7:Factors affecting travel time

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

v) Scheduling

In the transit operation planning process, schedulers create time tables for bus routes on a given network (Ceder et al., 2000). To do so, three decision levels are normally considered when developing a schedule (Ceder, 1986). They are as follows:

- Select a vehicle headway type, that is even or uneven headways
- Select a method for defining frequencies, that is maxim load or load profiles
- Select one or more objective functions based on which scheduling will be implemented. This is normally based on which perspective the scheduler is performing the design for, for example, minimising operator or user cost while varying the quality of services provided. Usually, a global approach from a user's perspective is to minimise travel and waiting times.

2.6 Coordination and scheduling of transit systems

With the growing urbanization, the requirement for intermodal transit systems consisting of buses on trunk lines and feeder routes connecting to transfer stations is also growing. Ferro & Behrens (2015) have motivated the restructuring to a formal trunk-feeder as the way to a sustainable transit system. In many cities where the trunk-feeder systems are used, studies are being conducted to design optimal transit operations with the objective of minimizing transit costs on passengers and operators (Chowdhury & Chien, 2000). Minimising total time spent transferring between vehicles through implementation of schedules and coordination can reduce the effects that the transit system imposes on its users. Therefore, dispatching feeder vehicles in coordination with the vehicles on the trunk line can address the mismatch that causes time loss in transfers during transit (Sivakumaran et al., 2012).

The problem of trunk-feeder systems operation arises from different configurations at the transfer stations. The system can be analysed in two parts; the trunk line and feeder line. Along the trunk line, the service is normally a train or Bus Rapid Transit (BRT) system operating on dedicated lanes at uniform arrival patterns where the headway is constant. The trunk buses are high capacity vehicles. On the other hand, along the feeder route, the service operates in traffic and the vehicles have random arrivals. These are low capacity vehicles collecting passengers typically from residential areas. The randomness of arrivals in feeder vehicles which are meant to transport the passengers to the BRT buses are not operating in coordination with each other. This is what causes passengers to wait at transfer stations and trunk vehicle loading inefficiency (Sivakumaran et al., 2012).

Verma & Dhingra (2006) then developed a model to analyse the problem of trunk-feeder system. The idea of the model is to develop a BRT bus first since it is the main capacity transit system and then the feeder model to schedule. The feeder model is coordinated accordingly with the main system. The trunk bus model is used to generate the optimum frequency for the bus operation at a minimum headway which in turn gives the number of buses or fleet size required to cater for the trunk network at an efficient load factor. The feeder model is implemented at a schedule in coordination with the main system such that when the feeder buses arrive at a station, it is in time to allow for passengers to alight and board the trunk bus at the minimum time.

2.7 Methods to design for optimal services

This section presents the methods and procedures to design some transit features that can be manipulated to improve transit operations. It is fundamental to know the design and correct approaches when providing transit services. Ceder (2007) indicated that this is desirable in order to exploit the system's capacity to the greatest extent while maximizing its productivity and efficiency.

2.7.1 Vehicle size

Design for an optimal vehicle size adopts the vehicle-size square root formula which signifies that the optimal vehicle size varies according to the root of the number of passengers carried.

This formula accentuates the trade-off between vehicle capacity cost and passenger waiting time cost. It is assumed that operating cost per vehicle hour is constant, average waiting time is half the headway, riding time is independent of vehicle size, travel time and stopping time are independent. The optimal vehicle size Z_o is given by

$$Z_o = \sqrt{\frac{2C_bP}{C_w}}$$ Equation 2-3

Where;

Z_o is the vehicle size [number of passenger seats]

C_b is the operating cost per vehicle- hour in [unit cost/veh/hr]

P is the number of average hourly passengers carried in maximum load segment measure in [passenger/hr]

C_w is the value of waiting time [cost of waiting/hr]

2.7.2 Fleet size

Ceder (2007) developed a method to determine fleet size required for a circular route. In the algorithm, it is assumed that T_r is the round trip time measured in [min] including layover and turnaround times of a circular route *r* with the same departure and arrival points. The minimum fleet size is then equal to the largest number of vehicles that can depart with in T_r in [vehicles].

Assuming that *r* starts and ends at b, T_{rj} will be the average trip time on route *r* for a vehicle departing at t_j from b including its layover at *b*. Let n_j be the number of departures from *b*, from and including departure *j* at t_j until and excluding j' at t_j'. It further defines that *j* arrives at *b* and continues with departure j' at t_j' which is the first feasible departure from *b* at a time greater than to $t_j + T_{rj}$. From this, the minimum fleet size N_{min}^r required for the circular circle *r* is given as by;

$$N_{min}^r = Max_j\ n_j$$ Equation 2-4

Ceder (2007: Chapter 16) provides an example on the use of this method.

2.7.3 Frequency and headway

In practice transit agencies normally wish to save vehicle runs to perform a match demand and supply and demand with the minimum vehicles. To this effect, Koutsopoulos et al. (1985) developed a mathematical programming problem to determine frequencies in a transit network with a demand that varies along the daily period. In this mathematical problem, operating conditions, fleet size, vehicle capacity and some subsidy constraints are included in order to reflect reality.

2.8 Performance indicators

According to the literature above, trunk-feeder systems provide improved transportation benefits such as accessibility, mobility and high travel time saving (Roux, 2013). These systems make advancements towards sustainable and integrated public transport, at the same time prompting economic development and transit makers' quality of life (Gudmundsson, 2001).

But the challenge comes in knowing and measuring whether the systems or the developments that are to be made into the systems are in fact achieving the aims for which they are made to serve, and whether the goals that the transportation policy departments are setting are aimed towards sustainable transport systems. These concerns have raised the demand for the "performance indicators" in studies in order to evaluate the performance of transport systems and policies (Gudmundsson, 2001).

Furthermore, Randall et al. (2007) notes that KPIs form the basis of analytical measurement in projects. They enable performance to be measured, compared and understood on the same level in decision making bodies. KPIs are normally collected over a series of time to identify improving and declining performance in order to obtain a good database for consideration. Ryus (2003) further puts it that "what gets measured, gets attention". It is therefore important that the data used in such evaluations is within acceptable standards (Roux et al., 2011).

2.8.1 Performance indicator development

The purpose of the KPI development process is to provide guidance on the development of a set of integrated indicators for evaluation and comparison within the decision making bodies (Randall et al., 2007). Figure 2-5 shows a simple performance indicator process.

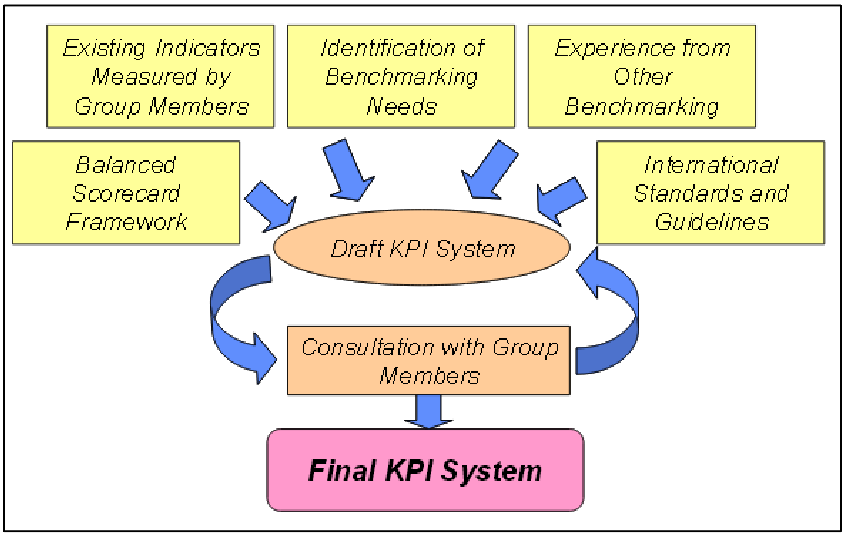

Figure 2-8: KPI development process

Source: Performance measurement Development, Challenges and Lessons Learnt (2007)

The above figure shows a simple framework used internationally to put emphasis on pointing out appropriation and reality of the KPI to the environment they are to be applied. The goals and objectives of the KPIs have to be SMART – Specific, Measurable, Achievable Relevant and Time-bound (Office of Planning and Institutional Assessment, 2008).

2.8.2 Selection criteria for KPIs

When developing a process for selecting transit indicators in public transport, it is important that a selection criterion is identified that the selected indicators must satisfy. This is also dependent on what we aim to use the KPIs for (Super Green, 2010). The indicators selected should not only focus on the methodology correctness, that is, trying to satisfy the positive goals of effectiveness, efficiency and service quality of the transit system, but should also consider the social, economic and environmental aspects of public transit in order to attain a sustainable transit system. Other selection criteria are data availability, expense and period of collecting data, consistence with the goals and objectives, and robustness of the system (Talley, 1986). In addition, the indicators selected should satisfy all stakeholders that will be involved in the usage of the transit system.

2.8.3 KPIs for trunk-feeder systems

Potential KPIs that could be used to evaluate a trunk-feeder system are discussed below.

i) Capacity

Transit capacity in intermodal transit systems is considered to be one of the principle indicators for its operational performance mainly because of its requirement to transport large number of users (Milan, 2014). For trunk-feeder systems, the variation in capacity of vehicles is also necessary to achieve efficiency in the system (ITDP, 2007).

One of the advantages of trunk-feeder systems is in its operational efficiency. The ability to match the demand of passengers to the transport services supplied. The Transit Cooperative Research Program (TCRP) states that capacity reflects the ability to meet the existing demand and determine the number of people that can be served by the existing transit system. If the passenger demand exceeds the transit systems capacity, then it is more likely that the system will suffer and the quality of service will reduce. The transit system may become less reliable, the travel speeds will decrease and the passenger loads will increase.

Data on the available fleet size of transit vehicles can be used to calculate the capacity of the system. A basic calculation was developed by the authors of the BRT planning guide and is illustrated in Eqn. 2-3 (ITDP, 2007).

$$Corridor\ capacity[\frac{\frac{passengers}{hour}}{direction}] =$$

Equation 2-5

$$vehicle\ capacity\ [\frac{passenger}{vehicle}] \times load\ factor \times\ service\ frequency\ [\frac{Vehicles}{hour}]$$
$$\times Number\ of\ stopping\ bays$$

ii) Queuing

In public transport, queuing is described as the waiting time of vehicles in transit. Queuing arises due to bulk arrivals of passengers using bulk services (high capacity buses) when the connecting modes of transit cannot accommodate the bulk arrivals. Therefore, queuing is associated with arrival patterns of customers, vehicle arrival patterns, and queue discipline normally based on first come first served (Wang et al., 2014).

iii) Scheduling

The Transit Capacity and Quality of Service Manual (TCQSM) describes scheduling as how often the transit service is provided and when (time of the day) it is provided. This is one of the important factors that passengers consider when choosing a transit service. If the service provided is frequent, then the waiting time is short in case a bus is missed or the time schedules are not known. This shows that in scheduling the number of hours that the service is provided is important as it provides greater flexibility for passengers to select a travel time. In the same sense the hours need to be scheduled at times when passengers desire to travel, if that is not the case, passengers will not opt to make trips. As the number of hours that the transit service is offered increase at the desired times, the greater the ridership (TRB, 2003).

iv) Travel time & transfers

Travel time for a general trip in trunk-feeder systems includes waiting time for a transit vehicle, travel time on board a vehicle, travel time from a transit vehicle to transfer station, waiting time at transfer station, travel time on board to a final destination. Some trip may necessitate more than one transfer. The perception of travel time varies across different people. Some people might find long trip undesirable while others find it as an opportunity to read or do some work on board (TRB, 2003).

Transfers at stations can make the service more efficient for operators but less convenient for passengers depending on different circumstances like if they are travelling with goods or just a general perception about transferring from one vehicle to another. Each transfer adds to the total trip time due to the time spent waiting and transferring between vehicles but this can have a net less travel time compared to direct transit services if transfers are timed and optimized. On the other hand, since the system is scheduled, if a transfer is missed, this increases the total trip time by one headway of the next bus (TRB, 2003).

v) Reliability

Reliability has a great impact on passenger's total travel time. It affects the amount of time a passenger must spend at a station waiting for a vehicle to arrive as well as their consistence to arrive at a station over time. When transit vehicles are unreliable, passengers tend to arrive at the station earlier than the estimated vehicle arrival to ensure that they do not miss the vehicle. Also, if the transit vehicle is unreliable, passengers fear for not being late to arrive at their destinations so they choose an earlier departure time even though they might reach their destination much earlier than they intend to arrive. This in the long run reduces ridership because of increase in travel time (TRB, 2003).

Furthermore, reliability has impacts on vehicle capacity utilization. Reliability is also concerned with the consistence of the headways between successive vehicles. If the headways are not consistent or even, then there will be uneven loading of vehicles. A lag will be introduced where the later vehicle will not only be loading the passengers it is scheduled to pick up but also the passengers that arrived earlier for the following vehicle or the passengers that were in time for the right vehicle but missed it because it left earlier than expected. This may cause passengers that cannot fit in the vehicle to stand and wait longer for the next vehicle. On the other hand, continuous over capacity in the first vehicles may cause the next vehicles to be less loaded. This type of inconvenience is not desirable by passengers or even the operators (TRB, 2003).

It should be noted that some of the factors that influence reliability can be controlled by operators and others cannot be. They include unevenness in passenger demand, construction works, vehicle breakdown, traffic conditions and so forth (TRB, 2003).

vi) Service frequency

Service frequency is the measure of the number of public vehicles per certain time interval. This can also be defined as the headway between vehicles on a route. The more frequent the service, the shorter the waiting time and queueing. It is expected that the vehicles arriving are not fully occupied and can take passengers waiting at a station. This makes the service more reliable and flexible as passengers can easily manage their travel times (Roux, 2013; TRB, 2003).

2.9 General conclusion

The literature review resonated to the purpose of the study by providing understanding on the the status quo and issues of paratransit services, investigating possibilities of achieving integration and providing concepts of modelling trunk-feeder services that will help in evaluating the system's performance.

Firstly, the literature reviewed the forms of public transport systems; formal and informal (paratransit) services. The literature further delved into their descriptions to understand their characteristics that make operational integration of informal and formal public transport services a challenge. Paratransit service operations have been identified as the main challenge to this objective. Thus, a more detailed review was presented to show the status quo and quality of services of paratransit public transport system in South Africa.

The literature then presented and compared possible ways of connecting informal and formal public transport systems as a way to achieve an efficient integrated and coordinated public transport system. Possible public transport structure arrangements were identified and investigated. They included; the direct service connections and the trunk-feeder connections. Based on the benefits and suitability of the trunk-feeder system to the conditions (density variation) of demand in South Africa, it was determined that a trunk-feeder system would be the appropriate public transport system to provide an efficient and effective public transport services.

Review investigations were then made to the trunk feeder system to understand ways of incorporating paratransit into the formal services. It was identified that the possibility of attaining integration mainly depended on how well the two public transport sectors work together to have a co-coordinated system. Additionally, a physical integration would be achieved through a well-designed multi-modal system where trunk services depart in a scheduled manner and in turn, feeder services would be connected to trunk services in a timed transfer system. The physical concepts of modelling a trunk-feeder system were also reviewed.

Finally, the literature provided a review on performance indicators. This section looked at the processes of developing key performance indicators that are required to evaluate a public transport system.

3. Study area and data collection

This chapter presents the study area and shows the procedure followed to gather all necessary data to build the simulation model. It begins with a discussion of the selected study area. It goes on to present the data requirements for model set-up that guided the data collection process. The section then describes the procedure followed to collect data and also presents the data that was collected.

3.1 Study area

The area selected for this study is located in Mitchells Plain, a suburb in the Western Cape Province in South Africa. It is located along the famous cape flats between Muizenberg and Khayelitsha, 20km from the Cape Town city centre. Figure 3-1 depicts the map showing the location of Mitchells Plain.

Based on the census conducted in 2011, it has a total area of 43.76km^2. It has a population of 310,000 people of which 91% are coloured. English (47%) and Afrikaans (47%) are the most commonly spoken languages. Up to 30% of inhabitants are unemployed, approximately 42% earn less than R 1,600 per month, 40% of people aged between 5 and 24 do not attend school because they have to work and 75% of adults do not have matric (Statistics South Africa, 2011).

Mitchells Plain was conceived as the model township built to provide housing for coloured victims of forced removal due to implementation of Group Areas Act where people were settled according to the Apartheid legislation in the 1970s. It was planned as a segregated and self-sufficient suburb far from the white areas of the city but also far from the black and Indian communities. It was built to accommodate 250,000 people though the number exceeds this currently. Although Mitchells Plain is no longer the "coloured township", it is one of South Africa's largest townships and is still largely occupied by coloured people (Urban Landmark, 2009).

Mitchells Plain is reasonably well served in terms of public transport. The public transport services include rail station (Metro rail), bus terminals (MyCiti and Golden Arrow) and two taxi ranks; the Hazeldene taxi rank and the bigger terminal taxi rank located North of the railway (Referred herein after as Taxi rank 2). These are all connected by the Mitchells Plain Public Transport Interchange (Town Centre) located at the Mitchells Plain station. The interchange constitutes a major bus terminus, taxi ranks around the station, and other commercial areas such as Westgate Mall and Promenade Mall. There are regular scheduled buses at the station and unscheduled taxis services that serve areas within Mitchells Plain and extending to Cape Town CBD, Claremont, Mowbray, Bellville, and other areas. Moreover, it is the third busiest interchange in the City of Cape Town, with its buses making approximately 30,000 passenger trips weekly and 75,000 people moving through the interchange during morning (AM) and afternoon (PM) peaks daily.

Of the two taxi ranks surrounding the Mitchells Plain interchange, the Hazeldene taxi rank was selected for this study. The Hazeldene taxi rank is managed under an association called Hazeldene Shuttle Services. It is a relatively small taxi association consisting of a fleet of approximately 35 taxis. The taxis operate on six licensed service routes which serve between Hazeldene and Promenade mall, Westgate Mall and the Mitchells Plain interchange.

The Hazeldene taxi rank operates a feeder network service taking passengers from within its feeder service catchment area to the the trunk (rail and bus) services that operate from the Mitchells Plain interchange. The setup of the public transport network services within the Hazeldene taxi rank feeder catchment area and the trunk services at the Mitchells Plan interchange fairly replicates typical hybrid trunk-feeder public transport network configurations.

While many public transport interchanges do exist in Cape Town, firstly, route operating licenses are more provided for direct service connections that do not require passengers to transfer from feeders to trunks and vice versa. Secondly, in other interchanges such as Mowbray and Claremont, there is no designated and licensed feeder network routes connecting paratransit feeder services to the interchanges. In addition, previous studies on passenger transfer at the interchanges revealed that only a small portion of passengers transfer from taxis to the trunk services. Therefore, those interchanges would not provide appropriate and sufficient information necessary to conduct this study.

It is for this reasons discussed above, that the Hazeldene taxi rank and Mitchells Plain interchange were selected as an appropriate case study area.

3.2 Data requirements

The first step towards developing a correct model is to establish correct requirements. Accordingly, data required for this study were based on operational characteristics of a trunk-feeder model as discussed in Chapter 2. The data requirements can be categorized as follows:

- Road network data

Firstly, road network was required to build a network for travel of people and vehicles. The network was based on a existing traffic system and geographic maps (Google earth maps). Road network data required included route geometry, distances between stations, a road network, bus stops, stations data, traffic control settings and passenger transfer zones.

- Vehicle data

Vehicle data was required to facilitate interaction between the road network and the flow of passengers. It included; a fleet of buses and trains to operate on the trunk, a fleet of taxis to operate on the feeder, vehicle capacity and vehicle speeds.

- Passenger data.

Planning for transportation models requires knowledge of passenger travel data so as to estimate their origins and destinations. Thus, passenger data include the number of passengers moving from their origins to their destination which is expressed as an Origin and Destination matrix.

Figure 3-1: Map of Mitchells Plain

Source: Google maps, South Africa

3.3 The survey process

In transport planning, surveys are appropriate methods to collect data. A survey to collect data is a formal process which follows logical and interconnected steps. Figure 3-2 illustrates a typical transport planning survey process. Richardson et al. (1995) states that surveys are of particular relevance in transport planning and various methods or types of surveys can only be used on particular fieldwork types. For this particular research, only two types were found to be relevant;

- Travel patterns survey
- Transport system performance survey

Travel pattern surveys were conducted on the trip-making process by taxis. It obtains information such passenger origins and destinations, time of travel, which route, which mode, and purpose of the trip. Secondly, a transport system performance survey is conducted on the trip making process mainly to analyse the system operation and characteristics. Data that is mainly collected include waiting time, travel time and vehicle occupancy.

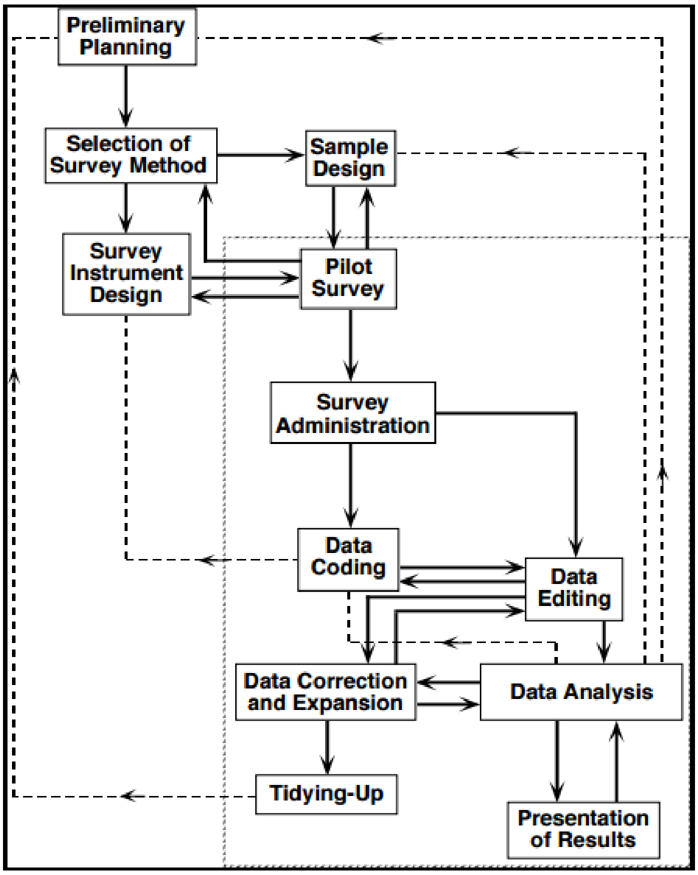

Figure 3-2: Survey process

Source: (Richardson et al., 1995)

3.4 Survey

From requirements of setting up a model, a survey was required to collect data that would feed into the simulation model. Figure 3-3 illustrates the organization of the process for the the survey.

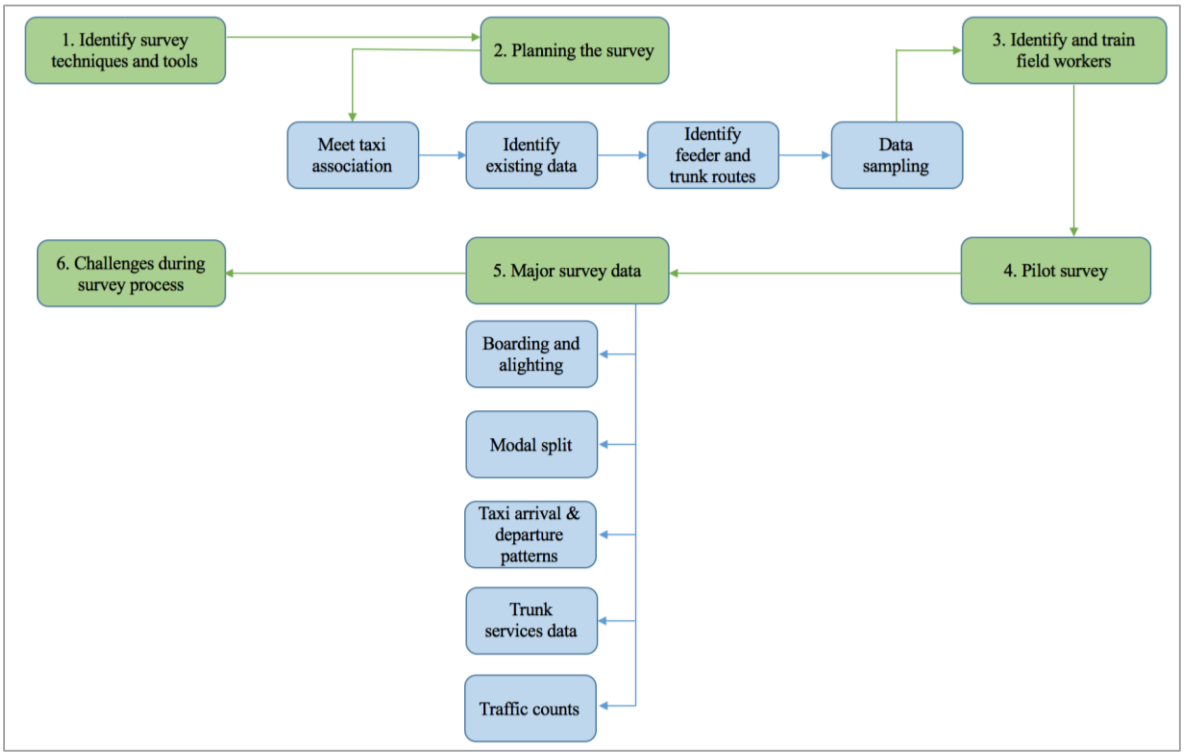

Figure 3-3: Organization of process for the survey.

The major survey was designed to:

- To collect data on vehicle boarding and alighting data, locate the major drop-off points, mini-bus taxi boarding and alighting, the number of people waiting at the major stops and their waiting times,
- To identify the modal split of arrivals at the interchange,
- To obtain travel patterns data along routes between commercial areas and residential areas, and the main public transport interchange in Mitchells plain,
- To collect data on scheduled bus service times, the actual time they depart at the interchange. These include MyCiti and Metro rail and Golden Arrow,
- To collect traffic count data required to create a close to reality situation in the model. The traffic congestion affects the flow and speed of taxis especially during peak hours, and
- To provide the taxi association with information about the performance of their business so that it can help them to better manage and improve it.

3.4.1 Survey techniques

Planning for the survey involved investigating into various survey methods and appropriate tools to collect the data. For different categories of data, an appropriate tool was identified. For technology based data, mobile phones that are GPS enabled were used and in the field, survey forms or data collection sheets were designed so as to fill in the required data. Traffic data could have been collected electronically using vehicle loop detectors on roads but this was quite expensive to organise. Some other data collected using the loop detectors by the City of Cape Town were used to validate the model at the intersections. Table 3-1 depicts the different data categories that were collected, type of survey and the tools used.

Table 3-1:Data categories and methods of data collection

Data categories	Type	Tool
Boarding & alighting	Technology based	Android mobile phone (GPS)
Modal split	Field based	Paper survey (Hand counter)
Traffic counts	Field based	Paper survey (Hand counter)
Arrival departure patterns	Field based	Paper survey
Network	Existing	Existing

3.4.2 Planning the survey

Planning the survey involved the following:

i) Meeting taxi association

Planning for the survey involved identifying a taxi rank that would act as a feeder distribution point. The taxi rank is operated by a group of people who own the taxis serving a taxi rank, and this forms a taxi association. Several meetings were set up between all the members of the association and the researcher, firstly to request to use their taxi rank for research study purposes, secondly to explain the intentions of the researcher, and thirdly to explain to them how the association could benefit from the information obtained through the survey. Although it seemed that all members agreed and were not difficult, there was a sense of foot-dragging as they fear that some of the information obtained could be shared with higher authorities and that can affect their business. It was agreed and there was an assurance that there would be privacy and this information would only be between the University of Cape Town and the association. Thereafter, the association and the researcher cooperated throughout the survey process and the association provided field workers for the survey.

ii) Identify existing data

Before commencing the data collection process, there was a discussion about the available data that the association filed. This was done in order to know if there was any information that was of relevance to the subject in question and not duplicate or re-do data in case of existing relevant one. The taxi association only kept record of the taxi departures at the taxi rank, and not their arrivals. Unfortunately, this was not the appropriate data as there would be no co-ordination between origins and destination or identification of a trip along a route. Since the required data was not found, this suggested conducting the whole survey.

iii) Identifying routes

The association marked out six routes that the taxis travel as dictated by the City of Cape Town Authorities. The routes are between three points; Hazeldene taxi rank – West gate mall, West gate mall – promenade and promenade – taxi rank as depicted in Figure 3-2 (Study area). In preparation for the data collection, the researcher took a site visit and travelled on several taxis to check the routes as they had been marked by the association. It was identified that the taxis do not actually follow the marked routes. They have common routes at different peak periods where they normally travel to find customers. These routes were mapped after collecting the data with a GPS enabled tool – mobile phones.

iv) Sampling taxis

The Hazeldene taxi association has 35 vehicles that transport commuters around the Mitchells plain area. Of the 35 taxis, some move between Westgate mall and the taxi rank, others between taxi rank and Promenade mall while others work between the Promenade mall and Westgate malls. The taxis to be surveyed were sampled due to limitation in resource, time, cost and the impracticability of the situation (one cell phone per taxi – requiring 35 cell phones to sample all the 35 taxis). This could only be possible if the researcher employed people to sit in each of the 35 the taxis. As such, to collect boarding and alighting data along the routes, only one vehicle at a time between ends of a route was sampled and assumed to emulate all other vehicle behaviour between the end locations. If a vehicle reached a destination and has to wait to load, the field worker would get off and board the next vehicle departing that was normally full. The field workers kept looping in that manner.

3.4.3 Identifying and training field workers

Eighteen field workers went through a training session to demonstrate the use of the research tools and how they would be used to collect data. First, the field workers had to be identified. Mitchells Plain is considered as an unsafe area and even more so at the taxi ranks. Owing to the fact that it is quite unsafe, it was considered safer by the researcher to use the drivers, owners or taxi conductors of the taxis in the association as the field workers. That was also because they are familiar with the area and more comfortable to conduct the survey. The survey was divided into seven categories as depicted by table 3-2. The whole survey team was first met so as to communicate the overall purpose of the survey and they were later sub-divided into their respective categories. Each category was trained about their role. The training session involved taking the field workers through the Formhub application step by step, showing them what routes they would have to work on, and how the boarding and alighting survey was coordinated between Hazeldene, Westgate Mall and Promenade Mall. Each of the other field workers in their different categories were shown their spatial positions, were taken through the recording and tally sheets and made sure they understood what was required of them. Emphasis was made on the time when they could record and when to take breaks, submitting completed forms on the Android phones and tallying correctly.

Table 3-2: Organisation of field workers

CATEGORIES	PURPOSE	Field Worker	LOCATION
Category 1	To collect arrival/departure times & their occupancy for all vehicles arrivng and departing the 3 stops	Surveyor 1	Hazeldene taxi rank
		Surveyor 2	Promenade mall
		Surveyor 3	Westgate mall
Category 2	To sit in the taxi and record boarding and alighting data at every stop a taxi stops along the route	Surveyor 4	Hazeldene - Westgate mall
		Surveyor 5	Hazeldene - Promenade mall
		Surveyor 6	Promenade mall - Westgate mall
Category 3	To record the number of people at the train station and train information; number of doors and carriage	Surveyor 7	Train station platform
Category 4	To collect modal split data. How many people connect to the different modes of transport at the interchange.	Surveyor 8	Pedestrain foot bridge
		Surveyor 9	Pedestrian foot bridge
		Surveyor 10	Route connection to the mall
		Surveyor 11	Route connection to the mall
Category 5	Collect BRT data: Occupancy variation and the number of people left at the exixting bus stops	Surevyor 12	Bus stop at the interchange
Category 6	To collect traffic data at selcted stops that are representative of the daily traffic condition: Two people per road (one each lane)	Surveyor 13	Along the selected roads
		Surveyor 14	Along the selected roads
		Surveyor 15	Along the selected roads
		Surveyor 16	Along the selected roads
		Surveyor 17	Along the selected roads
		Surveyor 18	Along the selected roads
Category 7	Supervising the field workers	Supervisor	Hazeldene
		Supervisor	Hazeldene

3.4.4 Pilot survey

A pilot survey was conducted over two days to test the adequacy of the instruments that were designed for the different categories of the survey. Survey forms were given to the field workers and it was checked that each field worker was positioned at the correct location. This was necessary for data accuracy mostly at the points where traffic counts were to be recorded. Checking was also done to ensure that; the field workers recording arrival and departure data at promenade, Westgate mall and Hazeldene recorded it in the correct format. Changes had to be made to the arrival forms at Hazeldene; instead of recording the total (including pedestrians walking from the surrounding neighbourhoods) arrivals at the taxi rank, it was changed such that the field worker asked those passengers only arriving at the taxi rank using a taxi, what their connecting mode of transport from the interchange was. The changed arrival forms now recorded how many passengers were connecting to what mode of transport (as shown in Table 3.3) and this was considered as the modal split of passengers departing Hazeldene taxi rank as opposed to the latter.

Frequent monitoring during the survey process was vital especially for the boarding and alighting survey process which required technical knowledge to use the mobile phone application. During the first days of the pilot survey, the field workers were confused about the process and how to connect from one taxi to another such that they can constantly be on a taxi throughout the day. That was later understood after a meeting to help them through the process again before the main survey was conducted.

After data was collected for the pilot survey, it was important to capture the data into the computer excel spreadsheets. This was the easiest way to notice errors in the survey process. The errors identified included:

- Misinterpretation of methods of data entry
- Lack of adherence to the correct time intervals during which data was collected and as a result, there would be inconsistence in peak period data records.

The faults in the survey process were identified and rectified. A meeting was called for again to highlight the mistakes and changes that were to be made. The changes were also made on the recording sheets and finally all was sorted and clear for the main survey.

3.4.5 Major survey

The major survey was conducted over eight days; Monday to Saturday in the first week, and Tuesday and Wednesday the following week. Tuesday and Wednesday were repeated because they are days considered as typical days of normal occurrences in South Africa. The taxi rank association indicated that there was almost no activity at the taxi ranks on Sundays so no data was collected on that day. The survey was conducted from 6:00am to 9:30am for the AM peak, 10:30 to 14:00pm, after noon peak, and 15:00pm to 18:00pm PM peak periods each day.

The methods described in the section below were followed through the whole survey and data was recorded for traffic counts, arrival & departure, and boarding alighting.

3.4.5.1 Boarding and alighting

The boarding and alighting survey was conducted to record the number of people getting on and off the taxis at particular points along the feeder routes. This is an on board survey that required a field worker (person collecting data) to sit on the seat right behind the door in a taxi so that they can clearly see the number of people that got on the taxi and those that got off a taxi and record the observations at every location a taxi stopped.

Before selecting a tool, investigation was made into smart ways of collecting on-route boarding and alighting survey data. A reference was then made to several sources including (Vanderschuren & Gaibe, 2009) and to the *digital Matatu project* in Kenya, which inspired and directed the use of GPS enabled mobile devices to collect data on informal public transport systems. The study in Kenya; the Matatu project used cell phones to collect data and created an open source data for Nairobi's semi-formal bus system. Several other sources were reviewed specially on the use of technology to collect data in the field. The researcher adopted to use Open Data Kit (ODK) which was developed by the University of Washington. ODK form hub is an open-source set of tools which enables users to author and manage data collection using mobile devices. The data collected can be submitted to an online server in forms of XLS and KML. These can be visualised and analysed on google earth or exported to Geographic Information Systems (GIS). ODK Form hub provides three sequential solutions towards 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.

Using the coding format of ODK, a form was designed in MS Excel. The form shows the coding of the questions that needed to be filled in during the data collection. Once the form was coded, it was imported in ODK Form hub and could be accessed on android mobile devices as well as on the web. Figure 3-3 shows the starting of the "Mitchells-plain-survey" form on the android mobile phones and Figure 3-4 shows the layout of the survey questions in their respective sections.

The survey form designed consisted of three sections:

i) Location information

ii) Vehicle information

iii) Boarding and alighting

Section 1 was designed to gather location information using the geographical positioning system (GPS). The location information gathered information about the stops. Every time a taxi stops, the field worker would record the location coordinates, date and time when it arrives the stop. After several runs of the survey, it would be clear where the taxis stopped and those were deemed the stop points along the route. And as it is known that taxi behaviour is not consistent along a particular route, data recorded in this section could aid to trace out the routes followed by a taxi for a specific trip. Section 2 recorded information about the vehicle - that is vehicle registration number. This would be recorded once, the location for example at Hazeldene taxi rank. Since the surveyor would have to fill in the online form completely every time they stopped while using the same vehicle, the vehicle information had to be put at the beginning of every form. This would also aid in tracing a particular vehicle route. Section 3 recorded data about boarding and alight. It was in the interest of the taxi association and the research to identify the loading patterns along the route. The section was designed to collect data on how many people board or alight at a stop. It further collected information on whether there were people left at a stop if the taxi was full. This information would be helpful to the association to track performance of their vehicles and they could roughly estimate how much a vehicle makes so that they can better manage their businesses and to also check if there is efficiency in the association regarding whether there were more vehicles than required or they needed more vehicles to maximise profits.

The boarding and alighting survey form designed consisted of the following questions:

i) Location data - GPS location – [Degrees]

ii) Date and time – [Peak period]

iii) Taxi registration number – [CA registration numbers]

iv) The number of passengers who got on and off – [Number of people]

v) If the taxi was full at the location – [yes/No]

vi) If the taxi was full, how many people were unable to board – [Number of people]

Research assistants were required to submit a response of all the above questions at every stop a taxi stopped. The data set collected consisted of 1504 data points. The position of the data points is depicted in Figure 3-5 below.

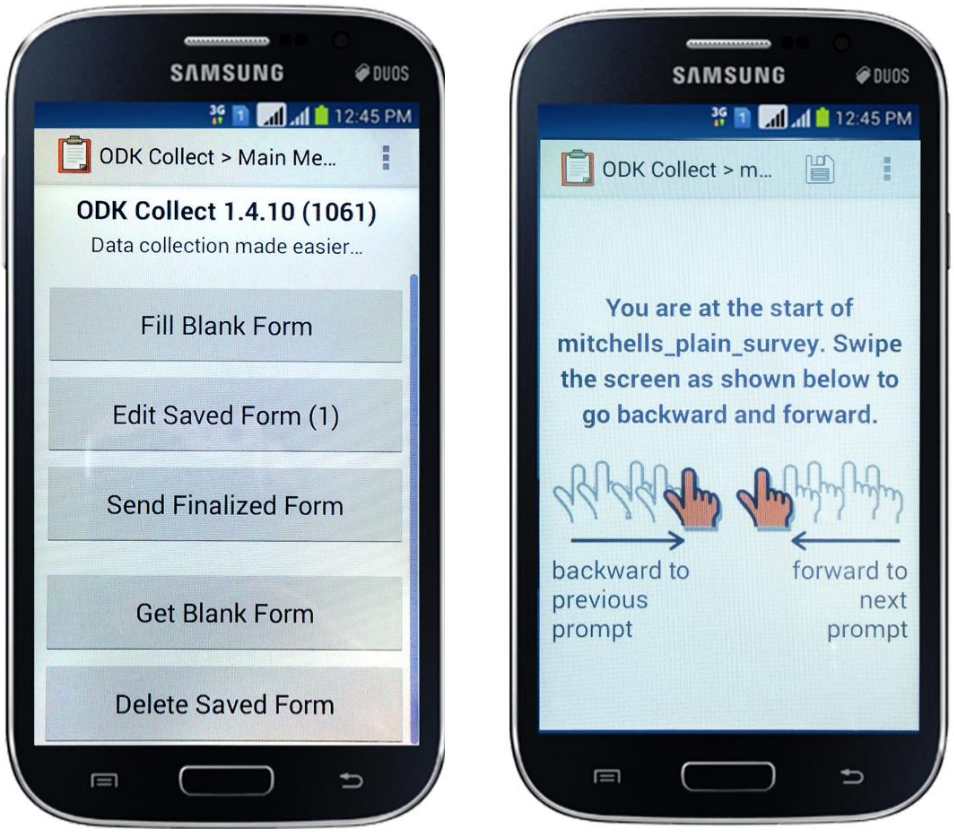

Figure 3-4: ODK form on the mobile phone; starting the survey

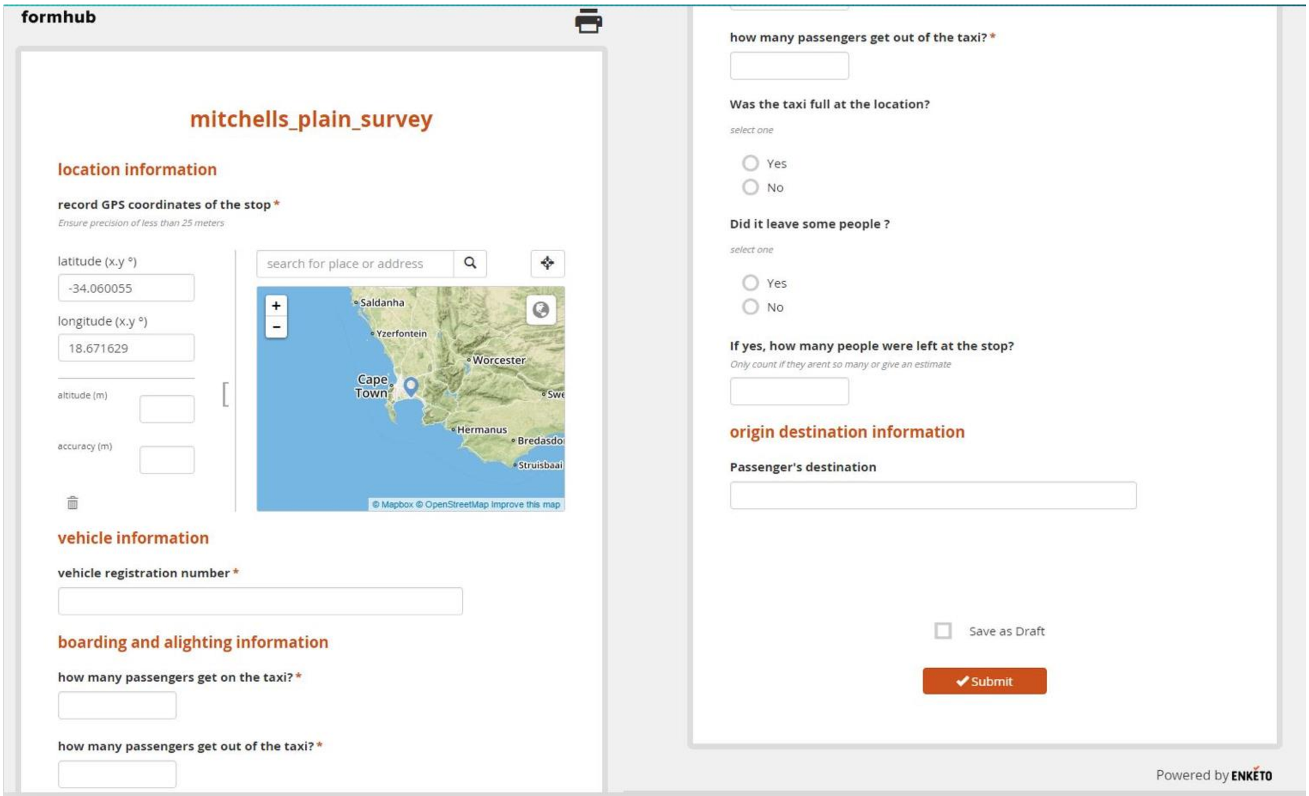

Figure 3-5:ODK - Formhub web form for Mitchells Plain Survey

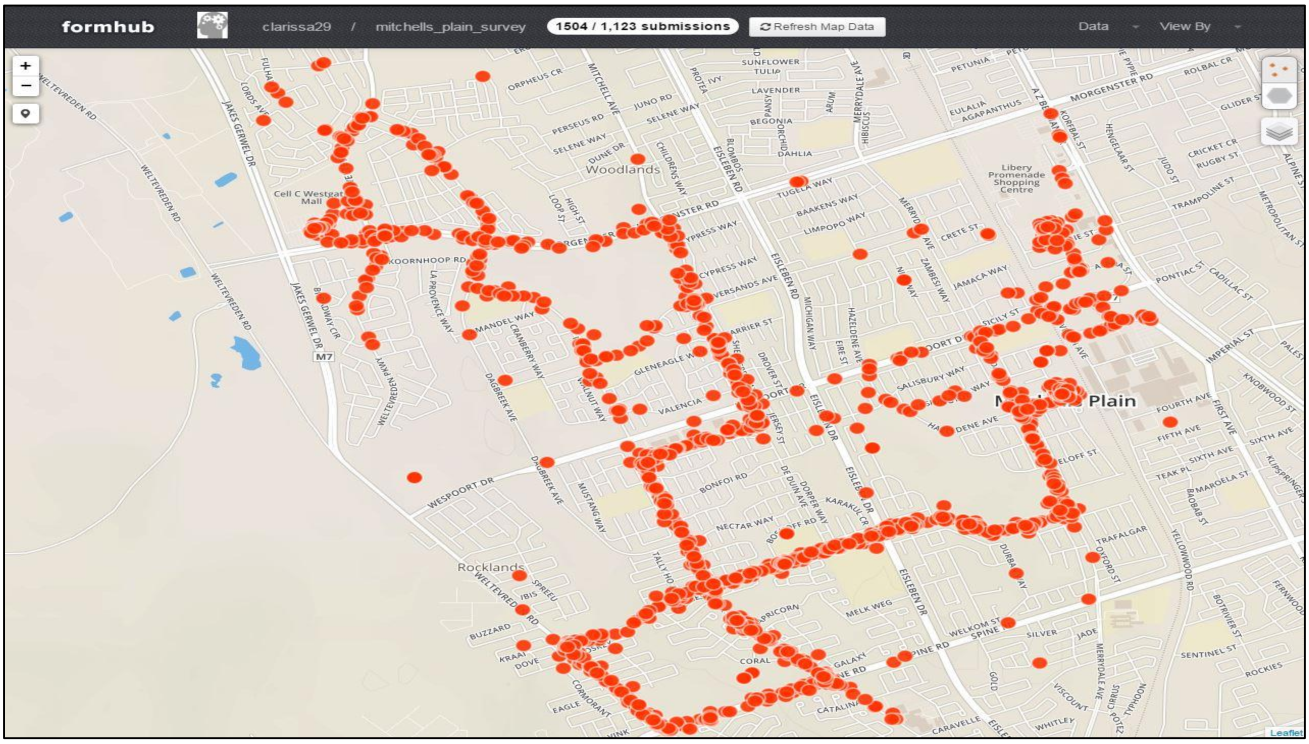

Figure 3-6: Data points in the study area

3.4.5.2 Modal split survey

This part of the survey was conducted to collect data on the mode split to connecting trunk services. At arrival at the Hazeldene taxi rank, feeder taxis dropped off passengers. They then connect to their respective trunk vehicle or they end the trip (Those that have reached their destination especially those that work in the market at the interchange). A poster shown in Figure 3-6 was designed such that passengers connecting can point and indicate where they were connecting to from the drop off point. During the pilot survey, it was discovered that conducting the survey in this way, collected data for all arrivals including the people walking from the surrounding neighbourhoods of the interchange. This made it difficult to track people who only arrived at the taxi rank using taxis. Consequently, the survey sheet for arrivals at Hazeldene was amended to record a modal split of Metro rail, MyCiti, Golden Arrow and Taxi rank 2. Table 3-3 shows an example of the data that was recorded for the various trunk mode types.

Figure 3-7: Poster for modal split survey

Table 3-3 Sample modal split data

Date	17-Nov					
Name Zone	Hazeldene					
Reg/CA No.	Arrival time	Number of passengers transferring				Destination
		Taxi Rank 2	MyCiti	Golden Arrow	Metro rail	
221805	6:28	3	1	1	6	Promenade
584390	6:28	2	1	1	8	Promenade
832673	6:30	4		2	5	Promenade
372344	6:30	2	1	1	7	Promenade
312570	6:30	1			4	Town Centre
311724	6:32	2		2	3	Town Centre
624486	6:35	1	1	3	5	Promenade
214919	6:40	3		2	7	Promenade
745308	6:40	1	1	1	6	Promenade
33843	6:42	3		1	10	Promenade
511721	6:42	2	1	1	8	Promenade
944113	6:48	4		1	6	Promenade
316454	6:50	3	1	1	10	Promenade

3.4.5.3 Arrival and departure patterns

This part of the survey recorded vehicle registration number, the arrival time, the number of passengers arriving at the interchange and where the vehicle was going from that point. Table 3-4 depicts the format and an example of data collected for this part of the survey at each of the 3 station, in this case at Westgate Mall.

Table 3-4: Arrival and departures at Westgate mall

Westgate Mall								
Reg/CA No.	Arrival time	Number of passengers	Destination		Reg/CA No.	Departure time	Number of passengers	Destination
311724	7:10	9	Westgate Mall		311724	7:20	6	Town Centre
221807	7:22	13	Westgate Mall		221807	7:30	2	Town Centre
603215	7:26	10	Westgate Mall		603215	7:33	1	Town Centre
315819	7:36	6	Westgate Mall		315819	7:44	7	Town Centre
271646	7:42	8	Westgate Mall		271646	7:50	3	Town Centre
311724	8:03	11	Westgate Mall		311724	8:08	4	Town Centre
84005	8:09	5	Westgate Mall		872334	8:12	6	Town Centre

3.4.5.4 Trunk service data

Data that was collected for trunk services concerned the schedule of connecting trunk services. This was done to display the operational behaviour of passengers as they transfer from feeder minibus taxis and connect to trunk services. Although Metro rail and MyCiti have online fixed schedules, it was noticed that they are not always on time so a survey was done to collect data on their exact arrival times for the period under study. For Metro rail, data on the demand arriving at platforms when the train arrives was also collected and was used to analyse the transfer performance.

3.4.5.5 Traffic counts

The traffic counts survey was conducted to determine the number of vehicles travelling along routes of interest in Mitchells Plain. In order to model a realistic model, which incorporated taxi delays due to the variation of traffic conditions, it was vital to get the traffic counts done and accurate. Three points along three main routes (also suggested by taxi rank chairperson) where traffic was known to be representative of the daily situation were selected and field workers collected the traffic data on tally sheets. This is an old method of collecting data but because the data was collected over a short period of time and collecting the data electronically would be quite expensive, the manual method was adopted. This data was validated using data that was collected in the past from the City of Cape Town.

3.4.6 Challenges

The following are some briefly described problems that arose during the survey process.

- **Mobile phone battery life**

The battery life of phones did not last that long and sometimes breaks had to be taken to charge them fully. This was an inconvenience and it brought some inconsistence in data recording. A possible solution to this could be the use power banks to avoid the inconveniences.

- **GPS accuracy**

There were several instances where the data points shown in Figure 3-4 did not appear on the road network – they appeared off the network or within an erf where a taxi could not possibly have passed. The source of this error appeared to be in the variation of GPS accuracy. There are lots of factors that could have influenced this variation such as; weather conditions and terrain.

- **Lack of skilled field workers:**

Some of the field workers could not grasp their tasks, terminologies used, or tallying and other recording methods. There had to be continuous interaction and monitoring of the process. One of the days during the pilot study, a field worker recording traffic counts did not come and told his friend to record both directions of traffic. Initially, there should be one person recording per direction of flow as it is not possible for one person to record traffic counts in both directions. Emphasis had to be made for each field worker to be present at the positions where they had to collect the data.

Also, using the mobile phones, one of the field workers, instead of recording GPS points and submitting a completed form at each stop, the field worker instead only entered the GPS data at the start of the trip and all along the trip he recorded the name of the locations and the number of passengers getting on and off and only submitted the form at the end of the trip. The field worker summed up all boarding and alighting numbers along the trip and one one GPS data point could be seen with this data. This error was easily noticed as it is not possible to have 26 passengers on-board in a 15 seater mini-bus taxi. Table 3-5 shows the error in recording and understanding the task. This kind of data was nullified and removed from the entire data. Fortunately, this was however noticed on the 3rd day of data collection and corrected.

Table 3-5: Errors in recording and understanding the task

vehicle_car_id	Boarding	Alighting	Full	Leave	O_D_destination
Ca 312 570	26	12	no	no	Driving from westgate mall to town centre 1passenger got up at fire station 1passenger got up at biscuit line 1passenger got off at apricot 1passenger got off at park and silversands 1passenger got up at roadhouse 1passenger got off at blue gum 1passenger
Ca 132 131	26	8	yes	no	Driving from westgate mall to town centre 1passenger got off at harvester 1passenger got off at boschendal 1passenger got off at law's 2passenger got off at robin road 1passenger got up at cormorant 1passenger got off at tyres in spine 2passenger got off

- **Data recording**

When recording data on, for example, arrival and departure or boarding and alighting data categories, some of the field workers would record the vehicle registration numbers wrongly or write the name of the owner of the car. Thereafter, when collating the data, it was difficult to match the vehicle registration number and the owner's name.

4. Data processing: Demand estimation procedure

The data collected was not necessarily in the correct format for model execution. Also, there were some errors and inconsistencies in the data that needed to be resolved in order to prepare a clean data set for further processes. This chapter, thus, presents the methods followed to manipulate and convert the raw data into a format that was acceptable as an input for the simulation model.

4.1 Passenger boarding and alighting data

Boarding and alighting data were collected using GPS enabled Android phones. Research assistants recorded where along the route a taxi stopped, how many passengers boarded and alighted. However, individual trip ends could not be recorded. Due to this limitation in data, an algorithm was used to convert boarding and alighting data into an Origin Destination (OD) matrix. The following sub-sections present the method followed to convert this primary data into an OD matrix – starting with selection of feeder and trunk routes on which the OD matrix calculations were based, obtaining representative taxi stops where passengers boarded and alighted, and finally the use of an algorithm to calculate the OD matrices.

4.1.1 Trunk and feeder road network selection

City of Cape Town provides an official route plan for MP taxi operation documenting routes where taxis from any taxi association should operate. Hazeldene taxi association was given six routes where its taxis should operate, as shown in Figure 4-1. Taxis, however, do not always operate on all these routes – Figure 4-2 shows an overlay of taxi activity data points and official routes. Based on this data, it was decided to consider two commonly used routes; route 1-Promenade to Hazeldene, and route 2 - Westgate mall and Hazeldene as shown in Figure 4-3.

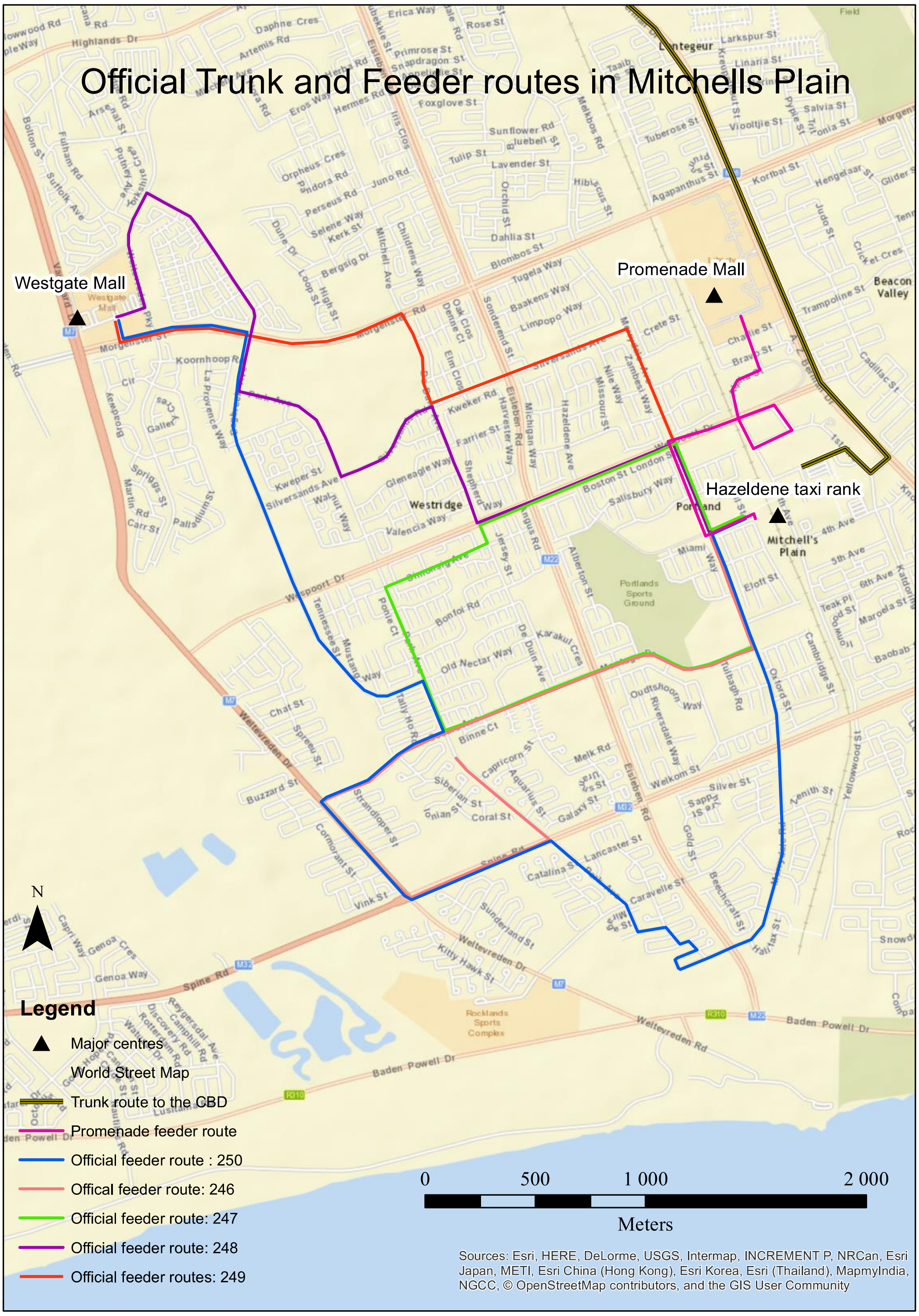

Figure 4-1: Official feeder and routes serving Mitchells Plain interchange

Figure 4-2: Overlay of data points on official feeder routes

Figure 4-3: Feeder routes considered for the study

4.1.2 Data sorting

The survey was conducted over a 10 day period although only data collected over six days – i.e. a typical week from Monday to Saturday was considered for further analysis. Of the six day period data, data recorded between 6:00 am to 9:00am was extracted to create a peak period data set. That data set was then averaged over the six days to produce a daily peak period data set.

Within the peak period data set, there were points that were still clustered in one point as in the original data. It proved cumbersome and not useful to model stops that were overlain together with their corresponding taxi operations because the model required a spread the stops at fixed locations. As such, a method was devised to generate stops within reasonable and justified distance to minimize complexity and make modelling the stops more manageable. A GIS analysis was adopted address this. A Fishnet analysis in ArcGIS was performed to aggregate the data or concentrate points that are very close to each other to one point (This was done to simplify reality in the model) – the fishnet area and data points were intersected to give a count of the total number of data points for boarding and alighting. A fishnet of 200m by 200m dimension was created on to the data points as depicted in Figure 4-4.

The 200 by 200 grids were selected based on the fact that it is the average walking distance allowed between stops along a route when using public transport on local taxi routes (TCQSM, 2014). There have been several debates in studies on what the appropriate distance or spacing between public transport stops is. According to Walker (2011) in a discussion about human transit, he describes how the geometry of walking space works. Every stop has a walk radius in which people would be willing to walk to a stop. Different people are comfortable or can tolerate different walking distances, but on average, a local transit system like taxis, a distance of 200m between stops was suggested as appropriate. This was adopted because it seemed appropriate to the transit system in Mitchells Plain and hence the 200m by 200m Fishnet mapping. The graph (Figure 4-5) in the TCQSM (2014) also shows that in low income areas and small communities, the breakdown of local transit system users by distance is approximately 200m and so does the extract from the Integrated Transport Plan (ITP) for Cape Town in Figure 4-6 below.

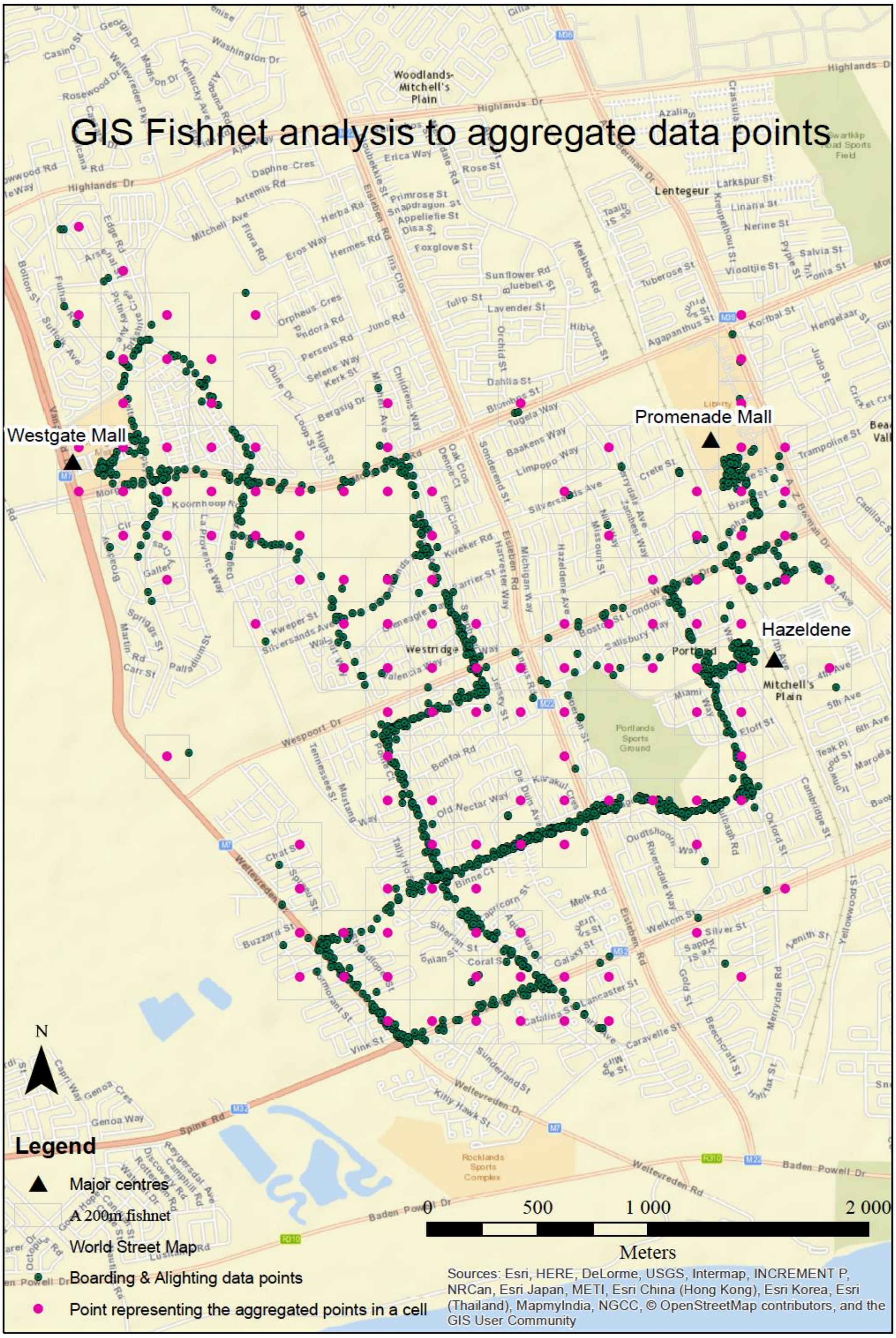

Figure 4-4: 200m by 200m fishnet analysis in GIS

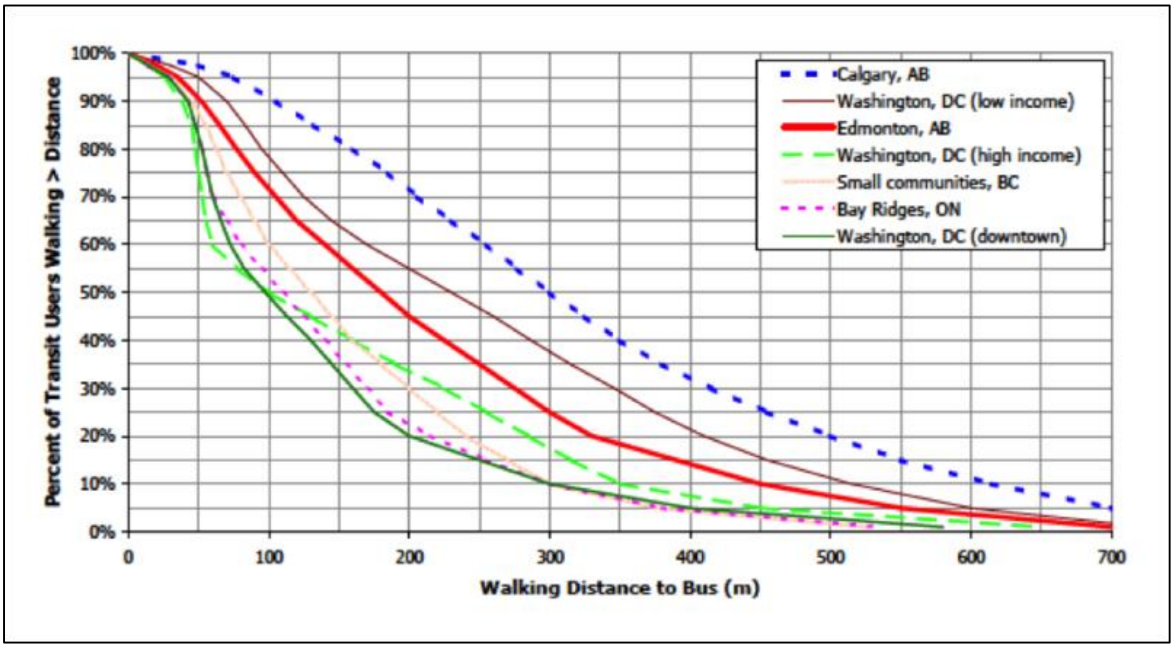

Figure 4-5:Walking distance to public transport stops

Source: TCQSM Chapter 3, Appendix A

Services	Scale	Service type	Capacity (pax/hour/ direction)	Average operating speed	Station or stop spacing	Frequency / Headway	Technology
Level 1 (Trunk & Express)	Metro-Regional	Express (skip-stop)	10.000 - 50.000	30 – 60 km/hour	2000 - 4000 m	10 min peak 20 min off-peak	Heavy Rail, LRT (BRT)
Level 2 (Trunk)	District-Local	Local	4.000 - 20.000	25 – 35 km/hour	500 - 1000 m	15 min peak 30 min off-peak	Heavy Rail, LRT, BRT, Bus, MBT
Level 3 (Feeder)	Neighbour-hood	Local	0 – 4.000	5 – 30 km/hour	<500 m		MBT, Bus, NMT, Metered Taxi, and alternative technologies (pedicabs, tuk-tuks)

Figure 4-6: Inter stop distance between public transport stops

Source: ITP for City of Cape Town

The number of boarding and alighting data points were then summed per grid cell. This was the total boarding and alighting counts for taxis moving in both directions – that is taxis moving along a route from Hazeldene to Westgate mall and vice versa. The model was set up such that it is one directional – modelling commuters leaving residential areas to connect to their work places. In light of that, the data had to be separated to obtain trips in one direction. To do this, the data was filtered per day and per taxi registration number. Thereafter, the time was sorted in an increasing order to indicate when the trip started till when it ended. A unique journey ID was given to each vehicle and each journey ID was given a sequence using numbers as depicted in Table 4-1. Using time, journey ID and sequence, a point to line tool in ArcGIS was used to connect the points according to the sequence and the direction of each trip could be obtained.

Table 4-1: Creating a sequence

Time	Date	Latitude	Longitude	Precision	Veh_Reg_Number	Boarding	Alighting	Grid Cell	Journey ID	Sequence
7:20	11/18/15	-34.047559	18.618435	48	CA 745308	0	4	196	CA 745308_18	1
7:21	11/18/15	-34.04219	18.617713	8	CA 745308	0	3	250	CA 745308_18	2
7:30	11/18/15	-34.053526	18.600315	16	CA 745308	4	0	116	CA 745308_18	3
7:31	11/18/15	-34.060182	18.600914	64	CA 745308	3	0	62	CA 745308_18	4
7:34	11/18/15	-34.063212	18.598088	16	CA 745308	1	1	25	CA 745308_18	5
7:35	11/18/15	-34.065309	18.603103	16	CA 745308	1	1	9	CA 745308_18	6
7:39	11/18/15	-34.057979	18.606822	12	CA 745308	2	0	83	CA 745308_18	7
7:40	11/18/15	-34.056799	18.61015	8	CA 745308	3	0	102	CA 745308_18	8
7:42	11/18/15	-34.056638	18.614593	16	CA 745308	0	3	105	CA 745308_18	9
7:44	11/18/15	-34.055409	18.617953	32	CA 745308	0	1	106	CA 745308_18	10

Figure 4-7 shows how trips were separated so as to identify the trips directions for each taxi. After filtering the directions, the data were aggregated again for route 1 and route 2 for trips going to Hazeldene only. This was done with the data that was used to estimate the OD matrices per route line.

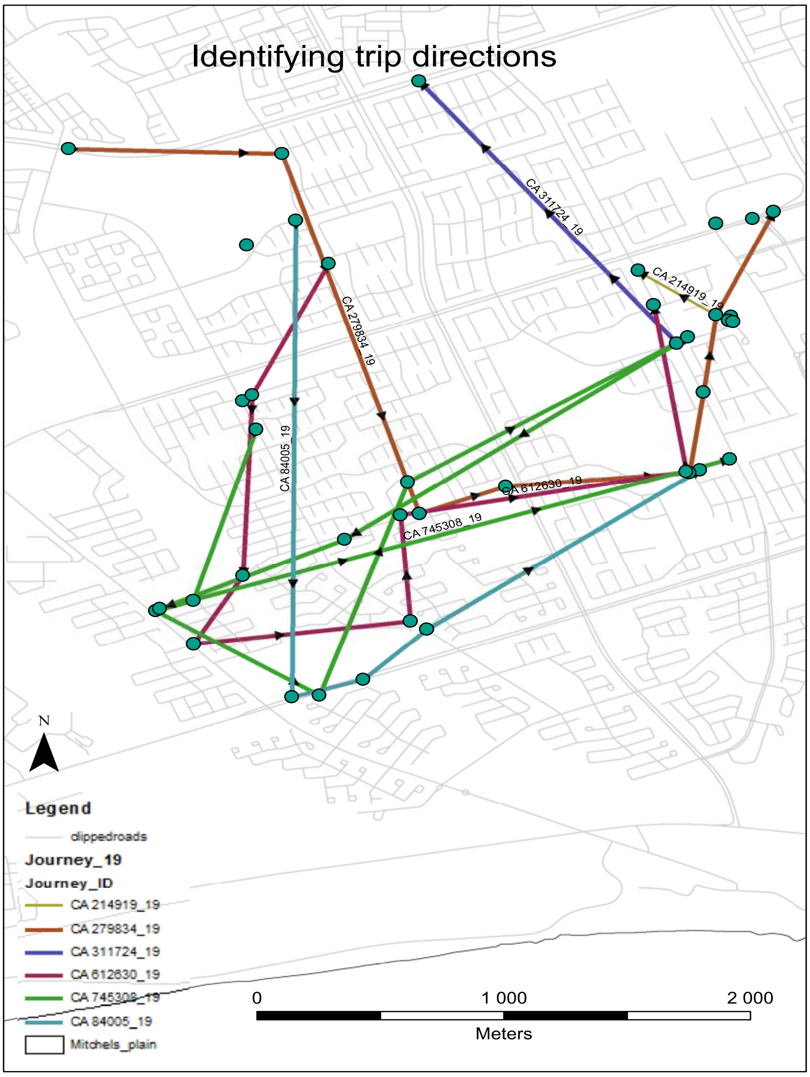

Figure 4-7: Identifying trip direction

4.1.3 Estimating total demand

The method used to process the data to OD matrices was developed by Li and Cassidy (2007) developed an algorithm to estimate a route level transit OD matrix from boarding and alighting counts. The input for this algorithm are the number of passengers boarding and alighting, and the threshold distance between the taxi stops. Before applying the algorithm, the following steps were followed;

i) Identify a grid cell that has GPS data points within the peak period and is the direction to the Hazeldene taxi rank.

ii) Identify the number of data points in each grid cell.

iii) Identify the number of days the data points that fall in a grid cell.

iv) Identify if a cell is a major stop or minor stop.

v) Calculate the total number of points for both boarding and alighting were the weekly demand.

vi) Divide the total weekly demand by the number of days to obtain the average number of points per day in the peak period.

vii) Divide by the number of taxi trips that were sampled in that cell to obtain the average boarding and alighting counts for one taxi in each cell.

viii) Average the number of taxis departing to Hazeldene for the week to obtain the total number of taxis for a full AM peak period (06h00 – 09h00) as shown in Table 4-2. The average number of trips of the taxis along each route was factored to the demand to obtain the daily peak period average boarding and alighting counts.

Table 4-2: Averaging the trips during the peak period per day

Day	Total trips in the peak period
Monday	17
Tuesday	17
Wednesday	12
Thursday	12
Friday	9
Saturday	12
Total	79
Average	13

ix) Apply Li and Cassidy's balancing algorithm such that the number of boarding passengers is equal to the number of alighting passengers. This done by multiplying the ratio of the highest total of either boarding or alighting and multiplying the ratio to the lowest.

Table 4-3: Data processing to a total of Li and Cassidy's balance

Stop ID	Grid cell No.	No. Data Points	No. days of the week	Stop Description	Total Weekly Demand		Factored Sum (No. Taxis going)		Averaged (Number of days)		Li & Cassidy's Balance	
					Sum Boarding	Sum Alighting	Boarding	Alighting	Boarding	Alighting	Boarding	Alighting
1	272	3	2	Minor	9	0	119	0	59	0	195	0
2	254	2	2	Major	2	1	26	13	13	7	13	15
3	236	1	1	Minor	0	2	0	26	0	26	0	59
4	238	1	1	Minor	4	0	53	0	53	0	53	0
5	225	2	2	Minor	5	0	66	0	33	0	33	0
6	207	2	2	Minor	3	0	40	0	20	0	20	0
7	189	3	3	Minor	7	0	92	0	31	0	31	0
8	172	3	3	Minor	2	1	26	13	9	4	9	10
9	154	2	2	Minor	2	1	26	13	13	7	13	15
10	136	1	1	Minor	2	0	26	0	26	0	26	0
11	135	3	3	Major	20	6	263	79	88	26	88	59
12	134	4	2	Minor	13	0	171	0	86	0	86	0
13	116	6	4	Major	14	0	184	0	46	0	46	0
14	99	1	1	Minor	3	0	40	0	40	0	40	0
15	64	1	1	Major	1	1	13	13	13	13	13	29
16	46	2	2	Minor	1	1	13	13	7	7	7	15
17	29	7	5	Major	18	3	237	40	47	8	47	18
18	26	2	2	Major	2	0	26	0	13	0	13	0
19	42	2	2	Minor	0	4	0	53	0	26	0	59
20	31	1	1	Minor	1	0	13	0	13	0	13	0
21	25	7	4	Minor	16	5	211	66	53	16	53	37
22	43	5	4	Major	8	3	105	40	26	10	26	22
23	62	3	3	Minor	4	5	53	66	18	22	18	49
24	63	9	3	Minor	7	4	92	53	31	18	31	39
25	83	7	5	Minor	12	1	158	13	32	3	32	6
26	84	2	1	Minor	2	3	26	40	26	40	26	88
27	103	4	3	Minor	9	0	119	0	40	0	40	0
28	104	4	3	Minor	6	0	79	0	26	0	26	0
29	105	4	2	Minor	0	11	0	145	0	72	0	162
30	106	9	5	Major	19	10	250	132	50	26	50	59
31	124	2	2	Minor	10	3	132	40	66	20	66	44
32	142	1	1	Minor	1	0	13	0	13	0	13	0
33	160	17	6	Major	62	70	816	922	136	154	136	479
Total					265	135	3489	1778	1125	504	1261	1261

The Li and Cassidy algorithm splits the stops to two types of stops; minor stops and major stops. The classification of the stops imply a specification of parameters for the probability of boarding and alighting at the stops. Major stops are considered to be stops around major activity centres such as schools and large business centres and others are treated as minor stops, where there is not much activity that is attracting people. This is however not the case all the time, there could be stops classified as major stops but with fewer number of boarding or alighting. In a thesis by Lan (2015), stops were considered as major stops if they have high volume of passengers boarding or alighting. Both of these ideas were considered to identify major and minor stops. Generally the process of designating types of stops can be made based on personal judgement or trial and error. Even though this is viewed as a limitation of the algorithm, it helps in the OD matrix calibration. For this study, major and minor stops were defined based on both the activity centre positioning and the concentration of data points on a route. Figure 4-8 shows the position of activity centres in Mitchells Plain that are likely to attract passengers along the routes.

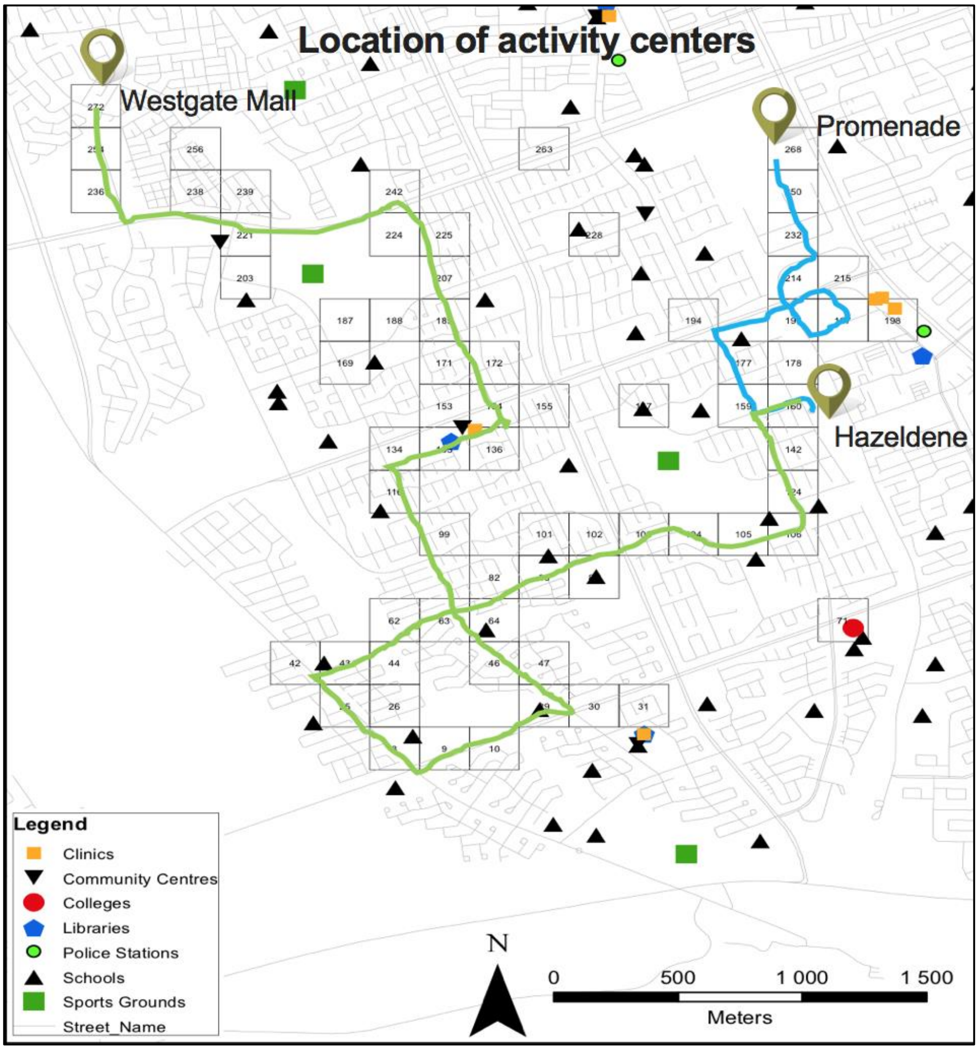

Figure 4-8: Location of activity centres

4.1.4 Applying the Li and Cassidy Algorithm

4.1.4.1 The algorithm

This section discusses the process of estimating the OD matrix using the algorithm of Li and Cassidy (Li & Cassidy, 2006). The probabilistic parameter α represents the relationship between the probability of boarding and alighting from a minor or major stop in the the equation below:

$$\frac{P_{as}}{P_{bs}} = \frac{1-\alpha}{\alpha} \qquad \text{Equation 4-1}$$

Where;

P_{as} denotes the probability that a passenger alights a certain stop s for an onboard passenger who boarded at a major stop,

P_{bs} denotes the probability that a passenger alights a certain stop s for an onboard passenger who boarded at a major stop, and

$\alpha \in (0,1)$. It is normally assumed that $\alpha = \alpha_a$ for major stops and $\alpha = \alpha_b$ for minor stops

Based on the theorem that immediately upstream of a stop s, there are N_a passengers who get on a taxi at major stops and N_b passengers who get on a taxi at minor stops. Also, suppose that of the n passengers who alight at that stop, n_a passengers boarded at major stops. If this assumption holds, the estimated number of alighting passengers who boarded at major stop (n_a) is estimated to be;

$$n_a = \frac{(1-\alpha)N_a}{(1-\alpha)N_a + \alpha N_b} \qquad \text{Equation 4-2}$$

n_a can be split upstream major stop proportionally according to their ratio of boarding counts in such a way that the origin contributing least or most to N_a gives the greatest or least contribution to n_a. Consequently, the number of passengers who alight at a minor stop, n_b is estimated as

$$n_b = n - n_a \qquad \text{Equation 4-3}$$

And is also drawn in the same manner as n_a to minor stops. The number of passengers from each upstream stop to the current stop are estimated. As a result, an OD flow matrix is generated by applying this calculation.

Furthermore, theoretically the estimate for n_a is taken as in equation 4-2 if $n\text{-}n_b < n_a < N_a$. However, should $n_a > N_a$ when ($\frac{\alpha}{1-\alpha} > \frac{n-Na}{Nb}$) then n_a is set to N_a. In the same sense, if $n_b > N_b$, n_a is estimated as $n\text{-}N_b$.

4.1.4.2 Estimating the OD matrix

The inputs for this algorithm are the number of passengers boarding and alighting at particular stops along a route, α values for minor and major stops that are first assumed, and finally the threshold distance.

The algorithm assumes there is a minimum distance within which passengers can travel. Passengers who have travelled less than this distance stay on-board while those that have travelled more than this distance have a chance to alight. The minimum riding distance that was specified in this study was 2km.

Before going in detail to discuss the procedure to estimate the OD matrix, an example calculation is presented example in Figure 4-9 below. The example shows the steps followed to calculate the route line OD matrix for stop ID 3 on the Westgate mall – Hazeldene route.

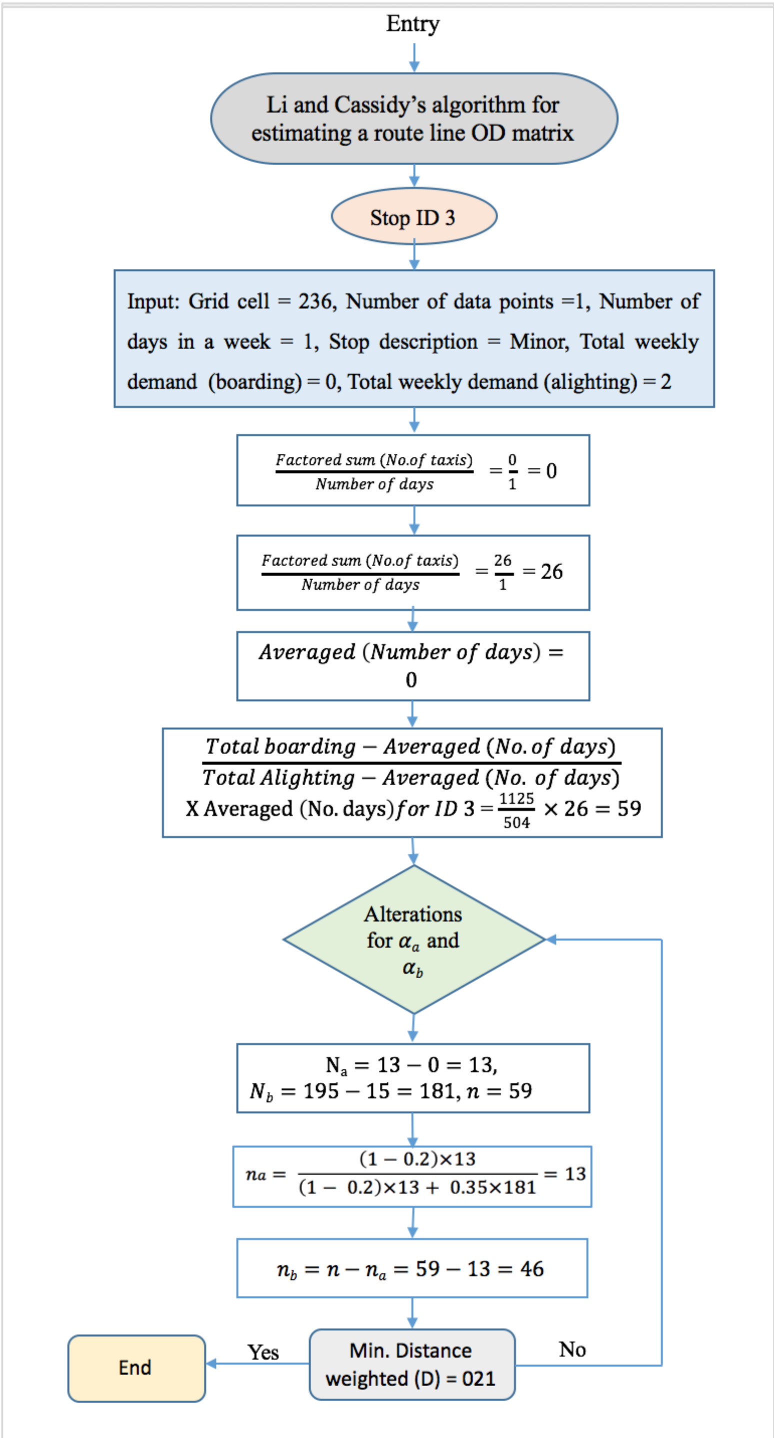

Figure 4-9: Flowchart showing the OD matrix calculation procedure

OD flow matrices were estimated for a given α_a and α_b i.e. α_a = 0.5 and α_b = 0.5. This was done using Equation 4-2 to obtain n_a and use n_a to obtain n_b. n_a and n_b were then converted to alighting probability matrix by splitting n_a amongst major stops and n_b amongst minor stops. The alighting probability matrix and boarding counts were used to estimate the distance weighted (D) to obtain the set of alphas. The steps were repeated for various α_a and α_b. The set of alphas that produced the smallest *D* are the parameters that produce the best estimate of the OD Matrix. The estimated *D* was 0.21 and α_a was 0.2 and α_b was 0.35.

At the start of the OD matrix in Table 4-6, there are no passengers who alight at stop 1. Passengers only board at the first stop and alight at the subsequent stop if a stop is after 2km. Stop 1 and stop 3 are minor stops while stop 2 is a major stop. To calculate the number of passengers who boarded at minor and major stops (stop 3), passengers onboard from the previous minor and major stops are considered respectively. N_a is the number of passengers onboard from a major stop and N_b is the number of passengers onboard from a minor stop. Therefore, N_a is calculated as the number of passengers who boarded at all major stops upstream of stop 3 minus the passengers who alighted from the major stops. The values used in this calculations are found in Table 4-3 and Table 4-5.

Following from the calculation was the computation of OD flows for stop 3. There is one minor stop and one major stop upstream of stop 3 so all the 13 passengers alight at stop 2 (major stop) and 46 passengers alight at stop 1 (minor stop) as depicted in the OD matrix.

The comprehensive process described above produced an OD matrix. However the OD matrix produced had some negative numbers implying negative passengers alighting. This was investigated further and resolved in the following section.

4.1.4.3 Eliminating negative trip loads

Amongst many methods that could be used to estimate the route level OD matrices, the Li and Cassidy method was selected because of its best fitness measure according to Lan (2015). The method however, has some computational limitations and difficulties. Based on the data that was used to estimate the OD matrices in this study, the method produced negative OD matrices. This happens when the number of passengers alighting at a certain stop was greater than the number of people onboard from the stop before. In order to resolve the negative OD matrices, the L-error method as used by Pukelshiem and Simeone (2009) was applied. The L-error method simply calculates the negative load and redistributes the absolute value of the negative load to the boarding and alighting accounts. The steps through the L-error method are described below:

Step 1: Calculate the number of passengers who arrive at a particular stop, n, the arrival load $L^{n}_{arrival}$.

$$L^{n}_{arrival} = \sum_{1}^{n-1} P_i - \sum_{1}^{n-1} Q_i \qquad \text{Equation 4-4}$$

Where;

P_i denotes boarding counts at stop i, and

Q_i denotes the alighting counts at stop i

Step 2: Calculate the number of passengers who travel from an upstream stop to a down stream stop. This through load, $L^{n}_{through}$ at stop n is calculated using equation 4-4.

$$L^{n}_{through} = \sum_{1}^{n-1} P_i - \sum_{1}^{n} Q_i \qquad \text{Equation 4-5}$$

The number of $L^{n}_{through}$ should be less than the arrival load or else the negative trip load occurs.

Step 3: To resolve the negative through load and keep a balance of the count for the number of passengers boarding and alighting, select the negative through load which has the maximum absolute value and add this to the boarding count at first stop and the alighting count last stop.

The calculations to show how the L-error method was incorporated into the Li and Cassidy method is shown below in Table 4-4. Before applying the L-error method, there are some cases of $n_a > N_a$ as depicted in in Table 4-4. As a result there is negative $L^{n}_{through}$ which indicates that there are negative passengers who travel from an upstream stop to a downstream stop. This negative load distributes downstream in the calculations for n_a and produces negative values in the alighting probability matrix. To eliminate the negative load, the total negative through load was summed up. This was equal to negative 136. The absolute value of negative 136 was then added to the first stop's boarding count and the same number was added to the last stop's alighting count. To obtain the output in Table 4-6.

Table 4-4: Application of the L-error method

Stop ID	Stop Description	Li &Cassidy's Balance		Alpha (Minor)	Alpha (Major)	N_a = Boarded at Major stops	N_b= Boarded at minor stops	n = Alighting at that stop	n_a= alighting at major stops	n_b=alighting at minor stops	$L_{n=arrival}$	$L_{n=through}$	na>Na	nb>Nb
		Boarding	Alighting											
1	Minor	59	0	0.2	0.15									
2	Major	13	15	0.2	0.15	0	59	15	0	15	59	45	No	No
3	Minor	0	59	0.2	0.15	13	45	59	37	22	58	-1	Yes	No
4	Minor	53	0	0.2	0.15	0	23	0	0	0	-1	-1	No	No
5	Minor	33	0	0.2	0.15	0	75	0	0	0	52	52	No	No
6	Minor	20	0	0.2	0.15	0	108	0	0	0	85	85	No	No

4.1.4.4 Reflection on Li & Cassidy and the L-error method

Initially, the Li and Cassidy method was used to estimate the OD matrices. The method states "However, should $n_a > N_a$ when ($\frac{\alpha}{1-\alpha} > \frac{n-Na}{Nb}$) then n_a is set to N_a. In the same sense, if n_b

$>N_b$, na is estimated as n-N_b" (Li and Cassidy, 2007, P.117). This was viewed as a way to resolve negative loading in the algorithm. However, this was never resolving the negative loading. When one parameter is changed, the others change and this went on and the APM was not giving realistic values. However, when the L-error method was applied in the manner described above, there was no negative loading. When the algorithm is used to calculate the alighting counts at minor and major stops, all n_a for major stops along the route is calculated using Equation 4-2 while n_b for minor stops is calculated used $n_b = n - n_a$. Figure 4-5 shows the results of the process of Li and Cassidy method and the L-error method

Table 4-5: OD matrix for the route Promenade to Hazeldene taxi rank

Stop No.	1	2	3	4	5	6	7	8	9	Boarding Sum
1	0	8	8	10	13	8	4	51	68	170
2		0	0	0	0	0	0	1	10	13
3			0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0
5					0	0	0	0	0	0
6						0	0	0	0	0
7							0	8	68	76
8								0	29	29
9									0	0
Alighting Sum	0	8	8	11	13	8	4	60	175	288

Table 4-6: Results of Li & Cassidy's method and L-error method

Stop ID	Stop Description	Li & Cassidy's Balance		Alpha (Minor)	Alpha (Major)	$N_{a=}$ Boarded at Major stops	$N_{b=}$ Boarded at minor stops	n Alighting at that stop	$n_{a=}$ alighting at major stops	$n_{b=alighting}$ at minor stops	$L_{n=arrival}$	$L_{n=through}$	$n_a > N_a$	$n_b > N_b$
		Boarding	Alighting											
1	Minor	195	0	0.35	0.2									
2	Major	13	15	0.35	0.2	0	195	15	0	15	195	181	No	No
3	Minor	0	59	0.35	0.2	13	181	59	13	45	194	135	No	No
4	Minor	53	0	0.35	0.2	0	135	0	0	0	135	135	No	No
5	Minor	33	0	0.35	0.2	0	188	0	0	0	188	188	No	No
6	Minor	20	0	0.35	0.2	0	221	0	0	0	221	221	No	No
7	Minor	31	0	0.35	0.2	0	240	0	0	0	240	240	No	No
8	Minor	9	10	0.35	0.2	0	271	10	0	10	271	261	No	No
9	Minor	13	15	0.35	0.2	0	270	15	0	15	270	255	No	No
10	Minor	26	0	0.35	0.2	0	269	0	0	0	268	268	No	No
11	Major	88	59	0.35	0.2	0	295	59	0	59	295	236	No	No
12	Minor	86	0	0.35	0.2	88	236	0	0	0	324	324	No	No
13	Major	46	0	0.35	0.2	88	322	0	0	0	409	409	No	No
14	Minor	40	0	0.35	0.2	134	322	0	0	0	455	455	No	No
15	Major	13	29	0.35	0.2	134	361	29	18	12	495	466	No	No
16	Minor	7	15	0.35	0.2	129	349	15	6	9	479	464	No	No
17	Major	47	18	0.35	0.2	123	347	18	10	7	471	453	No	No
18	Major	13	0	0.35	0.2	160	340	0	0	0	500	500	No	No
19	Minor	0	59	0.35	0.2	174	340	59	29	30	514	455	No	No
20	Minor	13	0	0.35	0.2	145	310	0	0	0	455	455	No	No
21	Minor	53	37	0.35	0.2	145	323	37	17	§	468	431	No	Yes
22	Major	26	22	0.35	0.2	128	376	22	13	9	484	462	No	No
23	Minor	18	49	0.35	0.2	142	366	49	20	28	488	439	No	No
24	Minor	31	39	0.35	0.2	121	355	39	15	24	457	418	No	No
25	Minor	32	6	0.35	0.2	106	362	6	2	4	448	443	No	No
26	Minor	26	88	0.35	0.2	104	390	88	29	59	474	386	No	No
27	Minor	40	0	0.35	0.2	75	357	0	0	0	412	412	No	No
28	Minor	26	0	0.35	0.2	75	397	0	0	0	452	452	No	No
29	Minor	0	162	0.35	0.2	75	423	162	40	122	478	317	No	No
30	Major	50	59	0.35	0.2	35	302	59	19	40	317	258	No	No
31	Minor	66	44	0.35	0.2	66	261	44	14	30	308	264	No	No
32	Minor	13	0	0.35	0.2	52	297	0	0	0	330	330	No	No
33	Major	136	479	0.35	0.2	52	311	479	193	286	343	-136	Yes	No
Sum		1261	1261					1261	437	804				

Table 4-7: OD matrix for the route Westgate Mall to Hazeldene taxi rank

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	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
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	1	0	0	1	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	1	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
20																				0	1	0	1	1	0	1	0	0	3	1	1	0	5	13
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	27
23																							0	1	0	2	0	0	4	2	1	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	11	6	2	0	20	39
28																												0	7	4	1	0	14	26
29																													0	0	0	0	0	0
30																														0	19	0	171	191
31																															0	0	65	65
32																																0	13	13
33																																	0	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

4.2 Feeder time tables

Data on arrival and departure times were collected for taxis travelling between the three major points. The timetable data on taxi departures were input in Commuter as it was collected from the field. From Table 4-10 above, there are on average 13 taxis that leave from Promenade or Westgate Mall to Hazeldene taxi rank during the peak period. Figure 4-5 shows the typical Tuesday time table from Promenade to Hazeldene taxi rank and just below it is the route (in Cyan colour) where the taxis travel.

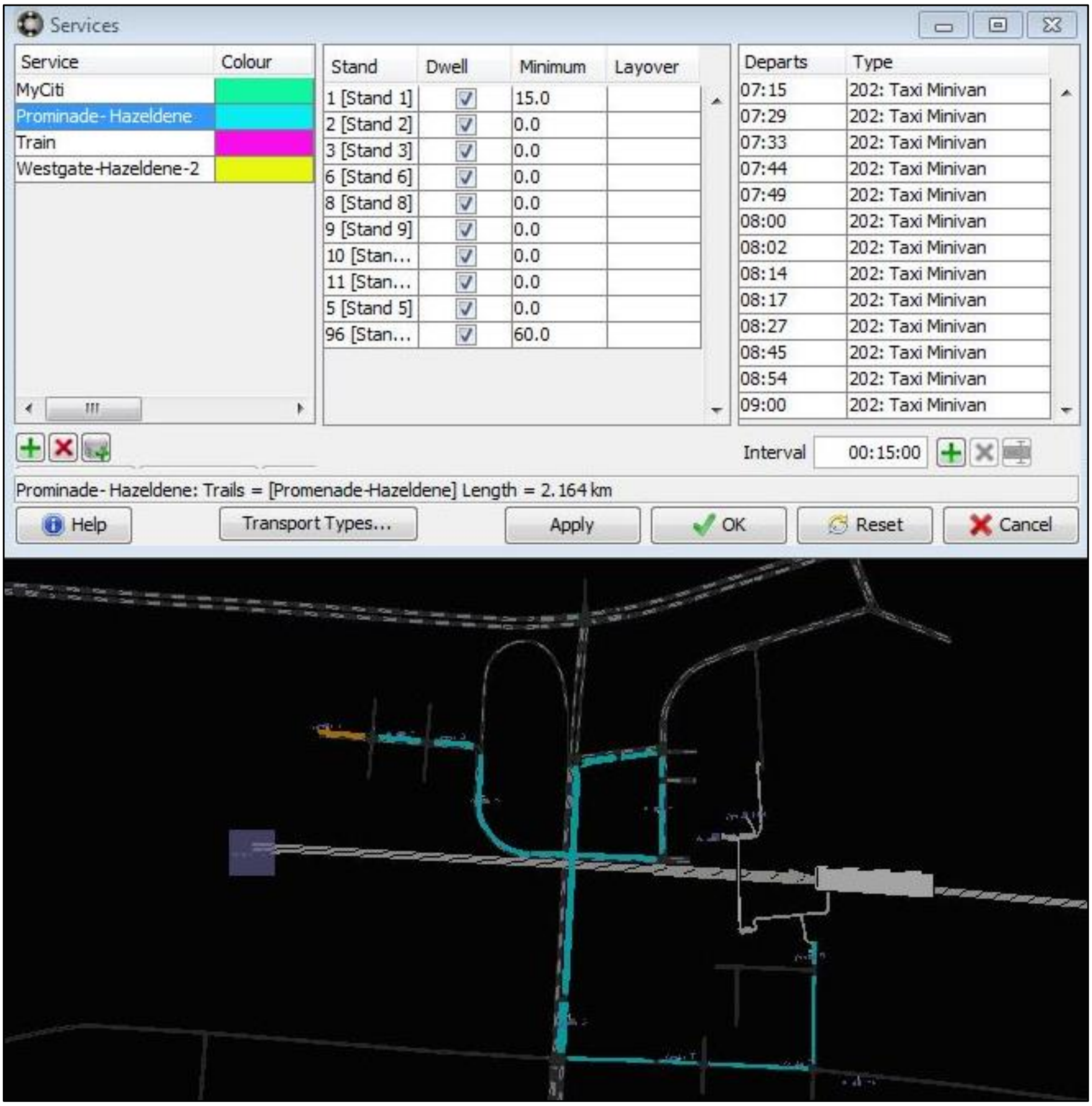

Figure 4-10:Promenade trail and time table associated with it

4.3 Trunk time tables

In the similar manner as feeder time tables, trunk time tables for the AM period for a typical Tuesday were used. The time table for MyCiti buses and Metrorail -Trains were based on real data collected in the field – as there is a little deviation from the online time tables. Golden Arrow bus time tables were obtained from their online websites because it was quite difficult to collect real time data on their arrivals and departures.

4.4 Traffic count data

Traffic data along the routes where the taxis travelled were collected and used to get vehicle demand volumes. Average daily traffic (ADT) demand for the peak period was estimated as in equation 4-5:

$$\mathrm{ADT} = \frac{\text{Total week demand volume per direction}}{\text{Number of days}} \qquad \text{Equation 4-5}$$

5. Modelling trunk-feeder operations

Transportation modelling has been used by many transport planners over the past 40 years to replicate real world situations such as vehicle and human behaviour while travelling. They have been used to analyse as well as to predict network performance which then forms a basis to optimize the operation and efficiency of the transport network.

Two types of modelling approaches are common; trip based modelling (TBM) and agent based modelling (ABM). Of the two, the most used approach; the TBM is also known as the four step model (FSM). In the past, transport planners traditionally followed the sequential FSM procedure to model for person travel and most of the demand modelling was dominated by this approach. Using this approach, travel is viewed as derived from demand for activity involvement and is modelled with trip based rather than activity based methods (McNally, 2007). In more recent years, agent based methods have emerged as a promising tool to provide planners with more sophisticated insights on social behaviour of individuals (Huynh, 2014).

In an ABM scheme, all elements in the model can be thought of as an agent. For example, passengers can be modelled as agents, vehicles can also be treated and modelled as agents, etc. This scheme then provides a platform where the interaction of different agents with distinct travel behaviours can be modelled within a transport network. In addition, the ability to define an individual agent travel and activity behaviour presents an opportunity for better control in the model and this provides a higher chance to forecast more accurately (Abbas, 2013). For that reason, one can see the importance of using the ABM approach to model connected corridor environments with different agents.

This research attempts to address many aspects of traveller behaviour involving, mode and route choice, network modelling as well as interaction of different agents. As such, this suggests exploration of various tools/packages that could potentially meet the particular needs of the model.

5.1 Research tool selection

Before selecting the modelling software package, the particular needs of the model were made explicit and clear. This was to test if the software functionality met the key requirements. As such, various software packages were initially reviewed to assess their capabilities for the research. A suitable tool for the simulation modelling was then selected based on its sensitivity and applicability to the research problem, considering that other software packages presented some risk of not getting the required output. It was seen as vital to use a simple, yet appropriate software package keeping in mind that the objectives of the research were paramount in making this decision. Table 5-1 depicts a summary of the software packages under consideration and the software capabilities that need to be met.

Table 5-1: Summary description of the programs capabilities

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

The objective of the simulation software package is to analyse and particularly visualise the effects of operations of trunk and feeder services on passenger flows. The operation consists of arrival and departure patterns that are based on taxi timetables as well as the interaction of passenger flows within the public transport systems, e.g. boarding and alighting. The effects on passenger flows such as transfer times from feeders to trunks and waiting times for transport services along the routes would then dictate the overall passenger flows.

Three potential software packages were investigated: Paramics, Viswalk/Vissim, Commuter and MS Excel. Paramics simulation is based on origin-destination (OD) matrices and is useful in gauging arrival and departure patterns. Capacity and loading of public transport vehicles is based on setting initial capacity and occupancy of services. However, in relation to the operation of passenger behaviour at transfer stations, boarding and alighting are still not possible due to the fact that Paramics operates passenger and vehicles independently. VISSIM/VISWALK is capable of simulating vehicle arrival/departure times and loading, as well as capacity analysis. The operation at transfer stations requires a combination of both VISSIM and VISWALK software packages, which can be complex to integrate together and would also still lack the ability to model actual passenger journeys across modes. Microsoft Excel, even though it could model basic transport operations, it is not a simulation tool – implying that it is very limited and does not give a spatial representation of the idealised system so it would be quite difficult to model the system at an appropriate level of detail. Microsoft Excel is only appropriate in modelling randomised and stochastic vehicle operations.

Commuter, a nano-simulation software package developed by Azalient, was found to be able to handle all of the tasks in Table 5-1. Commuter is an end-to-end journey simulator that models trips made by people across modes and has the capability to explicitly represent pedestrian interaction with the road network. The technical features of Commuter were critically explored to ensure the core functions required for this research are met. Although it has posed some challenges in terms of modelling randomisation of arrival/departure patterns and locations along the feeder route, this is not unlike any of the other microsimulation packages explored due to the fact that traditionally, public transport modelling in a simulated environment adopts a service-stop-timetable approach. Working around how to achieve that element of the model was managed by manipulating the Gaussian boarding and alighting time distributions, while making assumptions in the data processing as discussed in the section above. Randomness in public transport operations is a function of a number of variables including the number of boarding and alighting passengers and the time each agent takes to undertake the activity. While public transport services are given an initial service start time, the arrival at any given stop along the route is also a function of external factors such as the operation of general traffic in the network and resulting congestion. As such, Commuter was selected as the most appropriate tool to use in modelling as it was the only package capable of modelling people interaction with vehicles as opposed to simple vehicle trips.

5.2 About Commuter software

Commuter is a multi-agent simulation platform used for simulation of intermodal journeys made by people where each person travelling may use a combination of modes to arrive at their destination. An agent in Commuter is a person or a vehicle whether private or public.

The analysis of the journeys may include:

- Walking trips: An agent can walk from home to a station or office
- Self-driven trips: Example is trips from driveway to a parking space
- Public transport trips: Example is trips from a station to a city centre

Each person in the simulation makes dynamic choices not only between possible routes of the same mode but also between different transport modes. Examples of route choice decisions include:

- The motor way is busy: the agent will take the next exit and go to either the park and ride or take a bus to a busy centre
- The train is late: The agent will walk and board a bus instead to get to their destination
- It is raining: The agent will walk through the a building to the parking and drive to their destination instead of taking a train

There are some simulation packages capable of showing all mode types but none of them is capable of integrating journeys made by people between them. The modal types that Commuter is capable of capturing the dynamics of:

- Taxi:
- Train
- Buses
- People such as pedestrians, passengers and drivers
- Cyclists
- Ferries etc.

5.2.1 Model parameters

Commuter has a parameter section where one can input model settings. There are various parameters but this research uses the following:

- Term: This refers to the defined period of the simulation. It can also be used to refine the model behaviour and operation.
- Behaviour: This defines the behaviour of agents in a model. It controls how agents behave and perceive things in the simulation. Each agent in the simulation must be assigned a behaviour so as to control how it acts in the model. A behaviour can be applied to one or more agent types and therefore one can define as many behaviours as they like for various agents.
- People: Travel behaviour for a passenger agent are; can walk, can drive, can ride, can drop off, can cycle tec.

- Vehicles: Attributes of vehicles can be defined here. Vehicle characteristics such as vehicle, size, shape, capacity, type, fuel type, engine types etc.

5.2.2 Zoning plan

A zoning plan is a spatial plan on a map that shows all origins and destinations for all the trips that are modelled. In an ideal case, trip-ends for vehicle or person trips should specify their origins and destinations. The trip end locations are:

- Areas: They represent origin and destination locations for person trips. They are also used to add fill-in people demand and generate people in the model.
- Zones: They are used to add fill-in vehicle demand and then generate vehicles. These are normally used to generate and add in extra vehicles on the roads so as to obtain realistic traffic flow in the model. And, the vehicles that carry people will therefore experience traffic delays, queues and travel times.

5.2.3 Network

The network in Commuter is set for pedestrians and vehicles.

- Pedestrians use walking network comprised of of walkways, connections and crossings.
- The roads consist of links and lanes connected by intersections. Commuter handles signalised and priority intersections.

5.2.4 Public transport services and timetables

Public transport services are created to provide facilities that connect pedestrians to the public transport vehicles.

- Stands and platforms: This is an area that connects the walking path to the road network and creates an area where public transport vehicles can stop to board or alight passengers. Likewise, platforms are areas where pedestrian can wait to board and where a train can stop to board the pedestrian.
- Services: Is a route taken by a public transport mode such as a bus or train. A service defines the location or stands where the vehicle can stop to board or alight passengers
- Trails: Routes are programmed in trails. A trail is a sequence of route elements that are used to control routing of public transport vehicles. A trail defines the route for each service.

5.2.5 Demand specifications

In Commuter demand can either be person trips or vehicle trips, both normally expressed in OD matrices. Commuter is primarily a tool to model for person trips but can also analyse vehicle trips. There are two levels of demand in Commuter;

i) Level 1: Person trips are generated between areas – person trips begin and end in an area. Each trip defines a door-to-door journey for a person who may use one or more modes of transport.

ii) Level 2: Vehicle trips are generated between zones – vehicle trips begin and end in zones. Vehicle trips can be generated to carry people on trips or they may be generated as background traffic – a mix of public transport vehicles and traffic or they may also be generated to study vehicular traffic flow only.

5.2.6 Trip generation

Trips are generated in a stochastic manner from the disaggregated demand before the simulation begins such that people or vehicles can be produced and be visible in the model.

Demand profiles are then created to control release of agents. Demand profile are created at time intervals hence a term defines a simulation time interval. The profile is used to vary the number of trips generated over the course of the term.

5.2.7 Simulation

After generating trips, the model is simulated. Simulation shows real life processes based on the data that was input and consequently one can observe how the modelled system works. Predications can be made about the behaviour of the system by changing parameters and variables.

Simulation modelling in commuter therefore follows the following process:

- Building a network
- Creating areas which are origins and destinations for people
- Creating zones that are origins and destinations for vehicular traffic and can also be used for parking studies.
- Define demand by inputting demand OD matrices
- Define people and vehicle behavioural parameters

- Generate trips from the aggregated demand
- Run the simulation
- Simulate scenarios
- Collect results

5.2.8 Collating results

When the model is built, the visualization in the simulation alone is not sufficient. A set of numerical results is required to summarise the findings of the study. After the model has run correctly, Commuter saves the results of person trips, vehicle trips, environmental effect results, economic analyses and Level of Service in XLS files. These results can then be used to evaluate the scenarios.

5.3 Conceptual model

The model was built for AM peak period of 3 hours, from 6h00 to 9h00. Its fundamental purpose was to simulate trunk-feeder operations. The model simulates typical operations and behaviour of taxis travelling along feeder routes, passengers arriving at stands to wait for taxis, passengers boarding and alighting along feeder routes and other passengers connecting to other modes of transport from the interchange in order to reach their destination.

Two feeder routes were modelled: one from Promenade to the interchange and the other from Westgate Mall to the interchange. From the interchange, passengers connect to their respective trunk route to the Cape Town CBD or end their trip. Primarily, the purpose of the research was to integrate and coordinate taxi arrivals at the interchange to form trunk departures – this would then focus on the activity at the interchange. However, taxi arrival patterns at the interchange are dependent on taxi operations along feeder routes and patterns of taxi departure from Promenade and Westgate Mall. This provided more control to manipulate the operations along the trunk network so as to integrate and coordinate the feeder to the trunk network.

Figure 5-1 shows a conceptual layout of the vehicle and passenger flow as modelled in Commuter. Passengers arrive at Promenade Mall or Westgate Mall. They then wait to board a taxi which drops them at the interchange. They alight at the interchange, walk through the interchange to connect to to the trunk services; train or buses. Once a trunk service arrives, they board and travel to their final destination which in this case is the CBD.

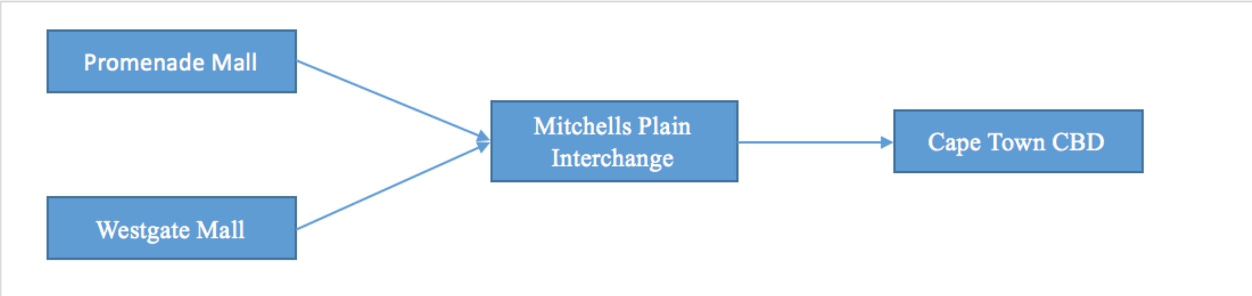

Figure 5-1: Conceptual layout of the transit system

5.4 Development of the base model

A base model was built and validated as discussed in the following sections. It is from this model that model scenarios will be developed.

5.4.1 Data input

The data required to build the base model included:

Network infrastructure and facilities: These define the overall model layout that would consist of roads, walkways, stairs, traffic intersections, platforms or stands for passengers to wait and vehicle parking zones along the routes. These components of the model would also define the geographical origins and destinations of agents.

PT services and timetables: This part of the modelling forms the foundation of providing directions to the flow of public transport vehicles within the network. Various trails are created in the network to form all existing bus as well as taxi routes. Subsequently, public transport timetables are then provided for each trail.

Demand data refers to OD matrices containing volumes of passengers between areas and of vehicles between zones. In Commuter, areas are origins and destinations for people and zones are origins and destinations for vehicles. Other demand inputs include time profiles that dictate the release profile of agents into the model, and existing data in order to validate the modelled intersection traffic counts.

Parameters, although not explicit inputs of the simulation model, were adjusted accordingly to refine the operations of the model. In this model, it was important to define the travel behaviour of passengers, the mode choice, routes choice, and trip characteristics.

5.4.2 Building the trunk-feeder model

Figure 5-2 below shows the steps followed to build the base model in Commuter. The subsequent section describes the model development in detail.

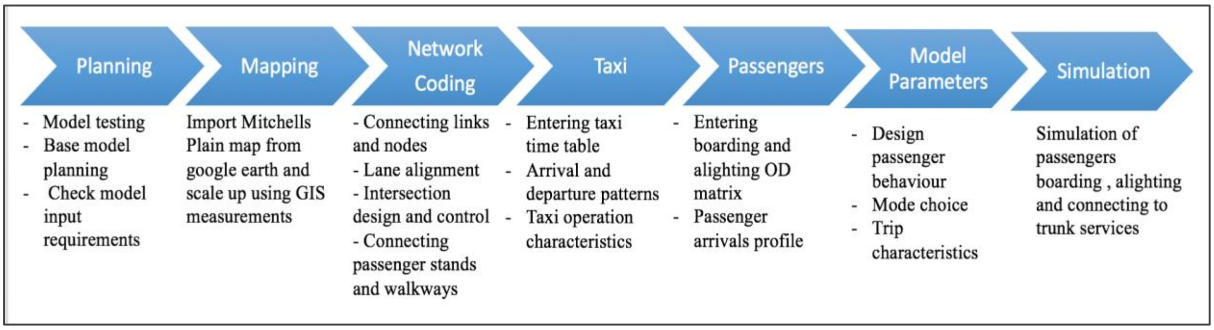

Figure 5-2: Trunk feeder model development process

The first step in building the trunk-feeder model was mapping. A background image was generated from google maps. The image was then imported in the Commuter software and scaled up to ensure that the distances in the model were correct (To obtain the true distances that will give accurate simulation calculation results). A network of roads and walkways that are used for travel by passengers and vehicles were then digitized (coded) on the scaled map. Following the network coding, a zoning plan was created in order to define the geographical locations of all trips between various origins and destinations. The modelled trips consist of private cars, buses, taxis and passengers. Zones and areas were then connected to the road network or walkways. Walkways create a walking path for passengers while stands were allocated to allow passengers to board or alight a taxi. It should be noted that in the model passengers did not walk from their actual origins (i.e. their homes). They only arrive at allocated stands and hence, walking time from their actual origins was not included in their overall trip time. Figure 5-3 depicts a Commuter screenshot of the network.

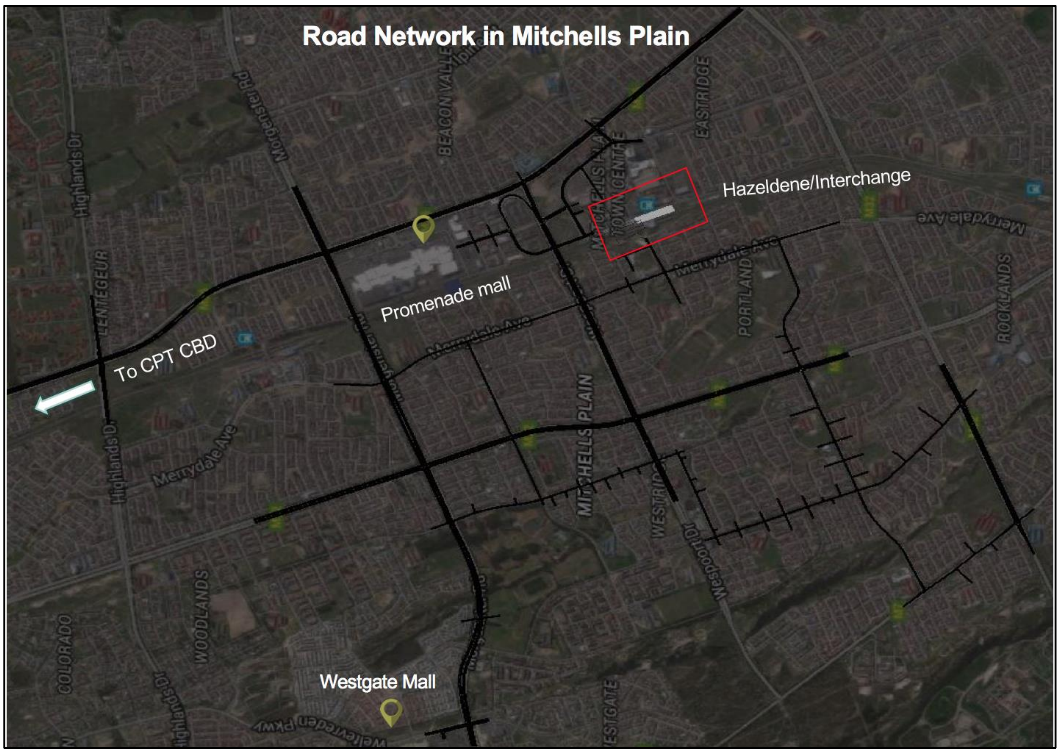

Figure 5-3: Mitchell's Plain road network

After coding the network in Commuter, trails were created. A trail is a sequence of road elements used to control routing of fixed route vehicles such as public transport. Using data from the Hazeldene taxi association, the taxi routes were defined and created in the model through this trailing process. Creating trails controls the routes taken by different public transport services. In this case, Golden Arrow, MyCiTi, Metrorail and taxis each had their own defined routes as in reality. The figures below show Commuter screenshots of some of the trails that were created and the interchange.

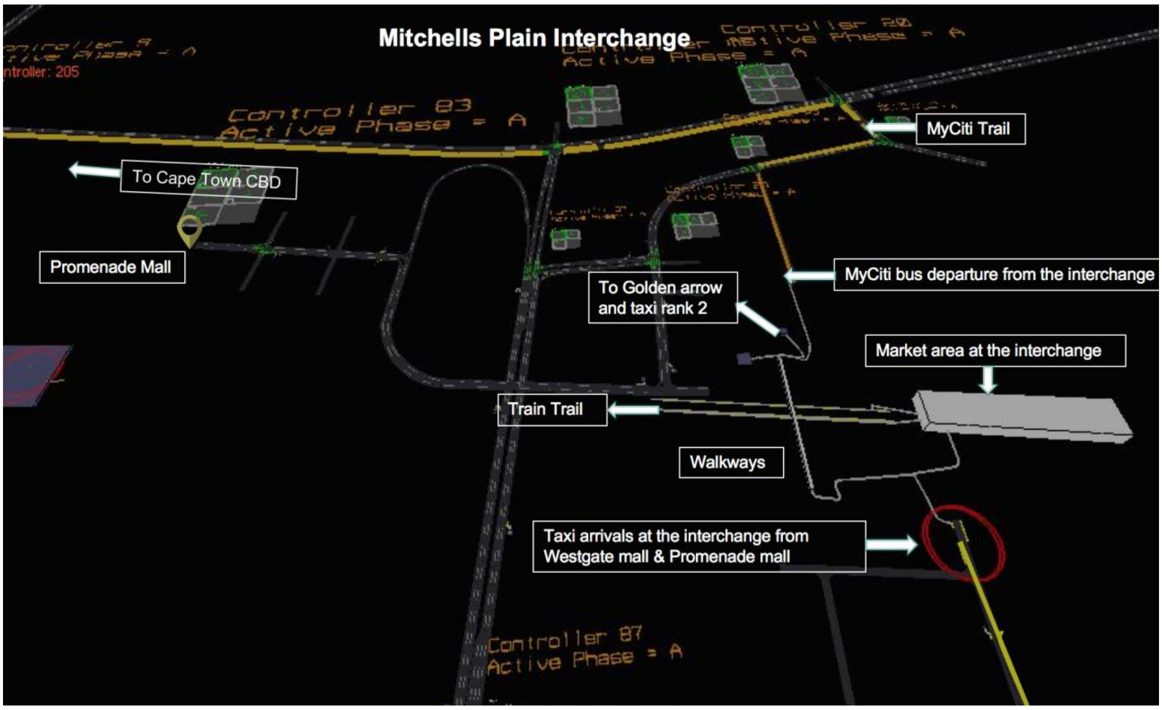

Figure 5-4: Mitchell's Plain interchange

Figure 5-5: Taxi trail from Westgate Mall to the interchange

After creating trails, services for buses and taxis were defined in the model. A service in Commuter defines a route taken by a public transport service (trail) and also the locations (stands) where the taxis or buses stop to board and alight passengers. The timetables for buses and taxis associated with their departure times at their respective origins were subsequently entered for each service. The timetables of a typical Tuesday AM peak period (6h00 to 9h00) were entered into the model.

5.4.3 Defining agent characteristics

Each element in this model represents an agent (each agent will be identified by its name to make a distinction between different agents). A taxi is an agent, a passenger is an agent, a private car is an agent etc. Each agent represents an individual's characteristics and each individual has a travel diary comprising of a sequence of events for the simulation period. For example, an individual passenger agent has defined origin, destination, departure and arrival time, route choice and trip mode. Below are some assumptions that have been made in terms of how taxis as well as their passengers were able to behave and interact in the modelled network:

- At the start of the trip i.e. at the taxi rank, Promenade and West Gate malls, taxis are modelled to replicate the fill and go typical behaviour of taxis, where by the taxis wait until they are full or almost full before they depart. Once they the taxis are enroute, they are assigned to stop; where an on-board passenger wishes to alight or where there is a pedestrians waiting to board. If the taxi is fully loaded, it will not stop to pick waiting pedestrians. This means that the fully loaded taxi will not stop or try to pick up additional passengers, unless there is an on-board passenger wishing to alight. In other words, a taxi stopping is determined by the taxis load variation and passengers boarding and alighting desires.

  Taxis, like any other private vehicle, are not able to drive faster than the posted speed of the road network. The taxis can also overtake other surrounding taxis as well as other private cars along the road.

- Pedestrians were restricted to a walking speed of 1m/s (3.6km/hr) along the walkways (Gates et al. 2006). A passenger can only board and not drive.

After defining these parameters, the demands for all agent types were inputted in the model. The demands in this model were passengers who wanted to travel while the supply were the taxis on the feeder route and buses and trains on the trunk routes. The demand was entered as OD matrices that were calculated in Chapter 4 using the Li and Cassidy algorithm. OD matrices for all passengers departing Promenade and Westgate Mall were inputted into the model. Of these passengers, some were alighting along the feeder routes while others were connecting to the trunk services. Using arrival data in Table 3.3 collected on Tuesday 17th November 2015, it was determined that 88.3% of the passengers were transferring to trunk services and 11.7% board and alight along the feeder routes. Figure 5-6 and 5-7 show illustrations Commuter screenshot of the origins and destination for the passengers transferring and those alighting along the Westgate Mall – Hazeldene trail. Figure 5-6 shows passenger egress trips - passengers who depart Westgate Mall and alight along the feeder routes (blue) and Figure 5-7 shows passenger ingress trips - passengers who board along the feeder trails, transfer at the interchange and connect to the Cape Town CBD.

Figure 5-6: Passengers' origin at Westgate Mall and destination along the feeder and trunk trails

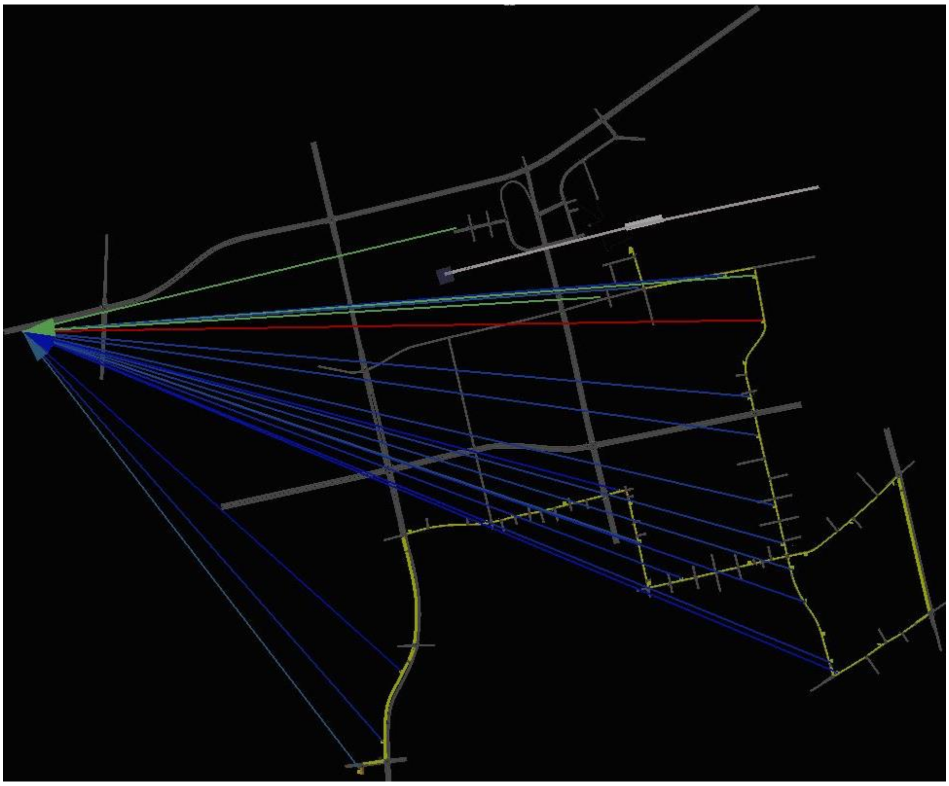

Figure 5-7: Passengers origin on the feeder trail and destination on the trunk trail (To CBD)

Additionally, of the 88.3% passengers transferring to trunk services, some of those will connect to MyCiti buses, some to Golden Arrow buses and others to use the train or the other taxi ranks at the interchange. Proportions of the passengers transferring to the different trunk services were determined using the same arrival data and the percentage proportions that were used in the model – these proportions are shown below in Table 5-2. It can be seen that the majority of passengers travel via trains and very few use MyCiti buses.

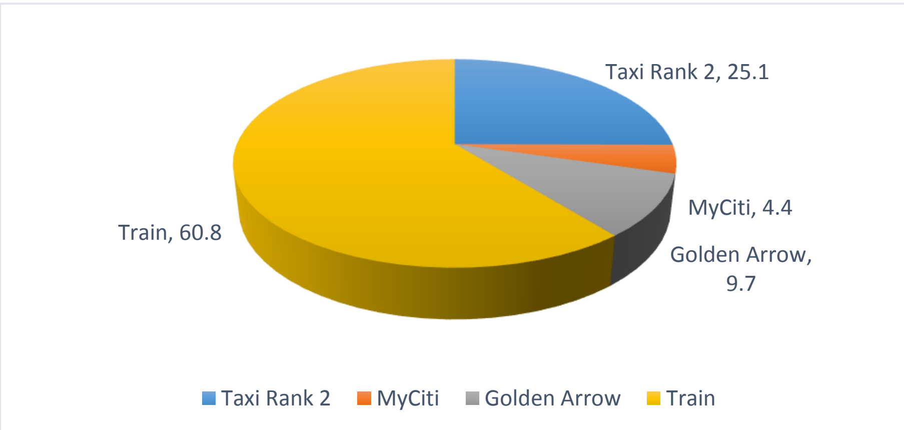

Figure 5-8: Percentage proportion of passengers connecting

Pedestrians walking to the stand to board are released using profiles which use a stochastic generation method – meaning that each pedestrian departure is selected individually at random but this must satisfy the O-D demand in each cell as well as demand percentage splits specified in the profiles. Profiles are created by defining time intervals between the modelled period. An interval of 30 minutes was considered because according to the data, there was a significant change in the volume of passengers arriving at stands at almost every 30 minutes. The profiles were determined by adding all the passenger's arrivals in 30-minute intervals from 6h00 – 9h00 and calculating the percentage of passengers that depart within each interval. The same methodology applied to releasing private cars and trucks. Figure 5-6 shows the profile of passengers and private cars.

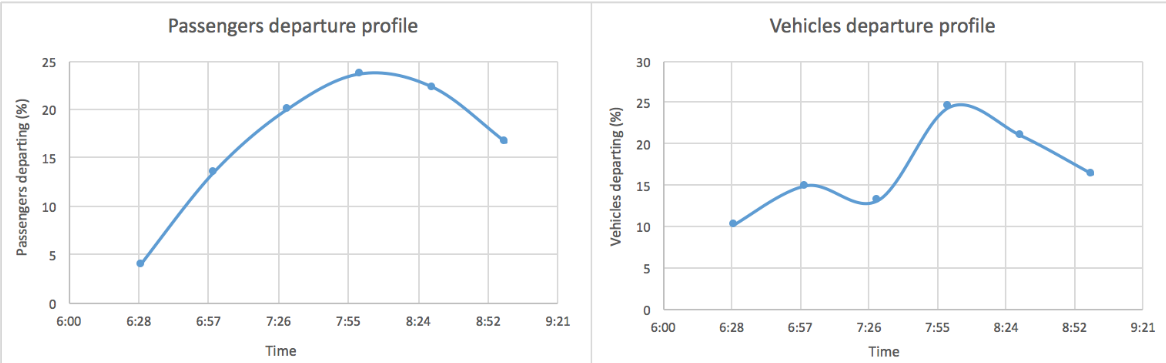

Figure 5-9: Passenger departure profile and private vehicle departure profile

5.4.4 Simulation

At the beginning of the simulation run, the network is empty. Vehicles are generated at the entry nodes of the road network and pedestrians are generated at the entry nodes of walkways so there is a build-up of passengers walking to the network to board and alight, taxis riding and making stops where there are passengers waiting, and private cars running between their origin and destination zones.

Finally, the model ensured that taxis operated like they do in reality aside from the competition characteristic of taxis, which is discussed under the limitations below. In this Commuter model, a taxi was assumed to work with no breaks throughout its trip. Taxis at the Westgate Mall dwell for about 2 minutes before departing so that passengers could board. As previously mentioned, taxis are only required to stop at stands where there were passengers waiting or where passengers wished to alight along the route. Taxis with empty seats would dwell at the stands until all passengers who could be accommodated in that taxi have entered and those wishing to alight have alighted. If a taxi was fully loaded and there were people waiting at stands, it would not stop at that stand and as a result, the waiting passengers would have to then wait for the next taxi, provided the next taxi will have empty seats.

The taxis kept moving and stopping to board and alight passengers until it got to the interchange. The passengers who were still in the taxi at the interchange alighted, and either walked through the walkways at the interchange and waited at their respective stands to board the trunk buses or train or ended their trip. The figures below show Commuter screenshot of passengers waiting at a stand, passengers boarding a taxi and passengers alighting a taxi at the interchange.

Figure 5-10: Passengers waiting at stands for a taxi from Westgate Mall

Figure 5-11: Passengers boarding a taxi

Figure 5-12: Passengers alighting the taxi at Hazeldene taxi rank

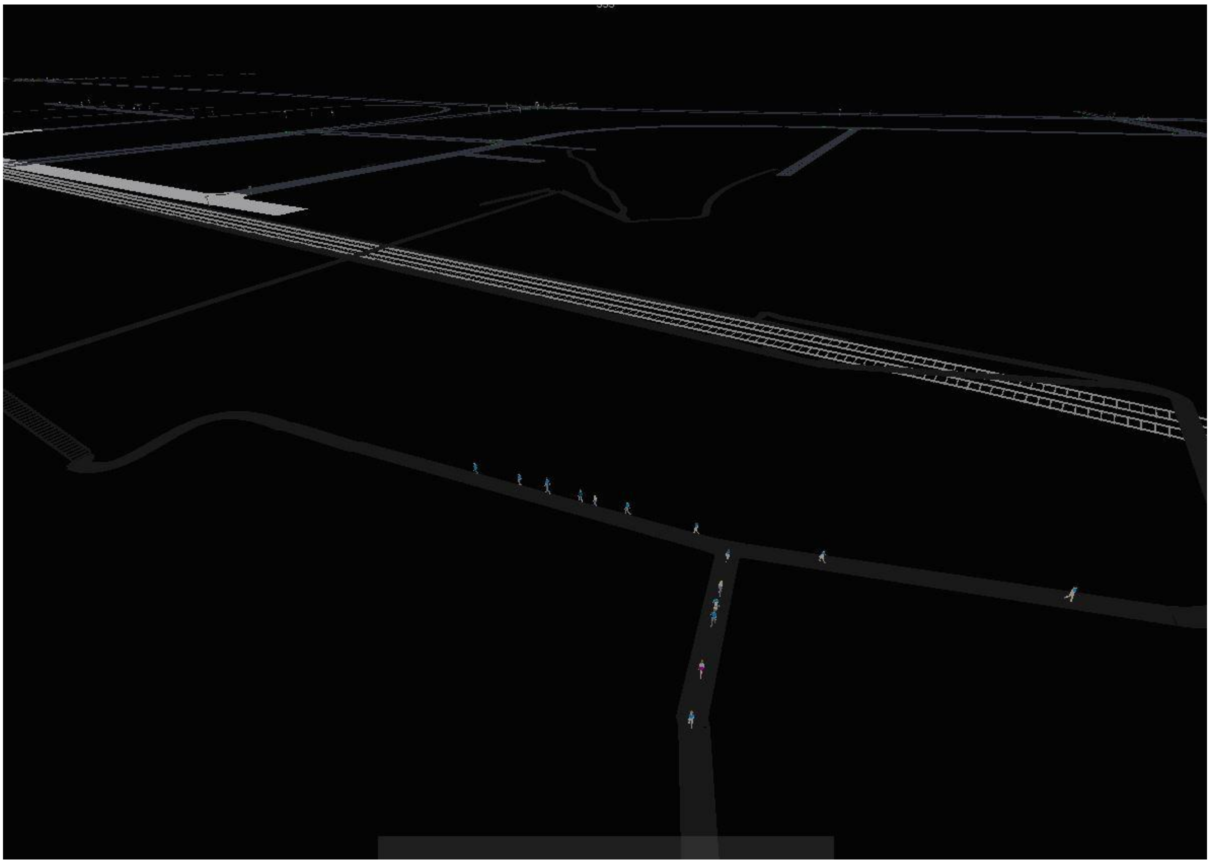

Figure 5-13: Alighting passengers walking through the interchange to their respective connecting trunk services

Figure 5-14: Passengers boarding a trunk bus to the CBD

Figure 5-15: Passengers boarding a train to the CBD

5.4.5 Randomness of passenger and vehicle flow

The trunk-feeder model was built to replicate the actual behaviour of the system. There are three ways in which the physical behaviour of this model was represented; using knowledge of relevant probability distributions, using real numbers as collected from the physical system, or assigning statistical distribution using random numbers to make the model make produce a stochastic behaviour – for example, dwelling time; the desired dwelling time would be randomly generated from an assumed normal distribution of the dwelling time, with a mean and standard deviation.

In reality, the departure behaviour of taxis is not predictable – they normally don't depart until the taxi is full. To represent a typical release of taxis from their origins, real departure times as collected from the physical system were used – that is using a typical day schedule. This method, however, is not possible when replicating their travel operations. The randomness (stochasticity) of the taxi operation during travel along the routes was achieved using the Gaussian boarding and alighting time distributions. The time required for a vehicle at a stop (dwell time) was defined in the model and the Gaussian distribution dictated the vehicle arrival at the stop, boarding and lighting, and its departure from the stop. A vehicle was assigned a mean stopping time of one minute for passengers to board and alight, and if there are no passengers waiting, the vehicle would not stop.

The representation of people's physical behaviour was achieved by using knowledge of relevant probability distributions – also called departure release profiles as depicted in Figure 5-8 above. And the same applied to private vehicles.

5.5 Simulation model audit

The following tests were conducted in order to validate and obtain a credible model:

- Model verification: It was checked that all entries such as bus and taxi timetables, OD matrices were correctly inputted. The road network was initially checked for connectivity as this would affect trip generation in the model. A few errors were identified and rectified so that the model was able to attain 100% vehicle and pedestrian trip generation. Furthermore, the model behaviour was also thoroughly verified, so that all taxis departed and used their trails to their destinations, with all passengers having boarded and alighted. The demands in the OD matrix were ensured to be equal to the total of complete and incomplete passenger trips.
- Demand calibration: Vital inputs such as passenger and private vehicle OD matrices were calibrated outside the model and input in the model. Parameters that could be calibrated in the model such as lane changing behaviour of vehicles were not considered necessary. However, vehicle mixes, phase times and vehicle counts were adjusted to reflect the data from City of Cape Town in November 2015.
- Taxi travel time validation: The taxi trip times also went through some validation. The simulation model was modelled using taxi travel time data collected as arrival and departure data collected at Hazeldene, West gate Mall and Promenade Mall. The modelled travel time was validated using trip time data extracted from the boarding and alighting survey data collected using the GPS enabled mobile phones – time recorded at the start and end of the trip. The modelled and observed were plotted to determine the model fitness (R^2) as shown in figure 5-16. The statistical measure R^2 indicated a model fit of 0.96 which means that there is a close correlation between what was modelled and observed.

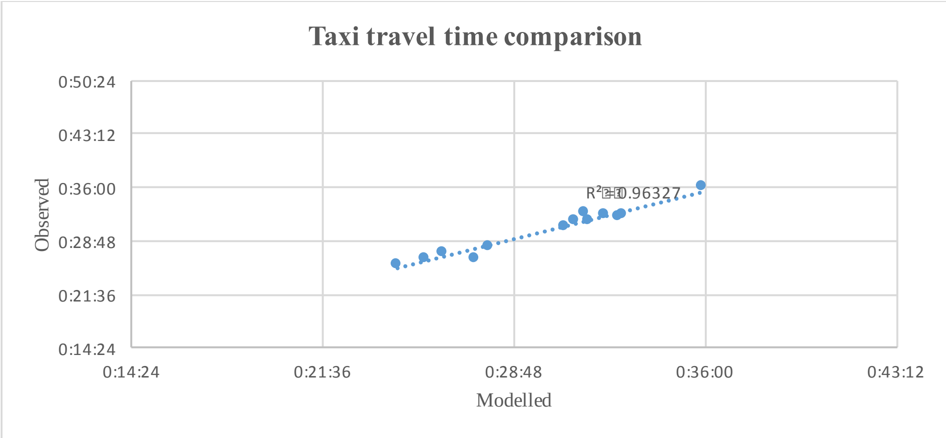

Figure 5-16: Correlation between modelled and observed taxi travel time

5.6 Limitations

The model mainly allowed validation using counts that is for vehicle and passenger counts. Passenger counts: The process of obtaining the passenger demand OD matrix was based on boarding and alighting counts. The counts could not be validated because it was time consuming and expensive to go through the process of collecting similar data and converting to OD matrix for comparison.

Commuter was chosen as the best available tool for modelling in this research. Nonetheless, the study had a few limitations in its capability to model typical stochastic taxi model. In reality passengers would typically depart from their origins and walk to the nearby network heading towards their destinations at random times. At the same time, taxis would also typically depart from their origin and pick up passengers wherever the driver saw them along an unspecified road network. However, in Commuter, a route for the taxi is defined as a public transport route; it uses trails and does not deviate from that trail (route), which means that this is not an entirely true reflection of how taxis would operate and behave. Even though this particular model satisfied the needs for this study because modelling was based on data collected along particular trails, the typical taxi model was limited by both data and Commuter capability to model the dynamic routing and competition behaviour of taxis. In order to improve this model, a function that models transport as a function of activity could be added. This would be such that an agent/passenger leaving an origin had a daily or periodic time plan and takes in the transit schedule and mode type. That way, because taxi activity and passenger activities are inter-linked, a taxi takes a route only when there was a passenger waiting. A passenger boarded a taxi taking the shortest route and the shortest time to arrive at their destination. This was also the case with vehicles whose route choice was based on where there was a passenger waiting.

6. Results and analysis

The previous chapter described the model building process. The model replicated operations of a typical trunk-feeder public transport system in Mitchells Plain in order to understand the status quo of its operations. The background of this study is that the lack of integration between trunk services and feeder services is a pressing issue, which, unless interventions are placed to improve and co-ordinate them, captive users especially will continue to suffer the consequences of this public transport system; such as increased travel time. This chapter then discusses the scenarios that were developed to explore operational improvements of the feeder services. By so doing, the research was testing the hypothesis by investigating if the scenarios tested can improve the quality of feeder services and consequently co-ordinate them to trunk services.

This section presents the output of the simulation. First, the presentation and discussion of KPIs that were used to evaluate the performance of the trunk-feeder model and then description of modelled scenarios. Thereafter, the following sections present how the scenarios performed for each of the KPIs and finally, an MCA is used to compare the performance of the scenarios for each KPI.

6.1 KPIs to evaluate the trunk-feeder model

In Chapter 2 of the literature, KPIs that could potentially assess the performance of a trunk-feeder model were presented. The output of the Commuter simulation model that fed in to those KPIs derived from the literature was considered as the KPIs to evaluate this trunk-feeder model. This section firstly shows the KPIs derived from the literature that feed into the output of Commuter, it then describes the output of Commuter (the KPIs that will evaluate this trunk-feeder model) and lastly puts a cross reference table to show how the output of Commuter feeds into the KPIs derived from the literature. The KPIs derived from the literature include:

- Capacity [space/vehicle]
- Queueing [minutes]
- Travel time [minutes]
- Transfers [minutes]

The KPIs above were selected based on variables that are fundamental to decision making and evaluation of any transport project. They mainly encompass around the concept of the value of travel time which is a critical factor in evaluating the benefits of any transportation improvements. Likewise, the output of Commuter simulation, which were used to evaluate the performance of this model also encompass around travel time. They comprised of:

- Feeder waiting time (queueing): queueing refers to waiting of passengers at stands or platforms for a taxi to board. The length of the queues is predominantly dependent on the service frequency [min].
- Transfer waiting time: this is the time passengers spent at trunk stands waiting for a trunk service when transferring from one mode of transport to another at the interchange [min].
- Transfer walking time: This is the time passengers spent walking from the drop off point by a taxi through the interchange to board a trunk service [min].
- Load factor: this represents the capacity utilization of a taxi. It is a percentage ratio average number of passengers carried by a taxi to the total capacity of the taxi.
- Waiting passengers that boarded: this is a percentage of the number of passengers that board a taxi to the total demand along a feeder route [passengers].
- Trip time: This is the time taken for taxi to move from its origin to its destination. This also includes dwelling time for passengers to board and alight as well as time in traffic [min].
- Dwelling time: This is the total time spent at stops as taxis board and alight passengers on a route [min].
- Crawling time: This is the time taxis spend waiting at traffic signals and congestion [min].

Table 6-2 depicts a summary of how the output from Commuter feeds into the KPIs

Table 6-1: Cross reference between KPIs derived from literature and output from Commuter

KPI \ Output	Feeder waiting time	Transfer waiting time	Transfer walking time	Load factor	Waiting passengers that boarded	Trip time	Dwelling time	Crawling time
Capacity				✓	✓			
Queuing	✓	✓						
Travel time						✓	✓	✓
Transferring			✓					

6.2 Modelled scenarios

The modelled scenarios described possible future developments. They were developed to explore and investigate possible improvement alternatives for trunk-feeder system. This will then allow decision making through consideration of outcomes and analysis of their implications. Each of the scenarios that were tested in the simulation model were geared towards manipulating at least one KPI that affected passengers' flows. In so doing, they explored how scenario intervention impacted the operational performance, integration and co-ordination of the feeder services to the trunk services.

A few considerations were made in this model for analysis. Firstly, in all the scenarios, passenger demand and trunk service departure times were kept constant, ceteris paribus. Secondly, two feeder routes were modelled; Promenade to Hazeldene and Westgate mall – Hazeldene but only one (the Westgate Mall- Hazeldene) feeder route was considered because it was longer, commonly used and had more data on it.

The scenarios were categorised into four groups. The four categories of scenarios including base model scenario were presented and discussed in this chapter. Some of the categories had one or more scenarios under them. The categories of scenarios are shown in Table 6-1 below;

Table 6-2: Scenarios

Category	Scenario ID	Scenario description	Purpose
Base model	Scenario 0	Base model	Reference scenario
Scheduling	Scenario 1	Taxi even headways Vs Trunk service scedules	Improve reliability
	Scenario 2	Passenger profile Vs Taxi departure profile	Match demand & Supply
	Scenario 3	Co-ordinated taxi arrivals and trunk service departure	Schedule co-ordination of transfers
Fleet size and capacity	Scenario 4	Increase fleet size of taxis	Minimize waiting time on feeder routes
	Scenario 5	Increase capacity of taxis	Increase passenger capacity
Taxi Stops	Scenario 6	Fixing taxi stops at 500m intervals on the feeder route	Minimize delays due to frequent stopping

The following section presents each of the scenarios, how they were implemented and their purpose to the study.

6.2.1 Scenario 0: Base model

The base scenario (BAU) reflects the status quo of trunk-feeder system operations based on the observed input from the study area. The output of this scenario was used as a base case and all other scenarios were compared against it to measure the level of effectiveness of other scenarios.

The distance-time graphs in Figure 6-1 and Figure 6-2 illustrate the configuration of taxis and MyCiTi buses and Metrorail. Only MyCiti and Train trunk services were considered in the scenarios. The distance between 0 and 8km shows the time that taxis departed Westgate Mall and the time that they arrived at the interchange. The gap distance around 8.4km on the vertical-axis is the walking distance for transferring passengers to connect to the trunk services. And at about 8.5km, the trunk services depart to Cape Town CBD.

Figure 6-1 and Figure 6-2 show that there is indeed no co-ordination between taxi arrivals and trunk service departures. Furthermore, at some times, it can be seen that trunk services might depart underutilized because there are no passenger arrivals from the feeder services at the interchange and at other times, there are many taxi feeder arrivals and not enough trunk service departures meaning that passengers who do not manage to board will incur a lot more waiting time at the interchange.

Something noteworthy that is expected of taxi travel behaviour is that at some point, taxis were seen to overtake each other or arrive at the same time even when they departed at different times. This was most likely because the taxi ahead of it stopped for a longer time to board or alight passengers.

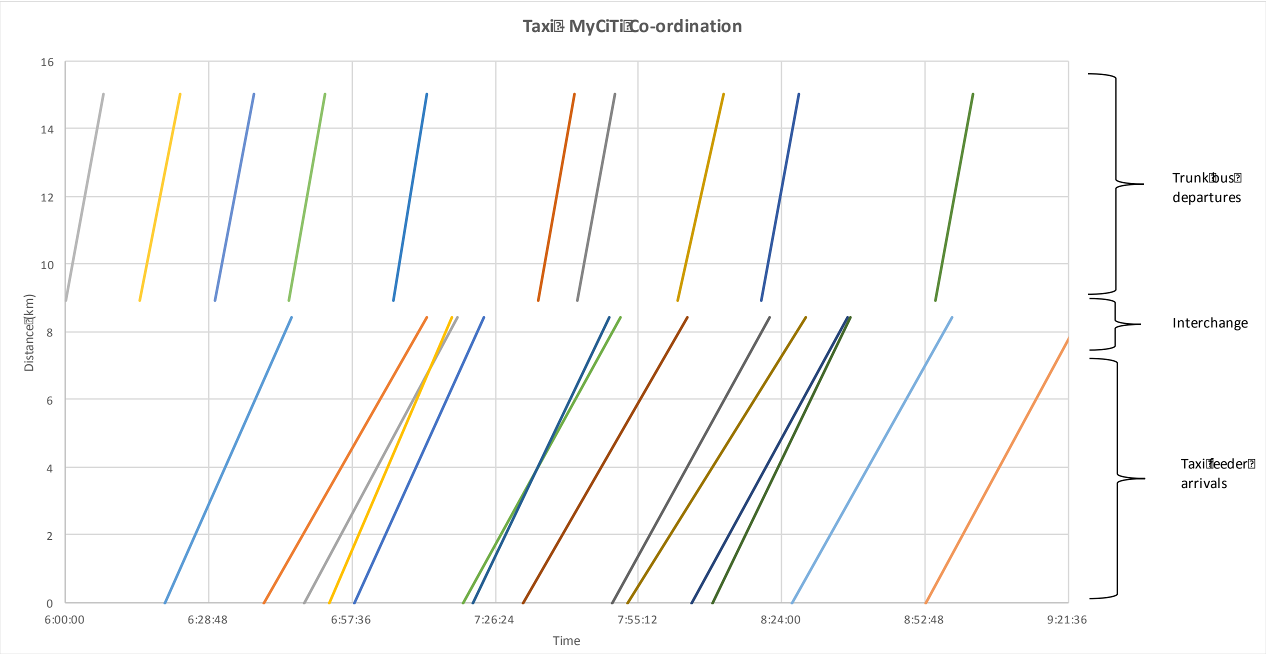

Figure 6-1: Configuration of trunk and feeder services

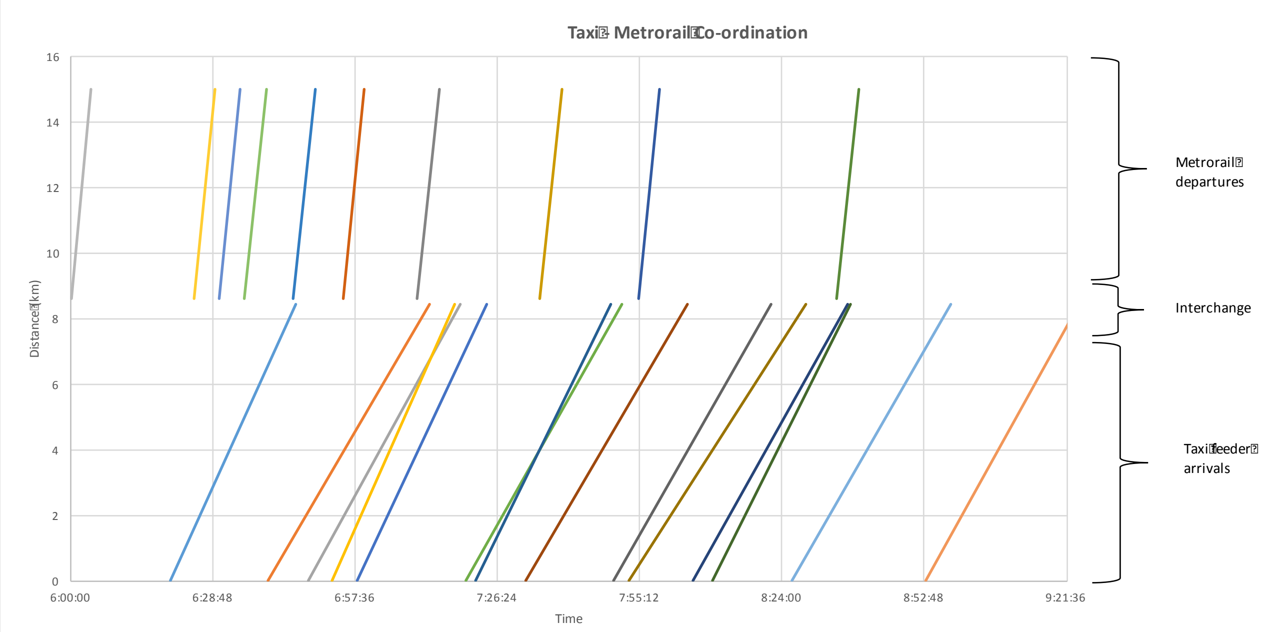

Figure 6-2: Configuration of trunk and feeder services

6.2.2 Scenario 1: For reliability

This scenario was implemented to investigate how scheduling taxi departure times affected the KPIs. It was a check of how reliability affected passengers' flows.

Taxi operational behaviour is such that a taxi drops off and picks up passengers at places convenient for them, do not have fixed routes neither do they have fixed departure or arrival times. As a result, passengers spend a lot time at stands waiting for a taxi to arrive. And if a passenger arrives at a stop to wait for a taxi, there is no guarantee of the time that the taxi would arrive. Even when it arrives, it stops several times to pick up and drop off people. This makes them unreliable (Arrive Alive South Africa, 2016). This is a problem especially when a passenger is having an intermodal trip where they are expected to connect to a scheduled bus with a fixed departure time. Due to this unreliability of taxi schedule and operations, passengers end up arriving earlier so as not to miss the taxi hence losing a lot of time in transit and this discourages ridership.

In view of this, a taxi schedule was determined by dividing the 3 hours of the modelled peak period by 14, the number of taxis departing Westgate mall to give 13 minutes uniform headway between each taxi. Therefore, taxis were departing Westgate mall at an even time interval of 13 minutes. Still, the trunk service schedule remained constant.

This scenario was implemented even though it has some limitations – It is not certain if this scenario would reflect the expected results as it would in reality. In principle, fixing schedules for vehicles influences their departure time choices – people tend to plan their departure from their origins to allow enough time to make it to the vehicle departure on the feeder route or interchange. However, this is not the case in the model. People demand is fixed in this model and their release from areas is based on the profiles, it is thus impossible to change people's behaviour in the model to respond to the new schedule. Therefore, the intended impact of this scenario might be limited.

6.2.3 Scenario 2: Match demand and supply

This scenario aimed at investigating how the relationship between demand and supply affected the KPIs, that is, the relationship between passenger arrivals at stands (demand) and taxi departures from Westgate Mall (supply).

To implement this scenario the number of passengers arriving at stands were summed up within 30 minute intervals of the peak period. A percentage of the number of passengers arriving at stands were calculated for each interval. The same procedure applied to the taxis. From this, a profile was created. A profile is a plot of percentage against time; it describes the time distribution release of percentages for passengers arriving at stands and taxi departures from Westgate Mall. Profiles of passengers arriving and taxis departing were generated and these were compared in Figure 6-3 below.

From the figure, it can be seen that there is no co-ordination between the taxi profile and passenger profile most especially at the peak demand around 7:30am. Thus this means that there was a mismatch between the supply of taxis expected to serve the existing demand of passengers; there was no co-ordination between the times when taxis arrived at stands to pick passengers and the times when passengers arrive at stands to board.

To address this, a new taxi schedule was created by manipulating headways such that the time distribution of taxi supply and passenger arrivals at stands were in co-ordination. From the new schedule, a new taxi profile was generated. This scenario had a significant impact on the taxi capacity utilization.

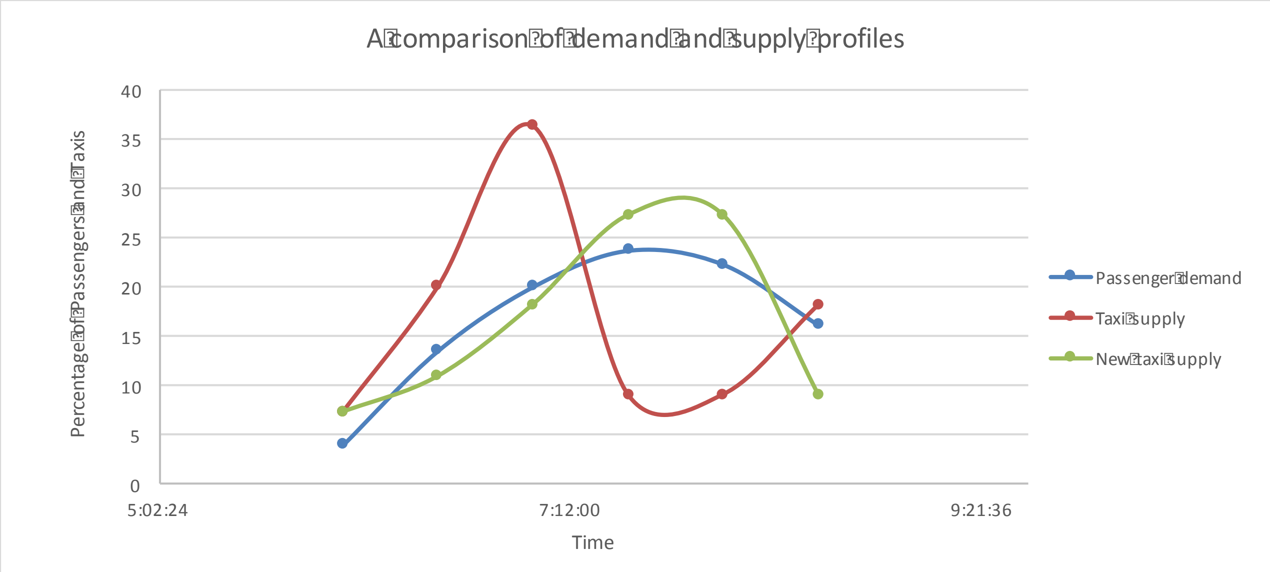

Figure 6-3: Comparison between demand and supply profiles

6.2.4 Scenario 3: Co-ordinate transfers at the interchange

Integrating and co-ordinating feeder and trunk services was a major component of the research. That is to co-ordinate taxis that are unscheduled and have dynamic departure and arrival times, and scheduled trunk services that had fixed departure times. The purpose of this scenario was to investigate the effect of operational co-ordination and integration of timetables between trunk and feeder system on the KPIs.

In this scenario, operations for passengers boarding and alighting along the feeder routes remained unchanged, but did change for the passengers that boarded and were transferring at the interchange.

This would in turn, ensure timed transfers whereby taxi arrivals at the interchange are co-ordinated to bus departures from the interchange

To investigate this objective, a new timetable for taxi was developed such that taxis are dispatched in co-ordination with the trunk service schedule. This would in turn, ensure timed transfers whereby taxi arrivals at the interchange are co-ordinated to bus departures from the interchange thereby reducing the lengths of wait from the origin to the final destination of a strip. First, the average trip time from Westgate Mall to Hazeldene (the interchange) and the average walking time through the interchange were added to obtain the passenger's total time from Westgate Mall to the trunk-bus departure point. That total trip time was subtracted from the trunk-bus departure time in order to obtain the new taxi departure times from Westgate Mall. This was the time used to generate a new taxi schedule that co-ordinated with the trunk-bus departures. This new taxi schedule allowed for a passenger to board from Westgate mall, travel to the interchange, and walk through the interchange and have minimum waiting time to board a trunk-bus.

The new configurations developed for Taxi-MyCiti and Taxi-Metrorail are shown in Figure 6-4 and Figure 6-5 respectively. Even though it was fairly simple process to develop those trunk-feeder configurations, the model did not behave exactly as expected. This is because in the model an average taxi trip time was used to develop the new schedule. It was assumed that all the taxis take that average trip time yet there is a standard deviation of ±5 minutes from the average trip time. The negative deviation was observed between 6h00 and 7h00 when the traffic was not intense and the positive deviation was observed between 7h00 and 8h00 when the traffic was peaking. This deviation results from the dynamic operations of taxis such as uncertainties in boarding and alighting of passengers en route. As such, it is almost impossible to have no waiting at the transfer despite the co-ordination. However, a few minutes waiting time (±5 minutes) is acceptable by most users.

It is also noteworthy that because co-ordination was made using the number of buses that departed, the new taxi schedule comprised of an equal number of taxis; the number of taxis was equal to the number of buses. Therefore the new schedule comprised a fewer number of taxis than in other scenarios.

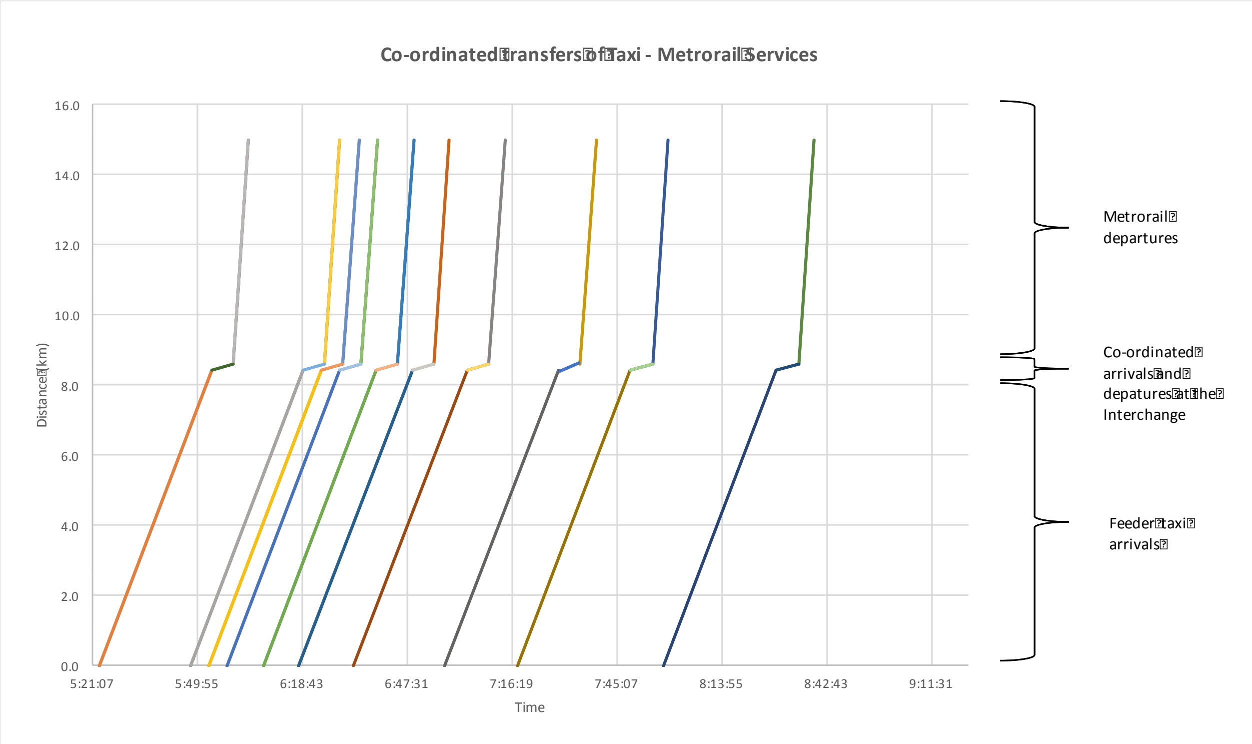

Figure 6-4: Configuration of co-ordinated trunk and feeder services for MyCiTi

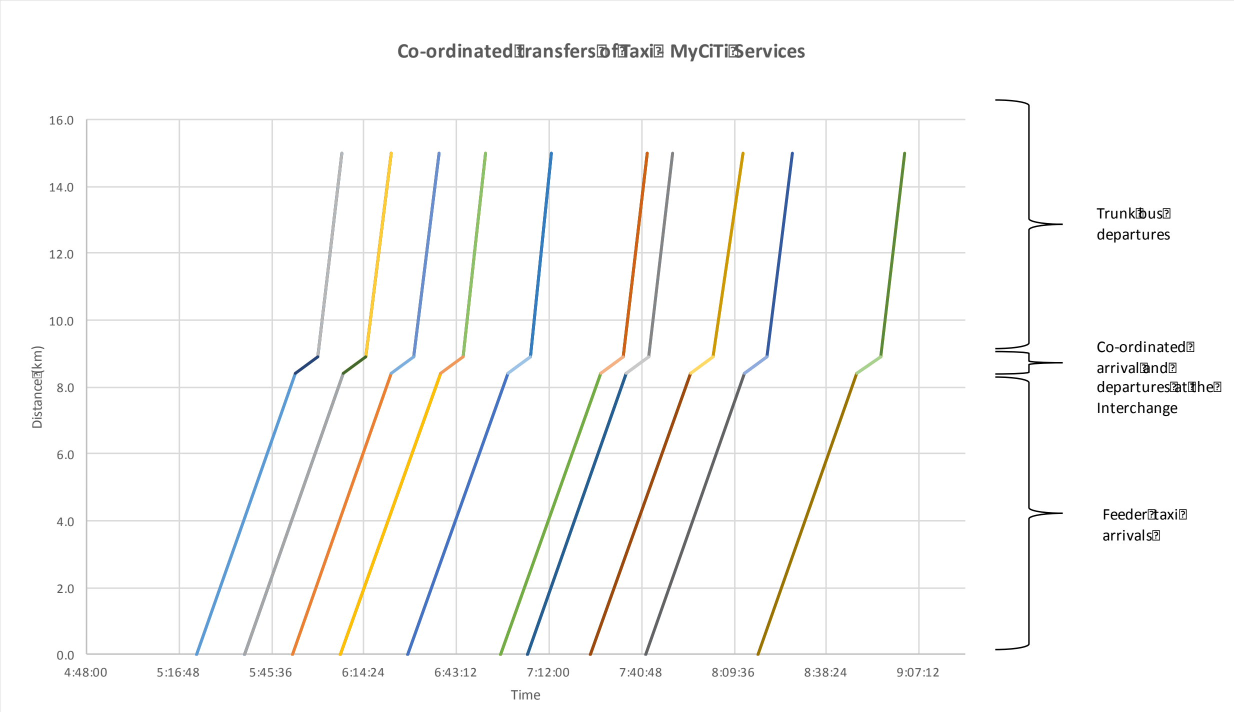

Figure 6-5: Configuration of co-ordinated trunk and feeder services for Metrorail

6.2.5 Scenario 4: Increase fleet size

Increasing fleet size improves efficiency in the public transport systems most especially for passengers. Some of the notable motivations for increasing fleet size of taxis were: to provide a regular and dependable service for passengers, to minimise waiting time for passengers who wished to board, and to increase the number of people carried along a route. Most importantly, this operational strategy reduced overall travel time whilst increasing the service frequency.

In order to determine the size of a new fleet of taxis, the passenger demand was compared with the existing taxi supply. There were 547 passengers in the OD matrix wishing to board and the supply of taxis in the BAU situation was 14 taxis with a capacity of 15 each. If all the taxis were used to full capacity (which was not always the case because the load factor was never 100%), approximately 210 passengers could board on the 14 taxis. Sometimes even more than 210 passengers because one seat could be used more than once along a route. This was the case when some passengers alighted along the route at their final destination.

Based on the above argument, it was suggested that an increase to a fleet size of 25 taxis would produce the expected improvements on the feeder operations.

6.2.6 Scenario 5: Increasing taxi capacity

The capacity of a taxi determines the ability of the public transport's system to cope with passenger demand on the route. The motivation for this scenario was that increasing the capacity of taxis accentuated; increases the number of passengers carried, reduces waiting time and reduces the overall travel time

In this scenario, the departure schedule of taxis from Westgate Mall remained unchanged as in the BAU. Changes were made only to the capacity (number of seats in a taxi). Several simulation runs were made to obtain an optimal and yet economical size of a taxi. The simulation suggested that a 25 seater taxi could potentially increase the load factor and increase the total number of people carried along the route by approximately 25%. Increasing the number of people carried by 25% means that of the 547 people wishing to board, 350 people could board a taxi; that is using 14 taxis each with a capacity of 25 seats. And since a seat can be used more than once along the route, the passengers wishing to board can potentially increase.

6.2.7 Scenario 6: Designating stops at 500m intervals

The behaviour of the taxi operations along the feeder routes is such that a taxi stops at every stand on the road where a passenger is waiting. For such a local neighbourhood, the Comprehensive Integrated Transport Plan (CITP) drafted by the City of Cape Town suggested that the spacing between stops can be at most 500m apart. In order to test this scenario, radii of 500m were drawn from the start to the end of the feeder route segment. All demand that fell within a particular radius was aggregated. The aggregated changes were then made in the demand O-D matrix in Commuter. Passengers from the aggregated demand would all walk to one stand within that radius. The final picture of the simulation was such that passengers could only walk and wait at stands which were 500m apart. That means that taxis were also limited to stop at 500m intervals.

The simulation was run again to determine the effect of this on the KPIs. Significant improvements were seen mostly in the overall trip time (due to the reduction in the number of times a taxi stopped along a route).

This scenario however may not be desirable for most passengers. The taxi industry still provides transport services for about 65% of commuters in South Africa. One of the reasons most passengers still choose to use taxis over the scheduled buses is in the manoeuvrable behaviour of taxis. Taxis allow flexible boarding and alighting and this provides convenience for passengers. For that reason, some may not be willing to walk 500m to wait for a taxi thus constraining passenger convenience. On a positive note, limiting taxi stops at 500m intervals improves operating costs for taxi owners by reducing fuel consumption of taxis.

6.3 Scenario comparison per KPI

The results of the simulation are presented in this section. As previously stated, the research sought to understand how the operations and configurations of a feeder public transport network affected trunk networks using KPIs. To analyse the results, the performance of the scenarios was compared for each KPI obtained from the output of Commuter.

6.3.1 Load factor variation

Load factor is a reflection of taxi capacity utilisation. When developing the scenarios, matching demand and supply was the operational strategy to improve load factor in taxis, that is, by matching the passenger departures with taxi departures on the Westgate Mall route. Figure 6-6 depicts how the scenarios performed in terms of load factor variation.

The current situation in the BAU appears to be performing well with approximately 88% capacity utilisation. That means that there were always approximately 13 passengers in a 15 seater taxi in the AM peak period.

Scenario 2 which purposed to match passenger demand and taxi supply by matching their demand and supply profiles had the highest percentage of load factor. The configurations of scenario 3 were not designed to have an impact on the feeder route but rather at the transfer only. Scenario 1, although designed to have an impact on the feeder route to provide reliability, as explained before, no significant improvements would be expected to due to the nature of the model.

Another scenario in close competition with scenario 2 is scenario 6. This indicated that clustering a denser number of people to wait at 500m stops intervals as opposed to a sparse distribution of people waiting at every stop closest to their actual origin increases the load factor in the taxis. The sparse distribution exposes people to a chance of missing the taxis compared to when a taxi driver knows designated stops and will always look out for if there are people waiting to board.

On the other hand, increasing the number of taxis in scenario 4 performed least. This was quite expected. Its primary aim was to increase the number of passengers carried on the entire route and not necessarily to improve capacity utilisation of taxis. In the category of fleet size and capacity, increasing vehicle capacity (Scenario 5) emerges as a better option than to increase fleet size.

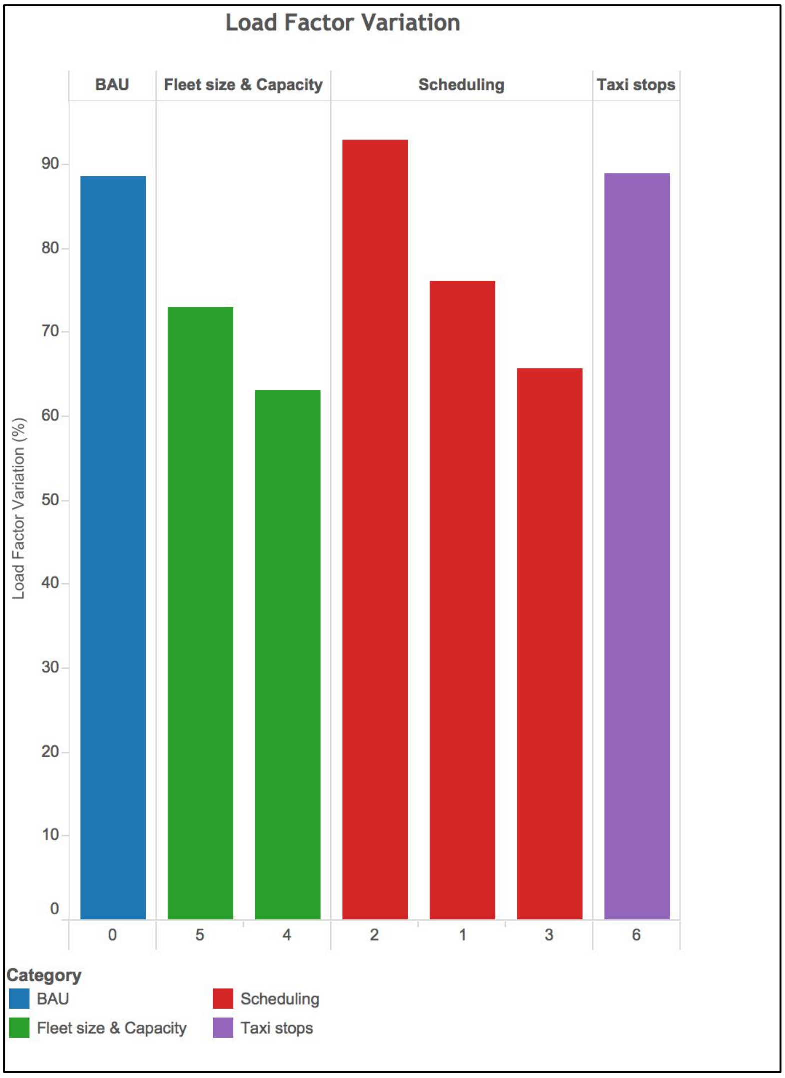

Figure 6-6: Load factor variation

6.3.2 Number of passengers boarded on a route

The category of Fleet and Capacity (scenario 4 and scenario 5) was the operational strategy to increase the number of people served by the taxis on the feeder route. The results of the simulation showed that in this category, increasing the taxi capacity from a 15-seater to a 25-seater taxi served more people than increasing the fleet size from 14 to 25 taxis. Scenario 5 beats scenario 4 by approximately a 20% increase in the number of people served. Comparing these two scenarios in the same category, each one of them has its advantages regardless of how they performed in this KPI. Increasing the fleet size means that there will be:

- Reduced headways,
- More frequent service,
- Reduced overall trip time,

- Reduced waiting time, and
- Improved ridership in the long term.

Nonetheless, this is a more expensive option. On the other hand, having fewer taxis of higher capacity means a lower cost of operation and serving the highest number of people on the route.

The category of "taxi stops" is in close competition with the category of "scheduling" as was the case in the "load factor variation" KPI above. Both of these categories were not designed to address this KPI, thus no significant improvements are expected. Overall, it can be observed that scenario 3 performed worst. This is also due to the fact that fewer taxis were used for that scenario. Only taxis that were used to co-ordinate to trunk services were input.

In conclusion, scenario 5 was the best scenario to increase the number of people that can be served on a route. Figure 6-7 shows how the scenarios performed with regards to accommodating the number of people on the route.

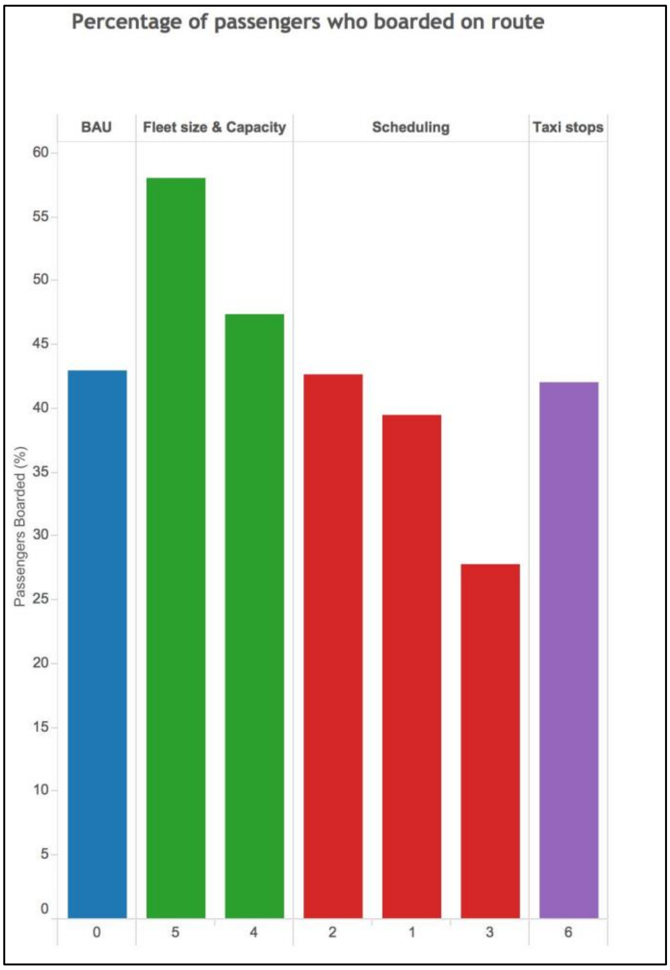

Figure 6-7: Percentage number of passengers boarded

6.3.3 Feeder waiting time

Figure 6-8 shows how all the scenarios performed in accordance with trip time along the feeder route. As described before, this is the time a passenger spends waiting for a taxi on Westgate mall route. A general observation is that all the scenarios implemented offer a substantial improvement over the BAU; that is they had a lower waiting time than the BAU scenario.

From figure 6-8 below, it can be seen that scenario 4 has the least waiting time. Following from the discussion above in the KPI to increase the number of passengers carried on a feeder route, there is a need to minimise waiting time by increasing the fleet size. So far, scenario 4 has benefits of increasing the number of passengers carried on a route and has the least waiting time. These are some of the imperative features of a transport system that passengers would appreciate. Still, comparing scenario 4 and 5, the results of the simulation points out some of the shortcomings of scenario 5. As much as scenario 5 produces a higher load factor and higher number of passengers carried on the route, passengers waiting time is a drawback to this scenario.

Another main finding is that scenarios whose purpose is to improve reliability and to match demand and supply have the second least waiting time. As discussed in the literature review section, reliability affects the amount of time passengers spend waiting for a taxi. To match demand and supply, the taxi capacity and passengers need to be the same in so as to minimise waiting time. On the other hand, scenario 3 whose purpose is to co-ordinate the trunks and feeder services has one of the highest waiting times. In order to get an efficient trunk-feeder system, it is vital that passengers experience minimum waiting time so that they minimise their overall trip time for commuting.

Scenario 6 appeared to be in close competition with the worst performing KPIs of the “scheduling” and “Fleet size & Capacity” categories. This is also because passengers spend more time boarding since there are many people boarding at a stop compared to other scenarios where the passengers are sparsely distributed along a route. This is under the assumption that time spent to board is counted as part of waiting time.

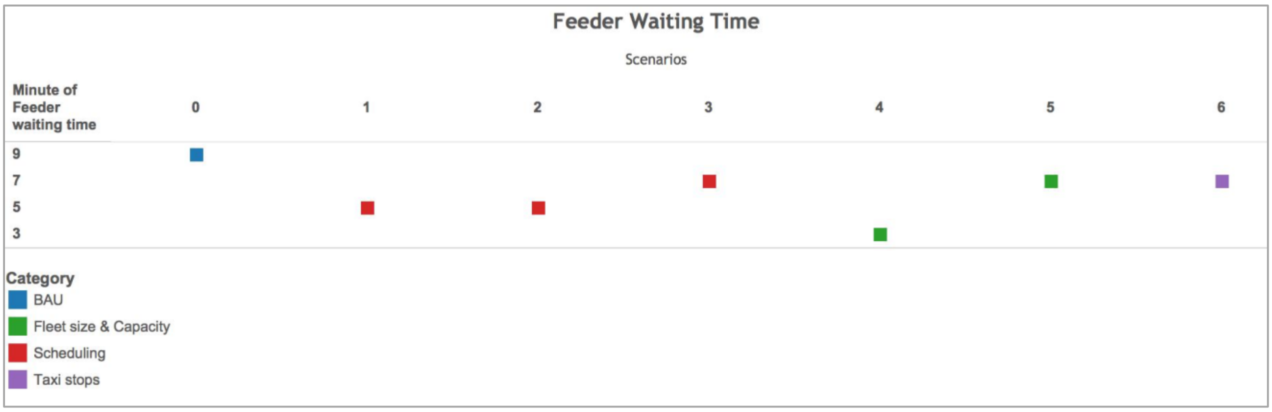

Figure 6-8: Passenger average waiting time on feeder route

6.3.4 Trunk waiting time (transferring time)

Transferring at the interchange involved passengers alighting a taxi, walking through the walkways to a stand where they wait for a trunk bus. Connecting or transferring time is the sum of walking time and waiting time. The time taken to walk through the walkways is constant whereas the time spent waiting for a bus was liable to change based on the passengers' arrival times and bus departure times.

This KPI was mainly aimed at investigating how the various taxi configurations and operations represented as scenarios affected the transfer time. Scenario 3, which was purposed to minimise the transferring time emerged with the least waiting time at the interchange. This is because taxis arrivals were co-ordinated with MyCiti departures to ensure minimum connecting time.

All other scenarios were not purposed to minimise transferring time at the interchange. Their operational strategies only aimed at improving the feeder network operations such as improving load factor, minimising waiting time and increasing the number of passenger carried. All these strategies contribute to better operational performance on the feeder network but there is no guarantee of them improving the overall trip time because they were not designed to do so. One strategy that would utilise the other scenarios would, for example, be simulating co-ordinated configurations in scenario 3 with higher capacity taxis and in scenario 5. This would produce better results in terms of increase in the number of passengers carried, high load factor, and minimum transfer time.

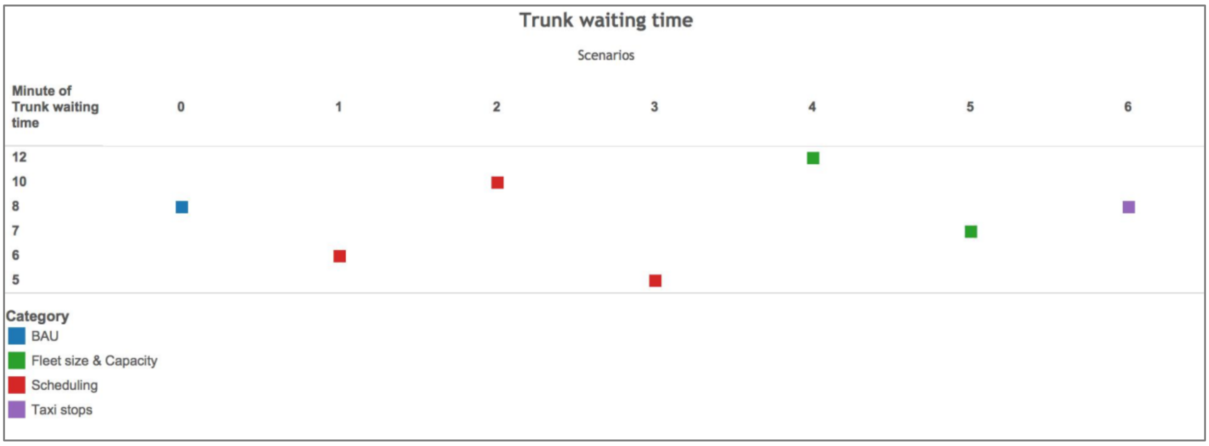

Figure 6-9: Average time spent transferring and the interchange

6.3.5 Overall trip time

The overall trip time is the passenger's in-vehicle time which composed of; cruising time (when a taxi is moving without any interruption and normally at a speed higher than 8km/hr), dwelling time and crawling time. The components' effect on the overall trip time is discussed in the subsequent KPIs. Figure 6-10 shows how all the scenarios performed in terms of the overall trip time from Westgate Mall to the Hazeldene interchange. Minimum travel time is one of the most desirable features by passengers when deciding on a trip.

Of the scenarios simulated in mixed traffic, scenario 3 emerged with the least overall trip time followed by scenario 1. Scenario 3, having the least travel time along the feeder route and the least transfer time, is possibly the best scenario for the whole trunk-feeder system in terms of travel time. On the other hand, scenario 2 which is in the same category had the least performance. This might be attributed to the taxi's multiple stops to board and alight passengers.

Scenario 6 comes out with the second least trip time. This is also attributed to the fact that putting taxi stops at 500m intervals reduces the number of times a taxi stops to board and alight passengers leading to a reduction in the overall trip time.

Scenario 4 and 5 are seen to have trip times that are very close. The trip time is dependent on crawling time and dwelling time. Their effect on this category is discussed in the subsequent KPIs.

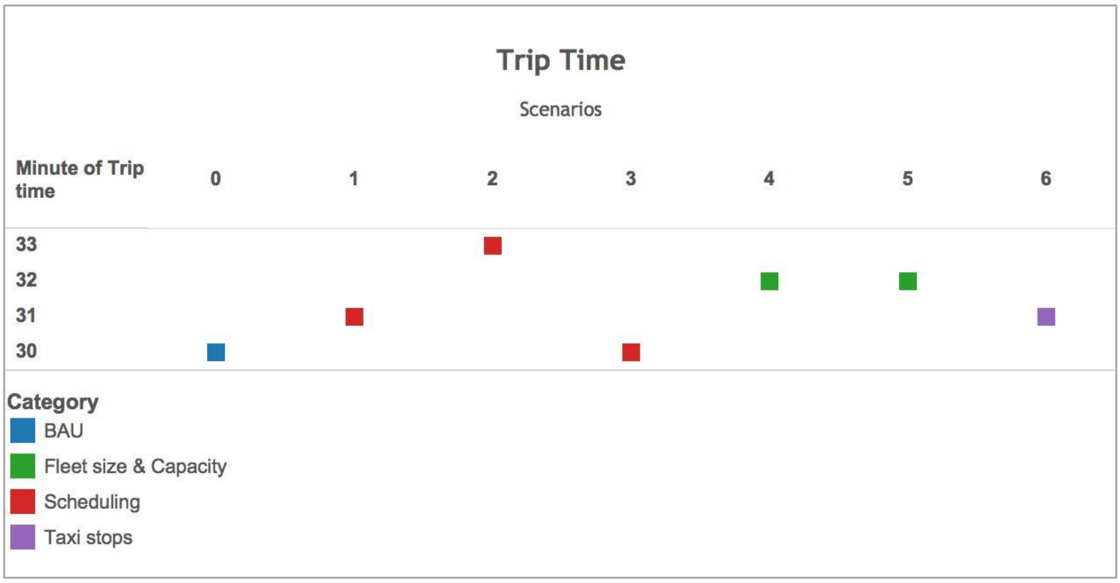

Figure 6-10: Over all trip time

6.3.6 Dwelling time

The dwelling time is mainly affected by the number of passengers boarding and alighting at a stop. A general observation is that dwelling times at stops ranged between 1 and 3 minutes with most of the scenarios dwelling for +/- 1 minutes (6% of the total trip time) except for scenario 5.

In the scheduling category, all the three scenarios' dwelling time is minimal. Minimal dwelling time also reduces the overall trip time. Since the dwelling time is approximately the same, it had no contribution to the variation in the overall trip time as illustrated in Figure 6-10 above.

In the category of fleet size and capacity, scenario 4 also emerged with minimal dwelling time similar to that in the scheduling category. Scenario 5 with high capacity taxis has the highest dwelling time. Running high capacity taxis means that they will dwell longer because they have to allow more people to board and alight. This is also one of the reasons for the high overall trip time as observed in Figure 6-10 above. Figure 6-11 below shows how dwelling time varies per scenario.

Figure 6-11: Average dwelling time at stops

6.3.7 Crawling time

A general observation in the comparative plot below is that all the categories of the scenarios have a higher crawling time than the BAU scenario. Averagely, the crawling time is approximately 14 minutes. This is approximately 46% of the total trip time. In summary, for an average trip, a taxi crawls for 46% of the time, 6% as dwelling time and 48% as cruising time.

Figure 6-12: Average crawling time

6.4 Summary of the KPIs and scenarios

A radar plot was used to present a comparative summary of the performance of the scenarios for each KPI. Closer to the centre of the radar diagram the percentage decreases to 0% while away from the centre, the percentage increases. This means that all time elements of the KPIs;

feeder waiting time, trunk waiting time, trip time, crawling and dwelling times perform better when they are lowest while, the other elements; speed, load factors and the percentage number of passengers boarded are more perform better when they are highest.

The simulation results of this study confirmed that each of the scenarios performed considerably well for the KPIs they were intended to improve. Notable in the plot is that scenario 3 offers passengers the best alternative for transferring because of the co-ordination of taxi arrivals and bus departures. Scenario 2 offers the best alternative for vehicle utilization by matching the demand and supply, Scenario 5 offers the best alternative for increasing the highest number of passengers carried on a route by increasing taxi capacity, scenario 6 offers the least dwelling time as a result of limited stops made by taxis. It also significantly and surprisingly emerges with the least feeder waiting time. Furthermore, as expected, increasing the fleet size of taxis emerges as the best alternative to reduce passenger waiting time. The more frequent the services, the least the waiting time. The trip time in all the scenarios was about the same and they all had more crawling time compared to the baseline scenario.

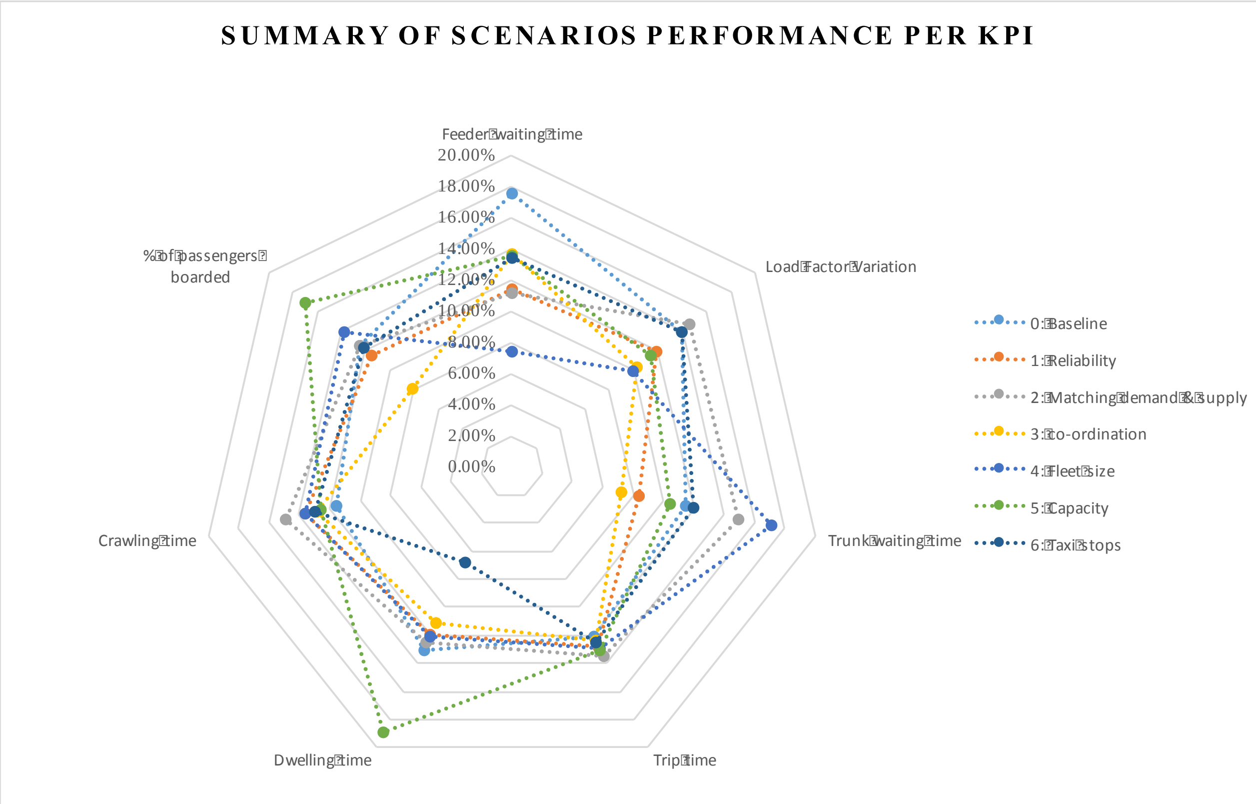

Figure 6-13: Summary of how scenarios performed per KPI

6.5 Analysis of simulation results

The summary illustrated in Figure 6-13 above alone cannot assist to identify the best alternative. As such, an analysis technique was employed to aid this decision making on this public transport trunk-feeder model. From the output of the simulation of the trunk-feeder model, evaluation criteria (KPI) and alternatives (Scenarios) were obtained for this analysis. Multi-Criteria Analysis (MCA) evaluation, was used for this assessment because of its ability to compare diverse ranges of information; for this case in particular, it is able to provide an analysis of various categories of scenarios which were implemented from different operational design approaches. It also takes in to account social, economic and environmental aspects in its evaluation and this makes the technique attractive for stakeholders. Using the MCA Score card method, the trunk-feeder public transport system was evaluated to determine how each of the scenarios ranked against each other. The process through the MCA is detailed below.

6.5.1 Performance Matrix

A performance matrix is the table that represents the performance of each scenario against a KPI criteria. This performance matrix was developed from the discussion of the KPIs (criteria) and the scenarios (alternatives).

Figure 6-14: Representation of performance matrix of the scenarios

Criteria	Units	Base	Scheduling			Fleet size & Capacity		Taxi stops
		Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Feeder waiting time	Minutes	0:09:13	0:05:59	0:05:52	0:07:08	0:03:51	0:07:06	0:07:01
Load Factor Variation	Percentage	88.6	76.1	93	65.8	63.2	73	89
Trunk waiting time	Minutes	0:08:12	0:06:03	0:10:43	0:05:13	0:12:18	0:07:32	0:08:38
Trip time	Minutes	0:30:04	0:31:36	0:33:29	0:30:47	0:32:10	0:32:29	0:31:07
Dwelling tiime	Minutes	0:02:04	0:01:54	0:01:59	0:01:46	0:01:55	0:03:00	0:01:05
Crawling time	Minutes	0:12:59	0:15:20	0:16:50	0:14:31	0:15:21	0:14:15	0:14:43
% of passengers boarded	Percentage	43.00	39.50	42.60	27.80	47.40	58.00	42.00

6.5.2 Scoring and weighting

Scoring and weighting is important to point out the significance of each criterion to stakeholders in evaluating the scenarios. Today, communities demand transparent and effective processes that enable community involvement in decision making. The community involved, normally known as stakeholders are anyone who can be affected or may affect research outcomes. Stakeholders in this study consisted of representatives from the government or policy makers, taxi rank managers and passengers using the transport services. The key issue of these stakeholders is to identify aspects of the output of this research that are likely to either negatively or positively affect them. They are indicated in table 6-3 below.

These impacts on stakeholders together with the scenario performance on KPIs were used as a basis for formulation of judgement to determine and give a score for each criterion. The score represents a summary judgement of impact of the criterion on the scenario and it was numerically expressed on a scale of 0 to 10. The weight of each criterion is then determined as the fraction of the score given to a criterion to the total score of all criteria. For example; the weight of trip time is obtained from dividing 9 by 51 to obtain a weight of 0.176. The scoring and weighting is shown in Table 6-3.

Table 6-3: Scenario impacts on stake holders

Categories	KPI, Scenarios, Affected groups				
	Categories	Impact	Passengers	Taxi rank operators	Policy Makers (Government)
Scheduling	Scenario 1	Positive	Reliability of services, Convinience	More passengers because of reliable services	Improved passenger ridership
		Negative			
	Scenario 2	Positive	Travel time saving	Vehicle utilisation	Improved passenger ridership
		Negative			
	Scenario 3	Positive	Transfering time saving		Induce travel using public transport
		Negative			
Fleet size	Scenario 4	Positive	Travel time saving		Induce travel using public transport
		Negative		Vehicle costs, Increased operating costs in fuel consumption	Vehicle air pollution
	Scenario 5	Positive	Travel time saving, Increase seating capacity	Increase bus operator productivity	Induce travel using public transport, improves ridership in the long run
		Negative		New vehicle costs, Operating costs for high capcity vehicles	
Taxi stop	Scenario 6	Positive	Travel time saving	Reduced operating costs because taxis don't over stop and operators can make more round trips in a time period	
		Negative	Passenger travel inconvinience		

Table 6-4: Scoring and determination of the weights for the criteria

Criteria	Units	Score	Weight
Feeder waiting time	Minutes	8	0.157
Load Factor Variation	Percentage	7	0.137
Trunk waiting time	Minutes	8	0.157
Trip time	Minutes	9	0.176
Dwelling tiime	Minutes	6	0.118
Crawling time	Minutes	6	0.118
% of passengers boarded	Percentage	7	0.137
		51	1.000

6.5.3 Standardising the criteria

In this step of the MCA, the performance matrix is standardized. It gives a uniform measure of all criteria such that it is comparable to each other. To determine a uniform measure, the scenarios are normalized by dividing the scenario with the highest score throughout all the scenarios. For example, taking the trip time criterion, 33:29 minutes is the highest score therefore those minutes will be divided throughout the scores of all scenarios. For the Scenario 2, 33:29 is divided by itself to give 1.

Furthermore, a criterion can be either positive or negative depending on whether it is a constraint or a benefit. For example, a criterion such as load factor is considered to be a benefit because it is desirable for public transport. Hence the positive sign while a criterion such as dwelling time becomes a constraint because it has negative impacts on a passenger's trip. Table 6-5 shows the standardized criteria.

Table 6-5: Standardized criteria

Criteria	Units	BAU	Scheduling			Fleet size & Capacity		Taxi stops
		Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Feeder waiting time	Minutes	-1	-0.649	-0.637	-0.774	-0.418	-0.770	-0.761
Load Factor Variation	Percentage	0.953	0.818	1.000	0.708	0.680	0.785	0.957
Trunk waiting time	Minutes	-0.667	-0.492	-0.871	-0.424	-1.000	-0.612	-0.702
Trip time	Minutes	-0.898	-0.944	-1.000	-0.919	-0.961	-0.970	-0.929
Dwelling tiime	Minutes	-0.771	-0.911	-1.000	-0.862	-0.912	-0.847	-0.874
Crawling time	Minutes	-0.771	-0.911	-1.000	-0.862	-0.912	-0.847	-0.874
% of passengers boarded	Percentage	0.741	0.681	0.734	0.479	0.817	1.000	0.724

6.5.4 Evaluation of alternatives using weighted sum method

After all the criteria have been standardized, the scenarios can now be compared. The weighted sum method was applied to rank the alternatives. In order to obtain the overall score for each alternative, the standardized value for each alternative is multiplied by the weight. Finally, the sum of all criteria for each alternative is summed up. Table 6-6 shows the results from the weighted sum method.

Table 6-6: Ranking of the scenarios using weighted sum method

Criteria	Units	BAU	Scheduling			Fleet size & Capacity		Taxi stops
		Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Feeder waiting time	Minutes	-0.157	-0.102	-0.100	-0.121	-0.066	-0.121	-0.119
Load Factor Variation	Percentage	0.131	0.112	0.137	0.097	0.093	0.108	0.131
Trunk waiting time	Minutes	-0.105	-0.077	-0.137	-0.067	-0.157	-0.096	-0.110
Trip time	Minutes	-0.158	-0.167	-0.176	-0.162	-0.170	-0.171	-0.164
Dwelling tiime	Minutes	-0.091	-0.107	-0.118	-0.101	-0.107	-0.100	-0.103
Crawling time	Minutes	-0.091	-0.107	-0.118	-0.101	-0.107	-0.100	-0.103
% of passengers boarded	Percentage	0.102	0.093	0.101	0.066	0.112	0.137	0.099
Total Weighted Score		**-0.369**	**-0.354**	**-0.410**	**-0.390**	**-0.401**	**-0.342**	**-0.368**

According to the results obtained in Table 6-6, the scenario 5 received the highest score of -0.342. Furthermore, from the visual interpretation of the scenarios, all the scenarios have a negative overall score. This means that all the scenarios have constraints overriding the benefits. A negative score is undesirable for any project but the lesser negative the score the higher the scenario ranks. Figure 6-15 shows a graphical comparison of the results from Table 6-6 above.

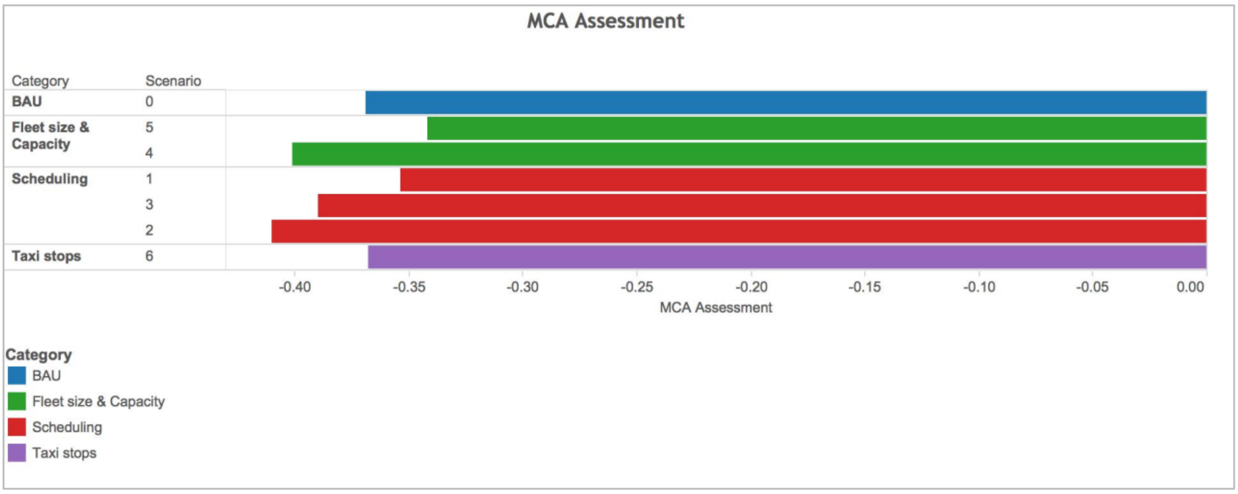

Figure 6-15: Comparative multi-criteria analysis of study scenarios

In Figure 6-15 above, output from the MCA, the impact of scenarios on stakeholders and the summary depicted in the radar plot were used to explain the performance of the output of the simulation model. The explanation will motivate and determine the best performing scenario for each category. But categories will not be compared because they were addressing different improvement aspects of the simulation model.

A notable outcome is that all the results of the MCA have negative values. As indicated before, time dimensions are constraints in travel and since most of the KPI had time dimensions, the aggregated score is bound to be negative.

In the Category of “fleet size and capacity” scenario 5 has a higher score than scenario 4 and is also a better option than the BAU scenario. Comparing the two, scenario 5’s positively significant output in the radar plot was the percentage number of people who boarded and higher load factor (both positives – benefits to travel). On the other hand, scenario 4 beats scenario 5 on the dwelling time and feeder waiting time KPIs but has a higher trunk waiting time which also has a significantly high score in the MCA. When scoring the KPIs that affect the two scenarios in the MCA, it turned out that scenario 4 scored higher mostly on time dimensions and this increases the negative values. This thus means that scenario 5 offers a more substantial operational improvement and therefore performs better than scenario 4. Also weighing these in the context of impacts on stake holders, the cost of operating 25 taxis with the initial capacity exceeds the cost of running 14 taxis of a 25 seat capacity. Scenario 5 is also option that taxi rank managers and the government are more likely to adopt, especially since it would mean hiring fewer taxi drivers, carrying more passengers and reducing the number of vehicles on the roads. Even though, running very many taxis (scenario 4) reduces waiting time for passengers, their back and forth manoeuvring behaviour increases the distraction of the flow of traffic.

The discussions of the “scheduling” category was quite different. It is unlike in the “fleet size and capacity” category where the different scenario approaches tested similar improvement aspects. The results of the “scheduling” category indicate that scenario 1 offers better configuration improvements than the other two and the BAU scenario. Despite that, it is still quite challenging to compare the 3 scenarios together. All the scenarios in the scheduling category offer positive impacts to the stakeholders. Moreover, the KPIs tested for these scenarios performed best for their intended purposes. It was thus suggested to incorporate all these improvements in the recommended trunk-feeder model.

The “taxi stops” category performs slightly better than the BAU and it offers significant travel benefits to passengers. However, as previously discussed, despite the benefits of this scenarios, its drawbacks in creating passenger inconvenience by limiting flexibility in travel and boarding and alighting may not be worth overlooking. As such, it be recommended to adopt a public participation plan that will involve all stakeholders to solicit information and consider all needs of the affected parties before it can be implemented.

The results show that there is no one best performing scenario but rather an integral of all improvement aspects tested in the scenarios would be the best solution for evaluating the effects of feeder public transport network configurations and operations on trunk bus networks. Scenarios in the “fleet and capacity” and scenario1 and 2 of the “scheduling” category offer improvements in the operation of the feeder network while scenario 3 can co-ordinate the improved feeder network to the trunk network by providing passengers with minimum time for transferring at the interchange. It thus stands that the status quo is not the best situation and can be improved through implementation of the tested scenarios.

6.6 Summary of findings

This Chapter summarises the discussion of the output of the simulation and the analysis from the results. Scenarios were developed and tested. KPI’s were then defined to evaluate the level of impact of the scenarios. The results show that improving feeder services to reduce travel time is possible though the tested scenarios. Similarly, the scenarios show that co-ordination is possible though dispatching feeder services and ensuring timed transfers at the interchange.

Therefore, working hypothesis is that integration is possible through the tested scenarios. But again, this worked under a few assumptions such as feeder services follow specific routes and do not deviate from them – which is a limitation of the data collected and capabilities of the software. This points to the need for a reform in the public transport sector. Because, should the taxis’ erratic and informal operational behaviour persist, the prospects of achieving an integrated and coordinated public transport system will remain limited.

7. Conclusion & Recommendations

7.1 Conclusions

The study focused on investigating the status quo of paratransit services to generate understanding of its informal operations which present a challenge of operational integration with the formal-trunk services. Subsequently, the research explored possible operational improvements of paratransit – with a focus towards integrating paratransit services to a trunk-line service. Using an Agent Based Model simulation software, Commuter, the trunk-feeder public transport network and operations in Mitchells Plain, South Africa were modelled to investigate how improvements on the operational design of feeder network affect the trunk network and how the two can be integrated and coordinated. This chapter presents the summary of findings by answering the research questions which guided the research.

1. What is the main challenge of trunk and feeder operation in the literature?

There is consensus throughout the literature that a significant percentage of South Africa's population commutes through the use of public transport. It, however, points out that the current forms of public transport are inefficient and time consuming. Literature further indicates that the inefficiency and time consumption nature the public transport system in South Africa is partly a result of lack of effectively integrated public transport across all modes.

In most areas, the public transport takes the form of a trunk-feeder public transport system – in which 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. The problem with this system is that these two public transport services are not integrated or coordinated. They co-exist but operate independently under different authorities, they exhibit different operational service structures; feeder services exhibit an informal-unscheduled structure while trunk line services exhibit a formal-scheduled structure, and there is no co-ordination of transfers from one service to another. Because of this difference in the nature in which the two public transport services operate, it is difficult to coordinate them – the informality of feeder services thus presents a major challenge to the success of an integrated trunk-feeder public transport system.

2. What is the modelling concept of trunk-feeder in terms of design and operations?

Varying population densities in urban areas prove to be a challenge when providing public transport. Most commercial areas have high population densities. Residential areas have scattered densities. However, all these areas require adequate access to public transport (ITDP, 2007). The challenge at hand is to develop systems that provide effective and efficient public transport. This is required to cover all areas and must be integrated across all modes of transport. In order to meet such challenges, areas with high density within the cities are served with high capacity vehicles, while those with low density areas are served with low capacity taxis.

In that regard, the model works in such a way that passengers walk and wait for feeder vehicles at a stop closest to their origin. They board the low capacity vehicles which operate on mixed traffic lanes and travel to an interchange or transfer station. It is noteworthy that the feeder vehicle arrivals at the interchange are erratic as they depend on departure patterns (normally do not depart until they are fully occupied) and delays caused by traffic. At the interchange, the passengers alight from the feeder vehicle, walk through the interchange and wait at the transfer station to board on to a high capacity trunk service. The trunk route on which the high capacity buses are operating is exclusively for buses, normally dedicated for bus lanes or Metrorail services (ITDP, 2007).

3. What tool was selected to execute the methods?

Several tools were investigated to select an appropriate tool capable of modelling operation of a trunk-feeder public transport system. The tool which was selected to build the trunk feeder model is an ABM simulation software called Commuter. It is an end-to-end journey simulator that models the trips made by people across all modes of transport. The technical features of Commuter were critically explored to ensure that the core functions required for this research are met. During the process of modelling randomisation of arrival/departure patterns along the feeder route, the simulator has posed some challenges. However, this is similar to other microsimulation packages explored, and is due to the fact that traditionally, public transport modelling in a simulated environment adopts a service-stop-timetable approach. Therefore, Commuter was selected as the most appropriate tool to use in modelling as it was the only package capable of modelling people as opposed to simple vehicle trips.

4. What is the appropriate public transport interchange with a feeder network catchment area that can demonstrate trunk-feeder network operations?

The corridor selected for this study is located in Mitchells Plain, a suburb located in the Western province in South Africa. The public transport network in this corridor has the third busiest interchange in the City of Cape Town, making approximately 30,000 passenger trips weekly and 75,000 people moving through the interchange during AM and PM peaks. The public transport services which are used by most commuters are characterized by overcrowding or congestion during peak hours and lack of safety during off-peak hours. These services include rail (Metro rail), bus (MyCiti and Golden Arrow) and taxis. They are all connected by the Mitchells Plain Public Transport Interchange located at the Mitchells plain station. The interchange constitutes a major bus terminus, and taxi ranks around the station and other commercial areas such as West gate mall. There are regular scheduled buses at the station and unscheduled mini-bus taxis services that serve areas within Mitchells Plain and extending to Cape Town CBD, Claremont, Bellville, and other areas. The corridor is thus reasonably served in terms of public transport. Figure 7-1 depicts the road network merging at the Mitchells Plain interchange.

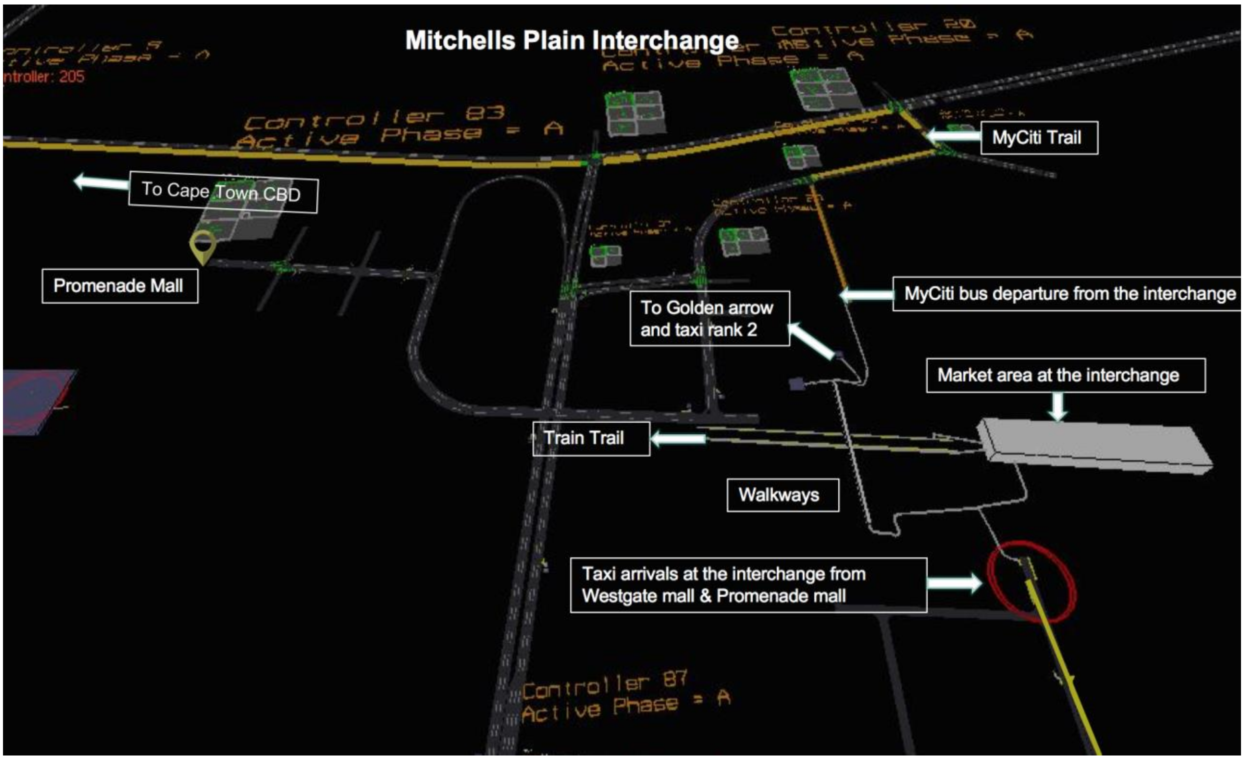

Figure 7-1: Mitchells plain network merging at the interchange

5. What data is required for developing a micro simulation model?

The data requirements for this study were based on operations of an existing public transport system where passengers use feeder vehicle services to the interchange and transfer to trunk services. The data can be categorized into three:

- Vehicle data: Vehicle data that was required included a fleet of buses that operated on the trunk, a fleet taxi that operated on the feeder, the bus timetables and taxi arrivals and departure times, traffic counts, vehicle capacity and vehicle speeds.
- Road network data: Road network data required included road dimensions, walkway dimensions, bus stops, stations data, traffic signal times and phases, and passenger stops and transfer zones.
- Passenger data: Passenger data included the number of passengers boarding and alighting and their location along the network and modal split data at the interchange.

6. What KPIs were derived to analyse a trunk-feeder system?

The indicators selected not only focused on the methodology correctness, that is trying to satisfy the positive goals of effectiveness, efficiency and service quality of the transit system but also considered satisfaction of all stakeholders that will be involved in the usage of the transit system. Four KPIs were selected to assess the performance of the model using the actual output that was extracted from the results of the simulation model. They are as follows;

- Capacity [space/ vehicle]
- Queuing [minutes]
- Travel time [minutes]
- Transfers [minutes]

7. What scenarios were developed to improve public transport performance?

Table 7-1 shows the scenarios that were developed to improve public transport performance. They are categorized into five groups. The summary of the five categories of scenarios including base model scenario (BAU) are presented below.

- Base scenario (Scenario 0): It is a run of the simulation to reflect the current operations as in reality based on the observed input from the study area. The output of this scenario is used as a base case and all other scenarios are compared against it to measure the level of effectiveness of other scenarios.
- Scenario 1: This scenario was executed to investigate how scheduling even taxi departure times affects the KPIs. By so doing, this was a check of how reliability affects passenger flows.

- Scenario 2: This scenario aimed at investigating how the correlation between demand and the supply affected the KPIs. That is the relationship between passenger arrivals at stands and taxi departures
- Scenario 3: The purpose of this scenario was to investigate the effect of operational co-ordination and integration of time tables between trunk and feeder system on the KPIs.
- Scenario 4: The purpose of this scenario was to investigate the impact of increasing taxi fleet size on the operations of the feeder public transport network.
- Scenario 5: The scenario focused on how increasing taxi capacity affects the number of passengers carried, waiting time and the overall travel time.
- Scenario 6: This investigated how limiting taxi stops at 500m apart affected passenger flows and taxi operations.

Table 7-1: Scenarios tested

Category	Scenario ID	Scenario description	Purpose
Base model	Scenario 0	Base model	Reference scenario
Scheduling	Scenario 1	Taxi even headways Vs Trunk service scedules	Improve reliability
	Scenario 2	Passenger profile Vs Taxi departure profile	Match demand & Supply
	Scenario 3	Co-ordinated taxi arrivals and trunk service departure	Schedule co-ordination of transfers
Fleet size and capacity	Scenario 4	Increase fleet size of taxis	Minimize waiting time on feeder routes
	Scenario 5	Increase capacity of taxis	Increase passenger capacity
Taxi Stops	Scenario 6	Fixing taxi stops at 500m intervals on the feeder route	Minimize delays due to frequent stopping

7. ***How did scenarios perform for each KPI?***

The radar plot below presents a comparative summary of the performance of the scenarios for each KPI. The simulation results of this study confirmed that each of the scenarios performed considerably well for the KPIs they were intended to improve. Notable in the plot is that scenario 3 offers passengers the best alternative for transferring because of the co-ordination of taxi arrivals and bus departures. Scenario 2 offers the best alternative for vehicle utilization by matching the demand and supply. Scenario 5 offers the best alternative for increasing the highest number of passengers carried on a route by increasing taxi capacity. Scenario 6 offers the least dwelling time as a result of limited stops made by taxis. It also emerges significantly with the least feeder waiting time. Furthermore, as expected, increasing the fleet size of taxis emerges as the best alternative to reduce passenger waiting time. The more frequent the services, the least the waiting time. The trip time in all the scenarios was about the same and they all had more crawling time compared to the BAU.

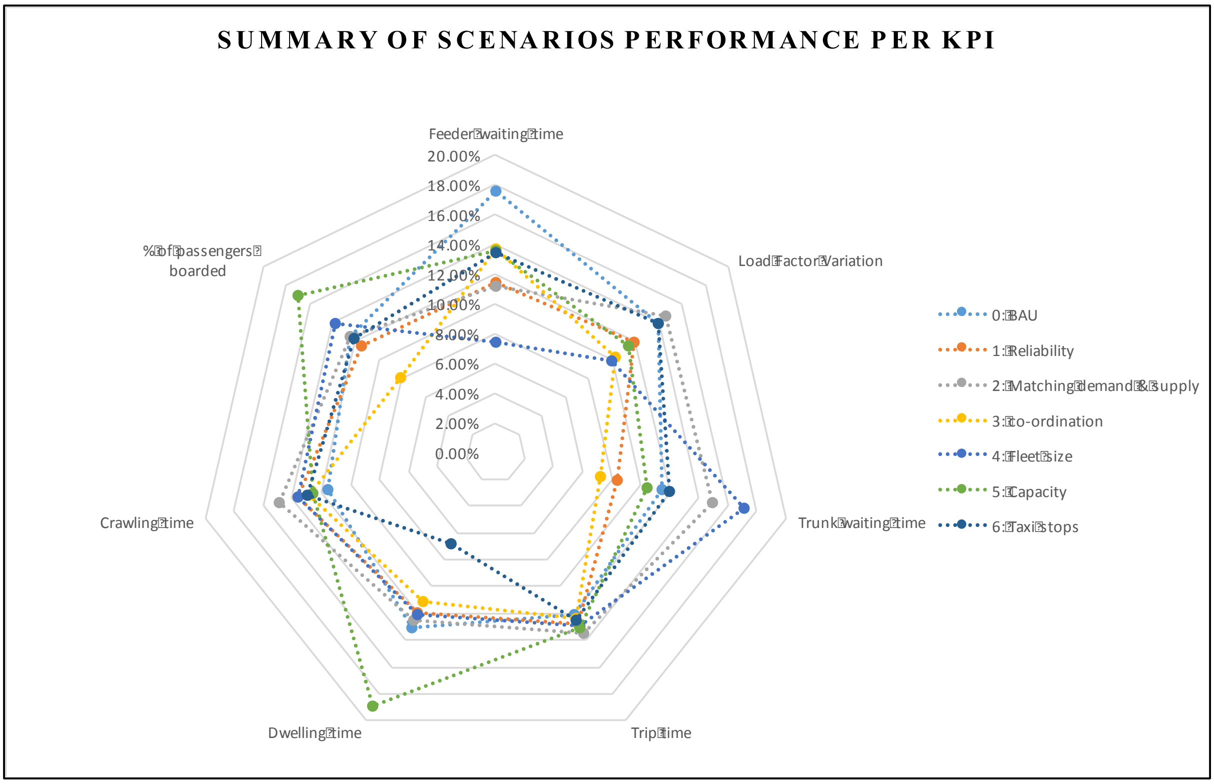

Figure 7-2: Summary of scenario performance per KPI

8. What is the best solution for all considered scenarios?

Six scenarios were modelled and simulated to provide results on their performance using KPIs. It was found that each of the scenarios implemented improved a particular KPI, two or more significantly. Scenarios in the “fleet and capacity” and scenario1 and 2 of the “scheduling” category offer improvements in the operation of the feeder network while scenario 3 can co-ordinate the improved feeder network to the trunk network by providing passengers with minimum time for transferring at the interchange but its operations for the feeder services were left as in the BAU scenario. In order to obtain the best performing scenario, a MCA was conducted. Scenario 5 emerged as the best performing scenario. This scenario offers significant improvements to the feeder network but it alone cannot provide a solution to the whole problem in question. It was thus concluded that, there is no one best performing scenario but rather an integral of all improvement aspects tested in the scenarios would be the best solution for evaluating the effects of feeder public transport network configurations and operations on trunk bus networks. For example, a feeder network could be improved by increasing taxi capacity, increasing the fleet size of the higher capacity taxis, ensuring that the new fleet profile match the demand profile, reduce the number of stops the new fleet stops at, and the improved feeder system can then be co-ordinated to the trunk service departures.

With that being said, it is hoped that the findings of this study will help decision makers to determine a systematic plan that provides maximum benefits for a trunk-feeder public transport system. This can inform policy makers to objectively explore the various scenarios tested and apply them where they are relevant. Thus this will thus contribute to the merging body of knowledge in integrating and co-ordinating feeder services to trunk services.

9. Can this simulation tool be applied in the South African Context?

Commuter was able to model and simulate the operations and configurations of the trunk-feeder network as was required by the objectives of the research. The software worked perfectly well for this study as the data was collected along trails, and because the study aimed to analyse a feeder trail connecting to a trunk trail. Thus Commuter modelled taxi behaviour as a public transport behaviour. In Commuter, a public transport service has a defined origin, a trail to travel through and a destination. In the model feeder routes and trunk routes were modelled with trails that have defined origin and destination. However, in the South African context, a taxi operates do not operate on fixed trails, they operate with a dynamic route choice as a result of competition for passengers. This is however is not possible in Commuter. It has a limitation in the capability to model a real feeder taxi model. And therefore Commuter cannot be used to model a typical taxi operation of the South African Context at this stage.

10. What are the potential practice and policy implications?

Data was collected using GPS-enabled mobile phone devices and mapped to show locations where taxis boarded and alighted passengers along the road network. Figure 4-2 shows an overlay of the data points and the road network. It is clear that taxis do not comply with the official routes they are supposed to operate in or serve. Lyles (2016) showed that there is an issue of route non-compliance meaning that the taxis do not pass in all official routes where they are expected to pass. As a result, there is limited supply of taxis for the demand in areas where the taxis do not pass or deviation off-route. Even though the Chairperson at the taxi rank insisted that taxis do not deviate from their assigned routes, the data shows the opposite. Thus, attention needs to be paid to such issues as the government embarks on the integration process. The government needs to work very closely with the taxi associations and monitor that the regulation they set for associations are followed, otherwise this could be a threat to improving the feeder system. The government could also subsidize the taxis to operate in the assigned routes. Without monitoring, the taxis will tend to operate in areas with high demand as operators are profit seeking as opposed to servicing the community.

The findings of this study can also inform decision making on the public transport design and operation. The current situation of the feeder and trunk services is that they operate independently i.e. the services are operated by different authorities. The findings of the study can have two positive implications for the associations if they worked jointly or cooperated. Firstly, with the knowledge of the feeder arrival times and the volume of passengers they deliver at the interchange, the collaboration could in turn help the trunk service authorities to optimally plan for the capacity and schedule for their services. Secondly, the benefits of integrating and co-ordinating the two transport services have the potential to attract more users. And because the government wants to increase public transport ridership, it might support this cooperated through financial incentives which benefit both associations and aid to improve their service operations.

There were some complaints from the public transport users at the interchange about the design and location of the transfer facilities at the interchange. At the Hazeldene interchange, transfers are facilitated by a pedestrian foot bridge that connects the taxi rank to the trunk services. The complaint is that it is not strategically positioned to provide the shortest connection, the path is long so they incur a lot of time transferring, and it is not safe especially early morning and after 18h00. This makes transferring an onerous experience. To make integration and co-ordination more attractive to users, special attention needs to be paid to the design of the transfer facilities such that the potential benefits in the improved services can be realised. Therefore, for future investment, it is recommended that in the same way transfer stations are designed for example for MyCiTi stations, the same should be done for transfers involving different rail and vehicle types to ensure efficient, safe and convenient transfers.

7.2 Recommendations

The following are the recommendations following from this research findings:

7.2.1 Optimization of the model scenarios

Scenarios were developed to improve the public transport system along the feeder routes. However, when scenarios were being developed, the parameters such headways, taxi capacity increase and increasing vehicle fleet sizes were estimated to get appropriate figures that would produce significant improvements in the performance. This could better be improved by optimizing the scenarios. Ceder (2007) in *Public Transit Planning and Operation* presented methods and formulae which can be used to optimize the scenarios applied in this model. The methods can aid to determine optimized vehicle capacity for a given network and demand, optimization tools to determine vehicle fleet size etc. Optimized facilities and designs translate to lower costs of operations. It was therefore recommended to apply these optimizations tools and methods to the scenarios.

7.2.2 A more realistic taxi model

Commuter was chosen as the best available tool for modelling this research. Nonetheless, the study had a few limitations in its capability to model a typical stochastic taxi model. In reality passengers would typically depart from their origins and walk to the nearby network heading towards their destinations at random times. At the same time, taxis would also typically depart from their origin and pick up passengers wherever the driver saw them along an unspecified road network. However, in Commuter, a route for the taxi is defined as a public transport route; it uses trails and does not deviate from that route, which means that this is not an entirely true reflection of how taxis would operate and behave.

In order to improve this model, a function that models transport as a function of activity was suggested. This can be modelled in such a way that an agent/passenger leaving an origin has a daily or periodic time plan which takes in the transit schedule and mode type. That way, because taxi activity and passenger activities are inter-linked, a taxi would take a route only when it expects that there would be a passenger waiting. A passenger would board a taxi that is expected to take the shortest route and the shortest time to arrive at it’s destination. This would also be the case with vehicles whose route choice would be based on where they expect a passenger waiting.

Multi-Agent Transport Simulation (MATSim) software may be capable of modelling the dynamic route choices on a network, as well as the competition behaviour of taxis. In reality, taxis compete for passengers. MATSim allows a certain degree of freedom where the taxis can deviate from their planned route and compete with other drivers on the network. Likewise, passengers have the freedom to choose a taxi that is expected to take the least travel time. This is a survival for the fittest principle based on demand (passengers) and supply (taxis) on a road network.

To supplement the model enhancement, a more comprehensive data set would be required to fully capture passenger’s travel activities. In order to attain this, an application that can be used by each each passenger is recommended. Instead of a placing a single surveyor/taxi conductor to record passenger activities in that specific taxi, using the passenger application, a more comprehensive data can be recorded of passenger activities (including transfers between modes) from their origins to their destinations.

Using an application that can travel with passengers and capture their entire travel activities, and a more comprehensive simulation tool that will incorporate taxi dynamic routing, it can be expected that a very close to reality taxi – trunk service model of the South African context is achievable. It is therefore recommended to obtain a simulation tool with sufficient features, collect a more comprehensive data set improve the data collected, and test the model again.

Estimating carbon dioxide emissions

Road transport contributes 60% of the 23% carbon dioxide emissions produced in the world (Schipper et al., 2009). On the positive side, public transport is known to reduce environmental effect by reducing in the CO_2 emissions. It is therefore important to accurately estimate the amount of emissions produced as it it's a critical KPI normally considered when designing public transport systems.

Data was collected on the number of public transport services and their trip end locations. This was realistic data from the field but no data was collected on fuel consumption and the mechanics of vehicles (engine types). There is variation on fuel types used by the various public transport services; diesel or petro. It would be difficult to determine the proportion of fleet that uses either one of them. This would undermine the validity of the result if presented as an output of the model. While building vehicle characteristics in Commuter allows for defining the type of engines and fuel type for the cars, the data on fuel and mechanics was not collected hence the output on the amount of carbon emissions produced would not be realistic estimation since its not based on actual collected data.

In order to obtain the actual amount of CO_2 emissions produced, the above relevant data on vehicle mechanics and fuel consumption should be collected, input in the model and simulated to obtain realistic estimates of the amount of carbon dioxide emissions.

7.2.3 Estimating cost of operation

Initially, data that was collected for passengers boarding and alighting taxis did not indicate passenger's origins and destinations. Using the Li & Cassidy algorithm, boarding and alighting data was converted in an OD matrix that represents each individual origin and destination.

Individual origins and destinations are associated with a taxi trip (given by a taxi registration number). For each taxi trip, its origin and destination could be determined. Therefore, for each trip, it could be identified where taxis stopped and how many passengers boarded and alighted, and the distance over which they travelled.

This information was of interest to the to the taxi association for the purposes of managing their business by estimating taxi costs of operation. If the trip fare is known for individuals' trip distance, the number of people that boarded and alighted on each taxi, it can be estimated the amount of money that a taxi makes per trip hence the overall money made in their system. Sometimes the taxi association makes losses because they don't know how much they actually make per taxi trip or per day. With this, the taxi rank association can correctly make decisions on how to manage their business.

In summary, it can be concluded that, dispatching feeder services in co-ordination with the trunk service schedule which ensure timed transfers at the interchange, coupled with scenarios tested to improve the operations of feeder services are a potential solution to achieving an improved, integrated, and coordinated trunk-feeder public transport system. However, this may not be achievable if the taxi industry remains unregulated – with taxi services retaining their erratic and informal operational behaviour, and if both trunk and feeder services remain operating under different authorities without cooperating or working jointly.

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Appendix A: Ethics clearance form

EBE Faculty: Assessment of Ethics in Research Projects

Any person planning to undertake research in the Faculty of Engineering and the Built Environment at the University of Cape Town is required to complete this form before collecting or analysing data. When completed it should be submitted to the supervisor (where applicable) and from there to the Head of Department. If any of the questions below have been answered YES, and the applicant is NOT a fourth year student, the Head should forward this form for approval by the Faculty EIR committee: submit to Ms Zakiya Chikte (Zakiya.chikte@uct.ac.za); New EBE Building, Ph 021 650 5739). Students must include a copy of the completed form with the dissertation/thesis when it is submitted for examination.

Name of Principal Researcher/Student: Claire Birungi **Department:** Civil Eng

If a Student: Yes **Degree:** MSc. Civil Engineering **Supervisor:** A/Prof. Mark Zuidgeest

If a Research Contract indicate source of funding/sponsorship: Yes

Research Project Title: Trunk-feeder simulation modelling

Overview of ethics issues in your research project:

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

If you have answered YES to any of the above questions, please append a copy of your research proposal, as well as any interview schedules or questionnaires (Addendum 1) and please complete further addenda as appropriate.

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

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

Signed by:

	Full name and signature	Date
Principal Researcher/Student:	Claire Birungi Signed	7/10/2015

This application is approved by:

Supervisor (if applicable):	Mark Zuidgeest Signed	7/10/2015
HOD (or delegated nominee): Final authority for all assessments with NO to all questions and for all undergraduate research.	Signed	12/11/15
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.		

ADDENDUM 1:
Please append a copy of the research proposal here, as well as any interview schedules or questionnaires:

ADDENDUM 2: To be completed if you answered YES to Question 2:

It is assumed that you have read the UCT Code for Research involving Human Subjects (available at http://web.uct.ac.za/depts/educate/download/uctcodeforresearchinvolvinghumansubjects.pdf) in order to be able to answer the questions in this addendum.

2.1 Does the research discriminate against participation by individuals, or differentiate between participants, on the grounds of gender, race or ethnic group, age range, religion, income, handicap, illness or any similar classification?	~~YES~~	NO
2.2 Does the research require the participation of socially or physically vulnerable people (children, aged, disabled, etc) or legally restricted groups?	~~YES~~	NO
2.3 Will you not be able to secure the informed consent of all participants in the research? (In the case of children, will you not be able to obtain the consent of their guardians or parents?)	YES	~~NO~~
2.4 Will any confidential data be collected or will identifiable records of individuals be kept?	~~YES~~	NO
2.5 In reporting on this research is there any possibility that you will not be able to keep the identities of the individuals involved anonymous?	~~YES~~	NO
2.6 Are there any foreseeable risks of physical, psychological or social harm to participants that might occur in the course of the research?	~~YES~~	NO
2.7 Does the research include making payments or giving gifts to any participants?	~~YES~~	NO

If you have answered YES to any of these questions, please describe how you plan to address these issues (append to form):

The objective of this research is to simulate and evaluate the impacts of a trunk-feeder public transport system configuration and operational characteristics on passenger flows using a microsimulation model and case-test this for a Cape Town corridor. A survey will be conducted in Mitchells Plain to analyse the travel patterns of vehicles (taxis at Hazeldene) in coordination to BRT (MyCiti and Golden arrow). 20 field workers will employed to perform observation on the following:

- To collect arrival/departure times & their occupancy for all vehicles arriving and departing the 3 stops (Hazeldene taxi rank, promenade mall and Westgate mall).
- To sit in the taxi and record passenger boarding and alighting data at every stop a taxi stops along the route.
- To record the number of people at the train station and train information; number of doors and carriage.
- To collect modal split data. How many people connect to the different modes of transport at the interchange?
- Collect BRT data: Occupancy variation and the number of people left at the exiting bus stops.
- To collect traffic data at selected stops that are representative of the daily traffic condition.

Appendix B: Appointment letter for fieldworkers

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

Faculty of Engineering & the Built Environment
Centre for Transport Studies

c/o Department of Civil Engineering
Private Bag X3
Rondebosch
7701
SOUTH AFRICA
Telephone: +27 21 650 1792
Email: Robyn.Joseph@uct.ac.za
Website: www.cfts.uct.ac.za

05 November 2015

For Attention: Hazeldene Taxi Association

Dear Mr/Ms

APPOINTMENT AS RESEARCH FIELDWORKER

It is my pleasure to offer you appointment as a data collection fieldworker for a UCT Centre for Transport Studies (CfTS) project entitled "Evaluating Effects of Feeder Configurations to a Trunk Bus Network: A Case Study of Mitchells Plain, Cape Town". The following are the conditions of employment:

- The fieldworker will assist in conducting a travel observational survey for the described project at specified times and locations.
- The duties will include 12 working hours a day up to a maximum of 10 days during Novermber 2015.
- The nature of employment requires that you are available on the days when the survey will be conducted.
- The remuneration will be R15 per hour calculated on actual hours worked.
- Remuneration will be paid in cash at the end of the survey. The fieldworker will be required to sign a receipt as proof that payment has been made.

The CfTS requires this to be a researcher/research assistant relationship and you will be expected to honour the researcher's procedures while conducting the survey.

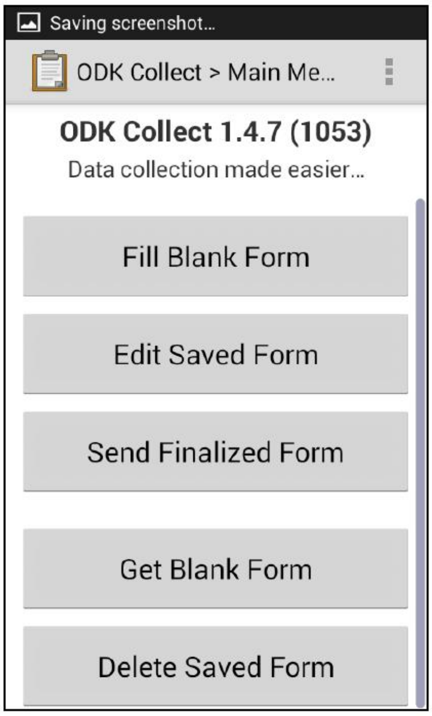
Signed on behalf of CfTS: Signed by fieldworker:

Claire Birungi Name:……………………………………

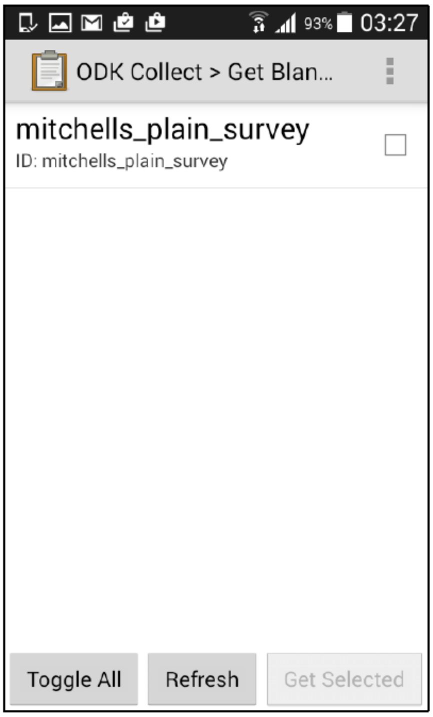
Appendix C: Mobile phone survey training guide

Start the phone

The app is called ODK Collect. Touch to open the app.

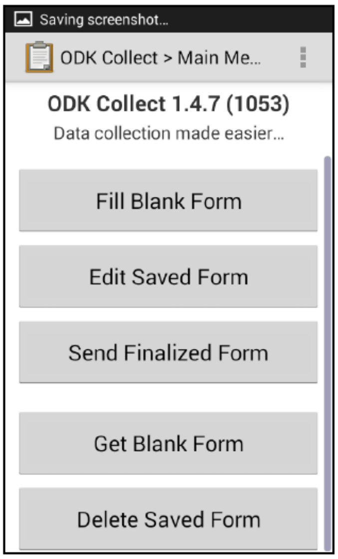


Select "Get blank form". It will load and bring up this page



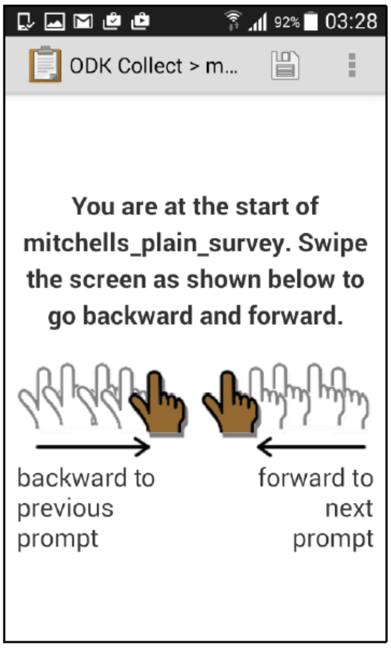
Touch the box right of "mitchells_plain_survey" it will show a blue tick. This activates the "Get selected" at the bottom right. Now Select "Get selected".

This loads and shows "Download Result". Press OK to go on. It now takes you to this page below.



Select "Fill in blank form". It will bring up the page below.

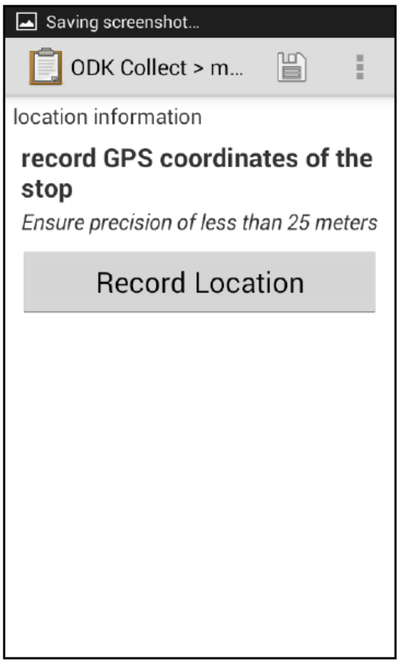
Select "Mitchells-plain-survey". It will bring up the page below.



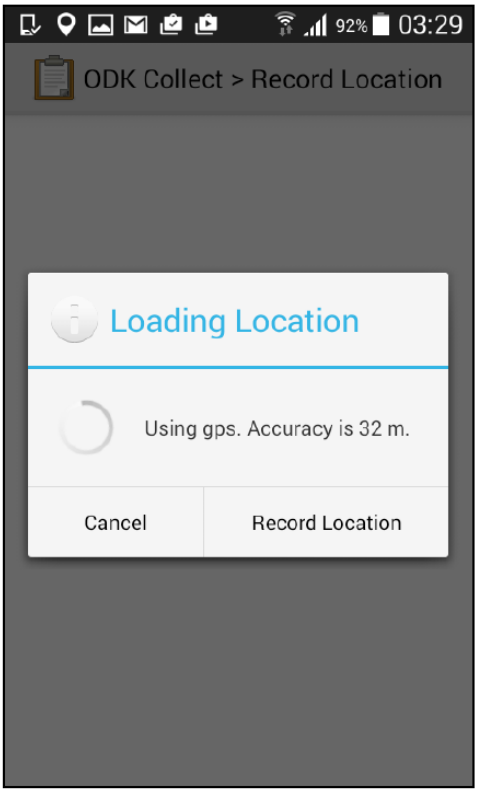
You will need to swipe to go to the next page. Some pages need to be filled in before you go to the next. So it will refuse to go to the next if you don't put in the required information.

Swiping will bring you to the page below.

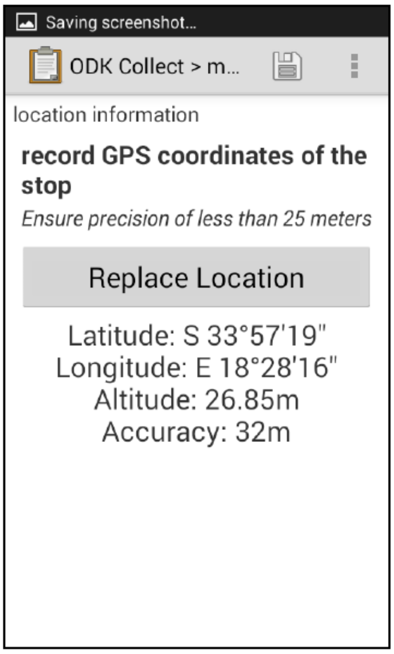
Select record location. This takes sometime to record at times. It depends on how good the reception is. But you MUST record it at the position where the taxi stops.



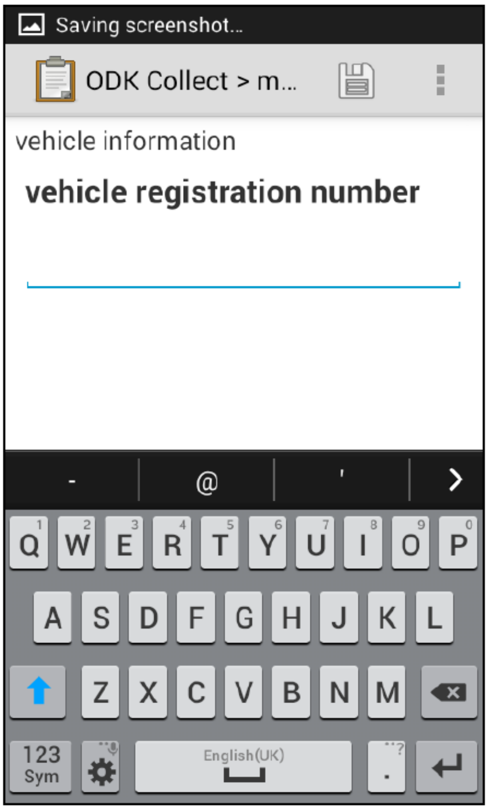
This is the result when it is done loading. Aim for an accuracy of atleast 20-25m. If you cant get it just move on to the next step.



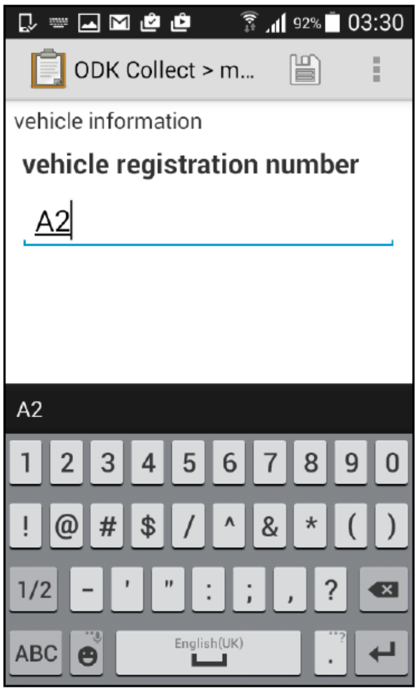
This is the result of the recorden GPS position.



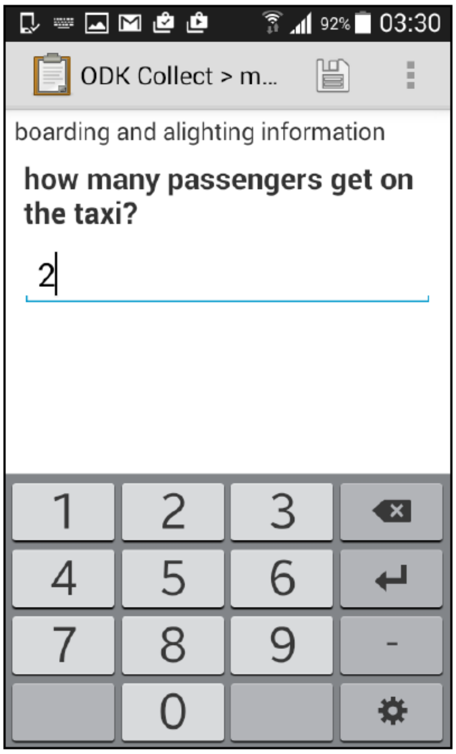
Swipe to the next page of vehicle information. Record the stahe Vehicle registration number. Be sure to get it at the station before the vehicle leaves. If you don't fill it in, then you cant go to the next step.



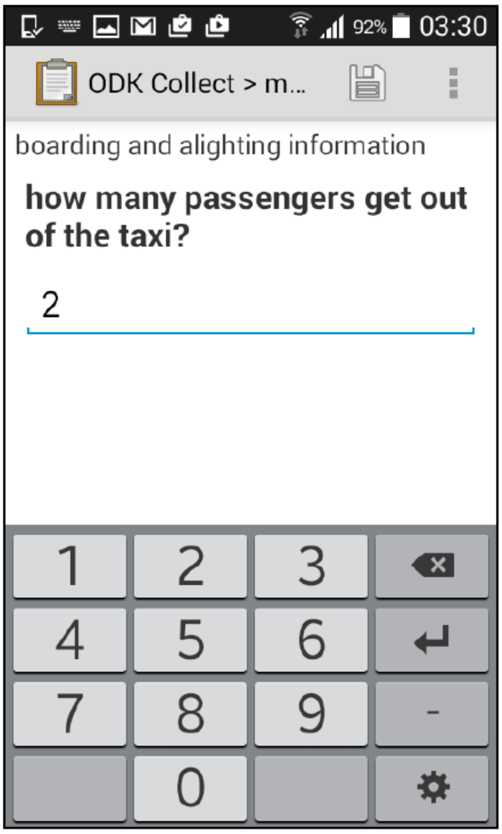
The filled in Form.. for example "A2" is the taxi registration number.



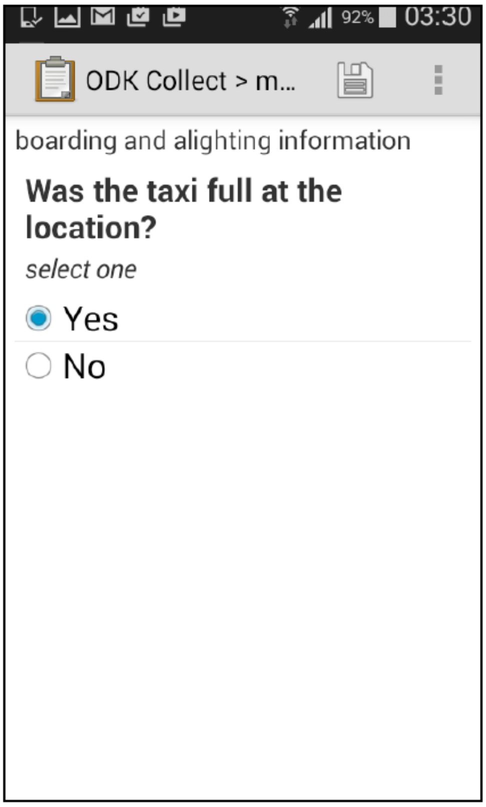
Swipe to the next page "How many passengers get on"

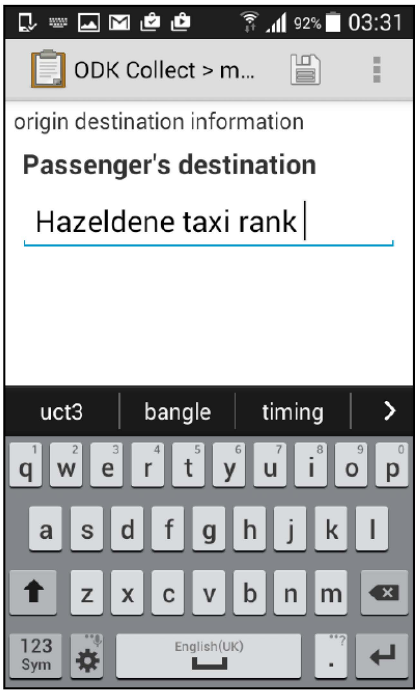


Swipe to the next page and answer the question.

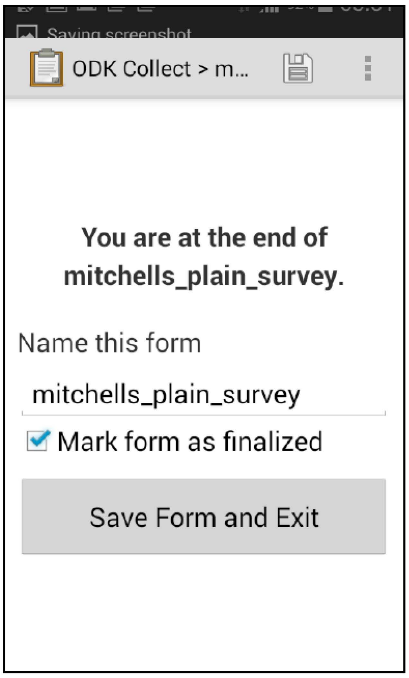


Swipe to the next page and answer the question.

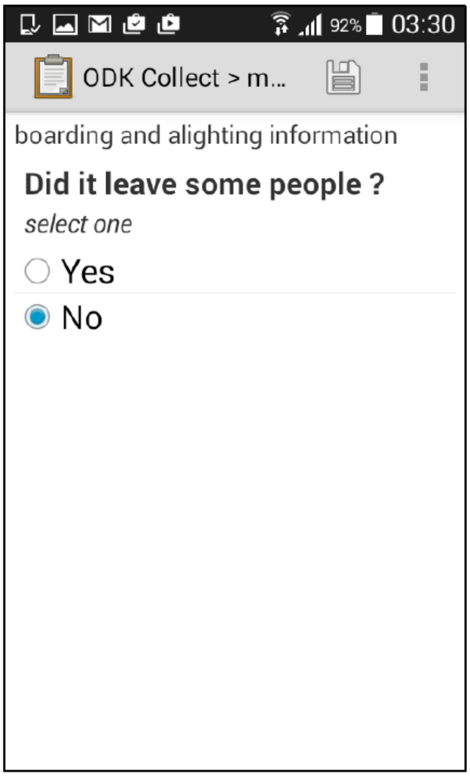




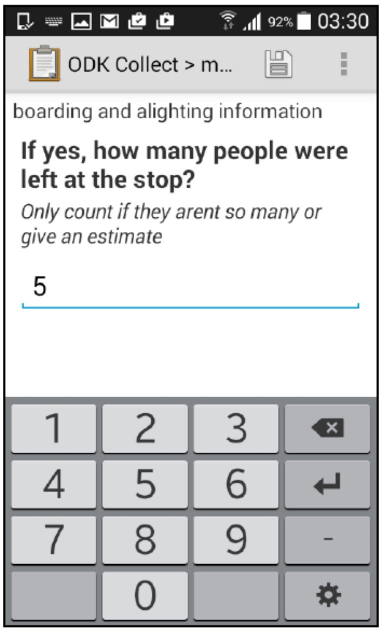
You have now reached the end of the survey. At that point where the taxi had stopped. You MUST select "Save Form and Exit". Other wise you wont have saved the information. I will be checking online for the forms saved hourly.



Swipe to the next page and answer the question.

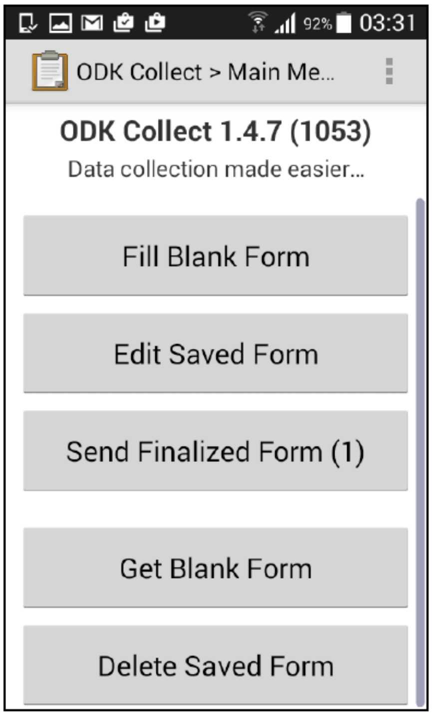


Swipe to the next page and answer the question.



Swipe to the next page and answer the question.

After you exit, it takes you back to the start. At another stop, you start the process again.



Thank you ☺

Appendix D: Templates for data collection

Train data		
Train stop		
Number of doors		
Number of carriage		
Train Capacity		
Train schedule		
Arrival time	Waiting time	Number of people at the platform

Link traffic counts form

TRAFFIC COUNT TALLY SHEET

Date:____________________ **Road surface condition:**_________________

Location:_________________________ **Weather:**____________________

Route Name					
Time intervals	Cars	Bus	Truck	Cycle	Walk

Intersection traffic data form

TABULAR SUMMARY OF VEHICLE COUNTS

Observer: ____________ Date: ____________ Day: ____________ City: ____________

R=Right Turn
S=Straight
L=Left Turn

Intersection of: ____________ AND ____________

Time Begins	from North				from South				TOTAL North/South	from East				from West				TOTAL East/West	TOTAL ALL
	R	S	L	TOTAL	R	S	L	TOTAL		R	S	L	TOTAL	R	S	L	TOTAL		

Arrivals at Hazeldene taxi rank form

MITCHELLS PLAIN PT DATA COLLECTION: ARRIVALS						
Zone name						
Reg/CA No.	Arrival time	Number of passengers				Destination
		Taxi Rank	MyCiti	Golden Arrow	Train	

Arrivals at Westgate Mall and Promenade Mall form

MITCHELLS PLAIN PT DATA COLLECTION: ARRIVALS			
Zone name			
Reg/CA No.	Departure time	Number of passengers	Destination

Departure data form

MITCHELLS PLAIN PT DATA COLLECTION: DEPARTURES			
Zone name			
Reg/CA No.	Departure time	Number of passengers	Destination