



UNIVERSITY OF CAPE TOWN

Department of Civil Engineering

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MASTER'S THESIS

THE IMPROVEMENT OF OPERATIONAL PERFORMANCE OF PUBLIC TRANSPORT

The Case for Gauteng Province, South Africa

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DECLARATION

I, RODWELL OWEN CLOETE, hereby declare that all the work contained herein is my own and that all references have been properly acknowledged.

This thesis is in partial fulfilment of the requirements for the degree of Master of Science in Engineering: Transport Studies offered by the Department of Civil Engineering in the Faculty of Engineering and the Built Environment at the University of Cape Town.

RODWELL CLOETE

DATE

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EXECUTIVE SUMMARY

Background and Objectives

Public transport operations in South Africa, and in particular Gauteng Province, are riddled with problems. The service is characterised by poor performance, most evident in late arrivals, over crowdedness, and non-availability outside peak hours, among other. Most often, old and unsafe vehicles are used in operations, which compromise the safety of passengers.

The 1997 Gauteng White Paper on Transport Policy provides for the monitoring of levels of service (LOS) as one of its key policy areas. To this effect, this research aimed to determine minimum and target public transport LOS, based on the actual level of service provision in Gauteng Province. Emphasis was placed on the provision of public transport services in areas where the greatest need exists and that will benefit most from improvements to the system.

Broadly defined, this research aimed to provide answers to the questions set out below.

- Is there any public transport service available and is it possible to gain access to it?
- How frequently are the services provided?
- Is the service affordable?
- What level of service can be expected?
- What are the demand and cost implications of providing an improved service?

The main objectives of this research was thus to develop appropriate and sustainable public transport KPIs and LOS, to test the practicality of formulated KPIs and LOS, and to establish the additional investment levels required to address the backlog within the public transport system in Gauteng.

Establishing Key Performance Indicators and their Status Quo

Following a review of both international and local examples with regard to public transport performance measurement, typical public transport problems were identified, which provided an indication of the wants and needs of passengers. The most pressing transport problems in Gauteng relate to:

- the availability and accessibility of public transport services;
- service capacity (i.e. crowding);
- frequency of service;
- cost of public transport; and
- safety and security issues.

The identified needs formed the basis for the development of ideal public transport KPIs. These KPIs provide a mechanism to evaluate the performance of the public transport system. The selected KPIs, together with the corresponding minimum and target LOS, are shown in Table S1.

The identification of ideal KPIs and LOS was followed by a screening process of municipal areas in the province, to identify pilot areas within which ideal KPIs and LOS could to be tested. The outcome of this process resulted in the selection of Soshanguve as the preferred pilot area.

Table S1: Ideal Minimum and Target Levels of Service

No	Parameter	KPI	Levels of Service ⁽¹⁾		
			Bus	Rail	Taxi
1	Availability	Hours of service	18 (24)	18 (24)	18 (24)
2	Accessibility	Walking distance to public transport	1 000m (500)	N/A	750m (400)
3	Service capacity	% Capacity utilisation (Volume to capacity ratio)	1.00	1.00 (0.90)	1.00
4	Frequency	Number of departures per hour in peak period	6 (12)	6	12
5		Number of departures per hour in off-peak period	1 (2)	1 (2)	4
6		Average waiting time in peak period	10 mins (5)	10 mins	5 mins
7	Cost	Percentage of income spent on public transport	10%	10%	10%
8	Safety	Maximum age of vehicles in the fleet	10 yrs	30 yrs	10 yrs
9	Security	Number of security officers per 1000 peak hour passengers	1	1	1

Note 1: Target LOS are indicated in brackets.

Although status quo information was not available for all KPIs, an analysis of the province revealed the findings listed below.

- Walking distances for train services are by far the longest and are the only mode for which walking distances exceed the proposed minimum level of service of 1000 metres.
- All modes have average waiting times less than the proposed minimum of 10 minutes.
- Although approximately 60% of public transport commuters spend more than 10% of personal income on public transport, the average spending is estimated at only 1.1% above the proposed level of service.
- Low satisfaction ratings prevail regarding personal safety at stations and on vehicles.
- Nearly 64% of minibus-taxis and 50% of buses are older than their expected lifespan of 10 and 12 years respectively.

Development of a Strategic Model

The next step involved the development of a model that aimed to predict impacts of improved public transport LOS on passenger demand, as well as the cost of implementing these LOS (or resources consumed). A demand (or service) model predicts the shifts in demand as a result of changes to service levels by means of a logit model, which feeds into a resource model that calculates the resources consumed along a specific corridor.

The resource model accounted for the additional investment required to improve public transport services as specified in the demand model. The cost components consist of the factors mentioned below.

- The total annual operating cost was based on the running operating cost of vehicles, operating cost of the infrastructure, other travel related costs and annual cost of providing security (if any).
- The total annual capital cost was based on the acquisition of new vehicles either to serve additional demand, or to decrease the average age of vehicles to improve safety.

Sensitivity Tests

Sensitivity tests were used to establish the impact of variables on mode choice in the demand model. It was shown that:

- a change in fares had the most impact on mode choice, and therefore ridership, in the range R3.50 to R5.50, with elasticities in excess of one;
- peak period frequency was most responsive in the range five to 15 departures, with moderate elasticities; and

- walking time had the most impact in the range zero to 20 minutes, with elasticities ranging between -0.10 and -0.21.

These findings are reiterated as they provide a useful indication of where the focus for policy changes should be placed, for the market segment in question. Special caution should be exercised when designing policies involving public transport fares for the low-income market.

Sensitivity tests of the resource model revealed the facts listed below.

- A change in fares resulted in the highest impact on public transport income and cost with elasticities in excess of one.
- Frequency changes had a moderate impact, with elasticities between 0.44 and 0.98.
- An increase in hours of service had a minimal impact on all services, and the measure can, therefore, be implemented at a rather low cost.
- The model was found to be extremely responsive to a reduction in train crowding, with a 10% reduction resulting in a 12% increase in cost.

Shortcomings of Model

An important drawback of the model at this stage is its inability to predict demand changes due to improvement in those attributes not included in the demand model, such as safety and security, off-peak frequency and hours of service. This has resulted in an underestimation of possible shifts in demand. Moreover, the significant influence of fare costs on demand is not reflected in the results, as expenditure on public transport for this market segment was found to be within the target level of service of 10%. As a result, the variable was excluded from the analysis. Walking distances for bus and taxi services were also found to be within the proposed minimum LOS.

There is also a marginal uncertainty associated with the base model. This is due to the uncertainty in the input variables such as the aggregation of travel distances to centre-to-centre distances between sub-regions, the application of generic cost-related input variables, assumptions made in terms of densification patterns of demand, and the application of generic peaking profiles for demand during the AM and off-peak periods.

Results and Conclusions

The research concludes with the deployment of the model in the pilot area of Soshanguve, to test the achievement of minimum and target public transport LOS. The predicted impact of changes to public transport LOS is set out in Table S2.

Table S2: Predicted Impact of Changes to Public Transport Levels of Service

MODE	Policy Tested	Change in Cost/One-way	Change in Budget Deficit ⁽¹⁾
BUS	Minimum Levels of Service	+ 80%	+ 230%
	Target Levels of Service	+ 260%	+ 940%
TRAIN	Minimum Levels of Service	+ 430%	+ 680%
	Target Levels of Service	+ 930%	+ 1150%
MINIBUS-TAXI	Minimum Levels of Service	+ 20%	+ 110%
	Target Levels of Service	+ 180%	+ 950%

Note 1: Indicative of investment levels required.

The implementation of the proposed minimum LOS will require investments in the order of approximately three times the current expenditure for bus services, eight times for train services and double the current expenditure for taxi services. The implementation of target LOS will require investments in the order of between 10 and 12 times the current expenditure.

Serious consideration must be given to the implementation of the most cost effective measure across all modes, which is the introduction of a minimum level of security. Although it could not be proven, this measure is expected to have a significant influence on possible demand shifts. Henceforth, the demand model needs a major overhaul to better predict changes in ridership due to each improvement to the system.

The most important conclusion is that the improvement of current public transport LOS to the suggested target levels may be unaffordable, due to tremendous increases in cost. Minimum LOS for bus and minibus-taxi services are more achievable in the light of their impact on cost. However, the improvement of public transport operations may still be an option, if the alternative is to build more roads for cars, encouraging congestion that would ultimately impact negatively on both the economy and the environment.

DEFINITIONS

This document uses the following key definitions:

Walking distance: The distance an individual has to walk in order to gain access to a public transport mode.

Frequency: The number of vehicle departures on a particular public transport route in one hour.

Percentage Income Spent on Public Transport: The monthly cost of public transport expressed as a percentage of gross monthly income.

Waiting Time: The time between arriving at the stop or station and the arrival of the public transport vehicle.

Vehicle Crowding: The ratio of the capacity of a public transport vehicle (or the supply) and the actual number of passengers (or demand) along a particular route.

Hours of Service: Hours of service, or service span, are the number of hours during the day when public transport service is provided along a route or between two locations.

Punctuality: Considers on-time performance for fixed-route services as a departure from a published time point 0 to, say five minutes after the scheduled time.

Public Transport vs. Car Travel Time: The door-to-door difference between private car and public transport travel times, including walking, waiting and transfer times (if applicable) for both modes.

Elasticity: Public transport service elasticity is defined as the percentage change in public transport ridership resulting from each 1% change in public transport service, such as changes in price or frequency.

Model Calibration: An analytical process whereby a model is checked for how well it's assumptions, constants, variables, and values fit a specific local system and predicts current conditions. This step necessarily preceded any forecasting.

Model Estimation: An analytical process that involves finding the values of the parameters, which make the observed data more likely under the model specification. Non-significant parameters can be identified and left out of the model.

LIST OF ABBREVIATIONS

AVKT:	Annual Vehicle Kilometres Travelled
CPTR:	Current Public Transport Record
CTMM:	City of Tshwane Metropolitan Municipality
GHTS:	Gauteng Household Travel Survey
GPDPtrw:	Gauteng Provincial Department of Public Transport, Roads and Works
GPG:	Gauteng Provincial Government
HCM:	Highway Capacity Manual
KPIs:	Key Performance Indicators
LOS:	Levels of Service
MNL:	Multinomial Logit Model
MSA:	Moving South Africa
NDOT:	National Department of Transport
NMT:	Non-Motorised Transport
NPP:	National Passenger Panel
NTS:	National Travel Survey
OD:	Origin-Destination
PT:	Public Transport
PTIS:	Public Transport Information System
SARCC:	South African Rail Commuter Corporation
TRB:	Transportation Research Board
v/c:	Volume to Capacity Ratio
VOT:	Value of Time

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Public transport operations in South Africa, and in particular Gauteng Province, are riddled with problems. The service is characterised by poor performance, most evident in late arrivals, over crowdedness and non-availability outside peak hours, among other. Most often, old and unsafe vehicles are being used for public transport operations. This compromises the safety of passengers and results in an unacceptable rate of accidents involving public transport vehicles.

The 1997 Gauteng White Paper on Transport Policy (GPDPTW, 1997) provides for the co-ordination of transport modes and services, which includes the monitoring of levels of service (LOS) as one of its key policy areas. The following is an extract from the document with regard to levels of service:

"The Department will establish, in conjunction with local government, and taking cognisance of user needs, appropriate minimum levels of service provision. The Department, in conjunction with local government, will ensure the establishment of data gathering and processing programmes to monitor the levels of service provision for all modes of transport of provincial significance in accordance with identified appropriate standards."

It also states that in the provision of public transport facilities, the emphasis will initially be on low cost and high impact solutions, satisfying affordable minimum levels of service and addressing basic user needs. To this effect, this research aims to determine minimum, as well as desirable public transport LOS, based on the current or actual level of service provision in Gauteng Province. The selected public transport KPIs and their corresponding LOS must be appropriate, i.e. tailor-made and relevant to transport and socio-economic conditions in the province. Secondly, KPIs must be sustainable to allow continuous monitoring of those identified. Lastly, target levels of service for KPIs must be justifiable, i.e. funds directed towards improving a specific aspect of the service should address actual customer needs.

1.2 PROBLEM STATEMENT

South Africa has gone through dramatic constitutional changes resulting in the reallocation of transport functions and responsibilities between its central and provincial government. Simultaneously, both the central and Gauteng government have developed and adopted new transport policies. These new policies place special emphasis on the promotion of public transport services.

Until now, very little has been done in Gauteng (and South Africa as a whole) towards the implementation of this policy. This is due, inter alia, to authorities' limited knowledge as to

what levels of public transport service are appropriate, in addition to the extent of the actual needs of public transport in the province. Moreover, no common procedures are in place to determine backlogs in the provision of public transport services.

In addition, KPIs and LOS for traffic operations on roads have been developed and are generally accepted by transport planners, but similar KPIs and LOS have not been accepted and promulgated for public transport in the South African environment. Therefore, in the absence of generally accepted KPIs and service levels, it is not possible to measure the adequacy of public transport operations in Gauteng province.

The achievement of appropriate service levels is also affected by the characteristics of the different public transport modes. Cognisance of the role and domain of the different modes of transport requires careful consideration in the development of appropriate public transport KPIs and LOS.

Broadly defined, this research aims to provide answers to the questions listed below.

- Is there any public transport service available?
- Is it possible to gain access to it?
- How frequently are the services provided?
- Is the service affordable?
- What level of service can be expected?
- What are the demand and cost implications of providing an improved service?

Examples of KPIs and their corresponding LOS that need to be developed are:

- threshold of public transport services (what determines the need to introduce public transport?);
- minimum frequency of service for both peak and off-peak periods;
- walking distances to public transport (what determines acceptable walking distances?);
- in-vehicle travel times; and
- affordable fare levels.

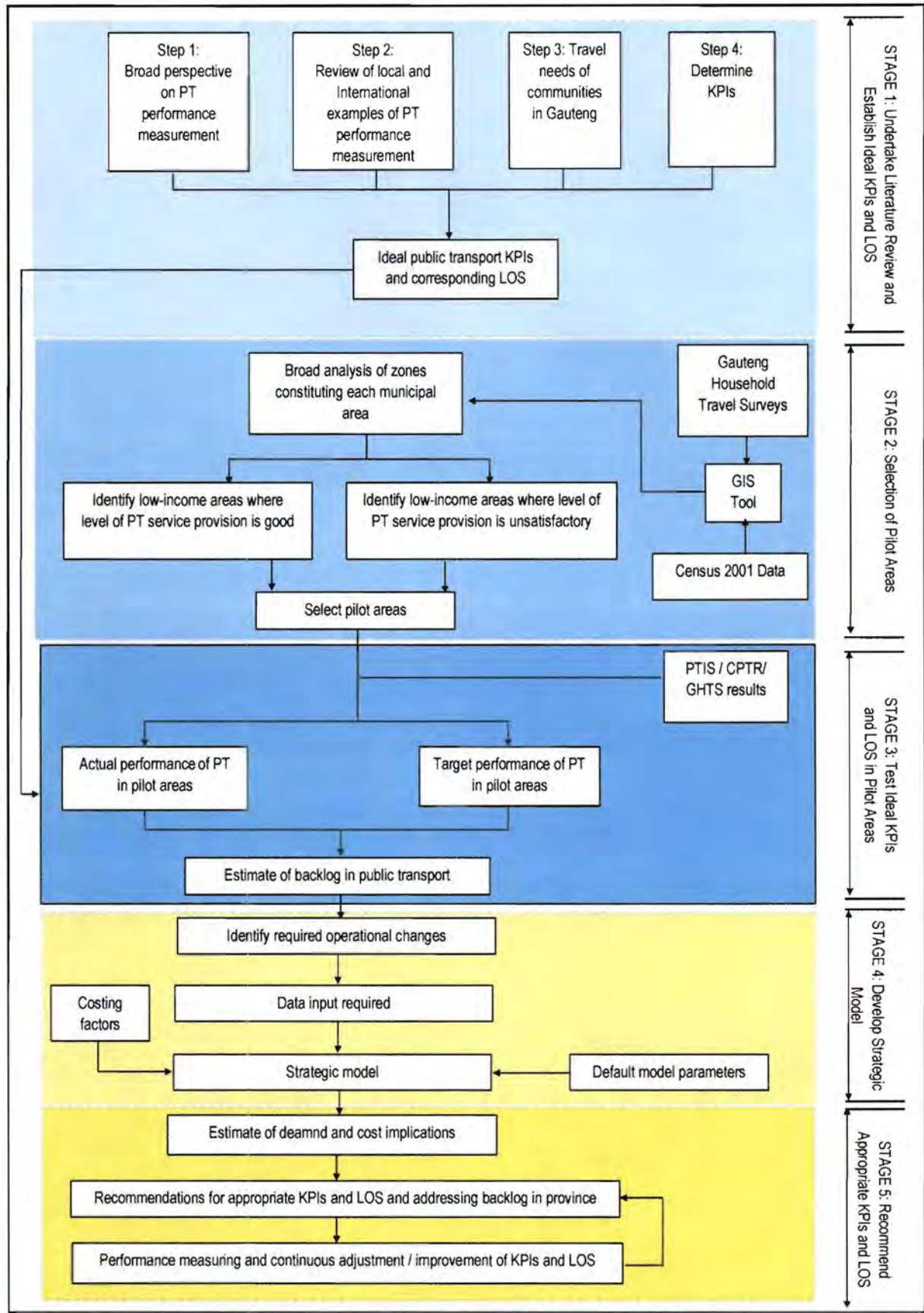
1.3 OBJECTIVES

The following are the main objectives of this research:

- to develop appropriate and sustainable public transport KPIs and LOS;
- to test the practicality of formulated KPIs and LOS; and
- to establish the additional investment levels required to address the backlog within the public transport system in Gauteng.

1.4 METHODOLOGY

This study, in essence, is three-fold in nature. Firstly, ideal public transport KPIs will be established; secondly, these KPIs and their corresponding LOS are to be tested by means of a pilot study to determine whether they are applicable in the Gauteng context. Lastly, the aim is to quantify the backlog within the public transport system in monetary terms through the development of a strategic model. Details of the actions to be carried out during the study are shown in Figure 1. The different steps and stages describe the process envisaged in a chronological order.



Note: Stages in blue denote, in part, the work that is based on a consultant report by Khuthele Projects(GDPTRW, 2005b)

Figure 1: Research Methodology

1.4.1 LITERATURE REVIEW AND ESTABLISHMENT OF IDEAL KPIs AND LOS

This stage is directed towards the establishment of ideal public transport KPIs and LOS (see Figure 1). The literature review sequentially looks at the procedures discussed below.

- Step 1: Provide a broad perspective on public transport performance measurement.
- Step 2: Review both local and international examples of public transport performance measurement.
- Step 3: Identify travel needs of communities in the province.
- Step 4: Determine key performance indicators derived from relevant policy, legislation and other documentation.

Ideal public transport KPIs and their corresponding LOS will result from this process. New levels of service will then have to be developed, taking into consideration the unique transport situation and specific local issues in South Africa in general, and in Gauteng in particular.

1.4.2 SELECTION OF PILOT AREAS

This stage entails the analysis of characteristics affecting public transport for areas within the province in order to identify pilot areas in which ideal KPIs and LOS can be tested. A GIS tool will be employed to facilitate the analysis of the data. The analysis draws heavily on data collected during the Gauteng Household Travel Surveys. Census 2001 data will also be utilised, as this was collected for different census districts in the province. This will result in the identification of critical areas in the province where there is an obvious need to promote or improve public transport service provision.

The outcome of this broad analysis will indicate:

- zones where a large percentage of people are poor, and
- zones with either poor or satisfactory utilisation of public transport.

1.4.3 TESTING OF IDEAL KPIs AND LOS IN PILOT AREAS

Once the level of public transport service provision has been established for zones in the province, a number of areas will be identified to be used in a pilot study. The objective of the pilot study is to test the applicability or practicality of the identified ideal KPIs and LOS and to provide a rough estimate of the backlog in public transport service provision. The analysis will utilise information that was recorded in the various municipal Current Public Transport Records (CPTRs) in Gauteng, in addition to information contained in the Public Transport Information System (PTIS).

1.4.4 DEVELOPMENT OF STRATEGIC MODEL

The preceding stage will result in the identification of the specific operational changes required to address the backlog in public transport operations. Once the data requirements and costing factors have been determined, a model will be developed aimed at estimating demand and cost implications of the required operational changes to meet the proposed minimum and target levels of service. The model should be able to quantify the backlog in monetary terms and estimate shifts in the current modal split as a result of certain operational changes.

1.4.5 RECOMMEND APPROPRIATE PUBLIC TRANSPORT KPIS AND LOS

Having established an estimate of the demand and cost implications of improving public transport operations, the costs need to be judged against the benefits in order to devise more practical and sustainable service KPIS and LOS. It is important to note that the main purpose of estimating the cost implications is to determine the viability and cost effectiveness of the proposed LOS. The study concludes by proposing recommendations as to what public transport LOS will be appropriate for implementation in Gauteng, and provides guidelines for the implementation of recommended KPIS and LOS.

1.5 SCOPE AND LIMITATIONS

Extent of Work Done for the Purposes of This Thesis

This research stems from a project by Khuthele Projects for the Gauteng Provincial Department of Public Transport, Roads and Works (GPDPTRW, 2005b), which entailed the development of appropriate and sustainable public transport levels of service for Gauteng Province. The author of this thesis was the primary researcher and author of the consultant report. Work based, in part, on the consultant's report, involves the first three stages of this thesis and is shown in blue in Figure 1. This work can be found in chapters 2 to 6 of this thesis, although many sections have been reworked. The development of the demand and resource model (the remaining chapters) represents additional work that was done specifically for the purposes of this thesis. It is important to note that the referencing in the first six chapters makes reference to the original documents from which information was sourced.

Geographical Area

The research focuses on the province of the Gauteng Province in South Africa, although the literature review will draw information from various cities and countries around the world. Two pilot areas were identified for testing the KPIS and LOS, but only one area was analysed due to time constraints.

Passenger Market to be Targeted

The research focuses on those public transport users who will benefit most from improvements to the system, i.e. low-income users few of whom, in all probability, own cars. Given the limitations on resources, ideal KPIS and LOS were tested by means of a pilot study in an area that conform to criteria set for the target passenger market. An evaluation of the zones in the province was carried out to identify appropriate areas. It is assumed that results obtained from the pilot areas can be extrapolated to the rest of the province, provided that areas selected for this purpose are representative of the rest of the province (for the market in question).

Costing of Public Transport Operations

The model developed has a base year of 2004, as most cost information such as fare data was collected during that year. Therefore, all other cost components were extrapolated to 2004.

Data Availability and Quality

The data availability influenced the final selection of key performance indicators. Moreover, the development of the demand model suffered at the hand of insufficient data, therefore, not all KPIS could be incorporated into the demand model. The results of any quantitative

analysis depend on the credibility of the data source. It should be noted that some of the data sources have been found to be rather unreliable in determining existing levels of service for the selected KPIs.

1.6 CONTENT OF THE REPORT

In pursuing the scope and objectives of this report, the outline of the remaining chapters is as follows. **Chapter 2** contains the findings of the literature review, and investigates local and international examples of public transport performance measurement. Travel needs facing the Gauteng public transport market are explored in **Chapter 3**, followed by the identification of relevant KPIs and their corresponding LOS in **Chapter 4**.

Chapter 5 provides a broad evaluation of socio-economic and travel characteristics for zones constituting the province, in order to select pilot areas in which ideal public transport KPIs and LOS are to be tested. **Chapter 6** documents information on existing service levels for the selected ideal KPIs in both the province and the selected pilot areas.

Chapter 7 documents the development of a strategic model to determine the demand and cost implications of identified KPIs and LOS in the Gauteng environment. **Chapter 8** elaborates on the estimation and calibration of the demand (or service) model, while **Chapter 9** deals with sensitivity issues related to the model. **Chapter 10** contains the findings of the policy analysis results for a particular pilot area in the province, applying the strategic model developed in previous chapters, and seeks to provide a reasonable estimate of the cost involved in improving public transport operations. **Chapter 11** concludes the research and makes recommendations with regard to appropriate public transport KPIs and LOS, its demand and cost implications, as well as future research opportunities.

CHAPTER 2

LITERATURE REVIEW

2.1 BACKGROUND

The literature review comprises the following components:

- a broad evaluation of performance measurement in public transport, and placing definitions and concepts in context;
- a review of local and international examples of public transport performance measurement;
- the identification of travel needs of Gauteng communities to provide an indication of aspects within public transport requiring attention; and
- confirmation of national and provincial transport policies to determine relevant key performance indicators (KPIs) for which required levels of service (LOS) ought to be developed.

These four steps will culminate in the establishment of ideal public transport KPIs and LOS, which will then be tested for possible application in Gauteng.

2.2 INTRODUCTION TO PERFORMANCE MEASUREMENT

2.2.1 DIFFERENTIATING BETWEEN KPIs AND LOS CONCEPTS

The efficient operation of an urban public transport system or individual modes of public transport requires the existence of a framework within which this operation is continuously monitored, evaluated and adjusted. Such a “framework” consists of performance indicators and their target LOS (benchmarks), which permit an objective evaluation of existing or proposed new services.

A Key Performance Indicator (KPI), also known as a performance measure, is a concept designed to express, in an objective and quantitative way, a certain aspect (economic, technical or operational) of the system’s performance. It is a quantifiable measure that can be reported as a single data value or as a ratio of two or more data values. The purpose of utilising key performance indicators is to:

- provide a mechanism to evaluate the performance of the system and of individual routes;
- provide an early detection system to single out undesirable trends;
- provide data to aid in decision making;
- help towards the achievement of a certain desirable performance; and
- provide a guideline for adjusting public transport service to meet budget constraints.

KPIs are the primary means of assessing how successful an agency is in accomplishing its goals. The purpose of performance measures is “to tell us where we are in terms of where

we want to go". When developing or selecting a performance measure, it should be clear what goal(s) the measure will help achieve (TRB, 2003).

Actual levels of service refer to the current performance of operations, i.e. the existing or current level of a KPI. Designated ranges of values pertaining to the achievement of a set target (target LOS) can also be developed for a specific KPI. LOS ranges are commonly accepted for traffic operations in order to gauge actual performance, and normally ranges from A (very good, with minimum capacity constraints) to F (very bad, with unacceptable capacity constraints). The Highway Capacity Manual of 2000 (TRB, 2000) employs the same convention to evaluate public transport performance.

Target levels of service, or target LOS, are desired or maximum values for a specific KPI that should not be exceeded. For example, a target level of service concerning walking distance will refer to the maximum permissible walking distance from home to a public transport stop or station.

Lastly, KPIs can also have minimum levels of acceptability, referred to as **minimum LOS**, which are lower or upper limits to target LOS. A minimum level of service is the absolute minimum requirement to which a KPI should conform, in order to be acceptable.

Figure 2 aims to illustrate the hierarchy of the main definitions used throughout this study.

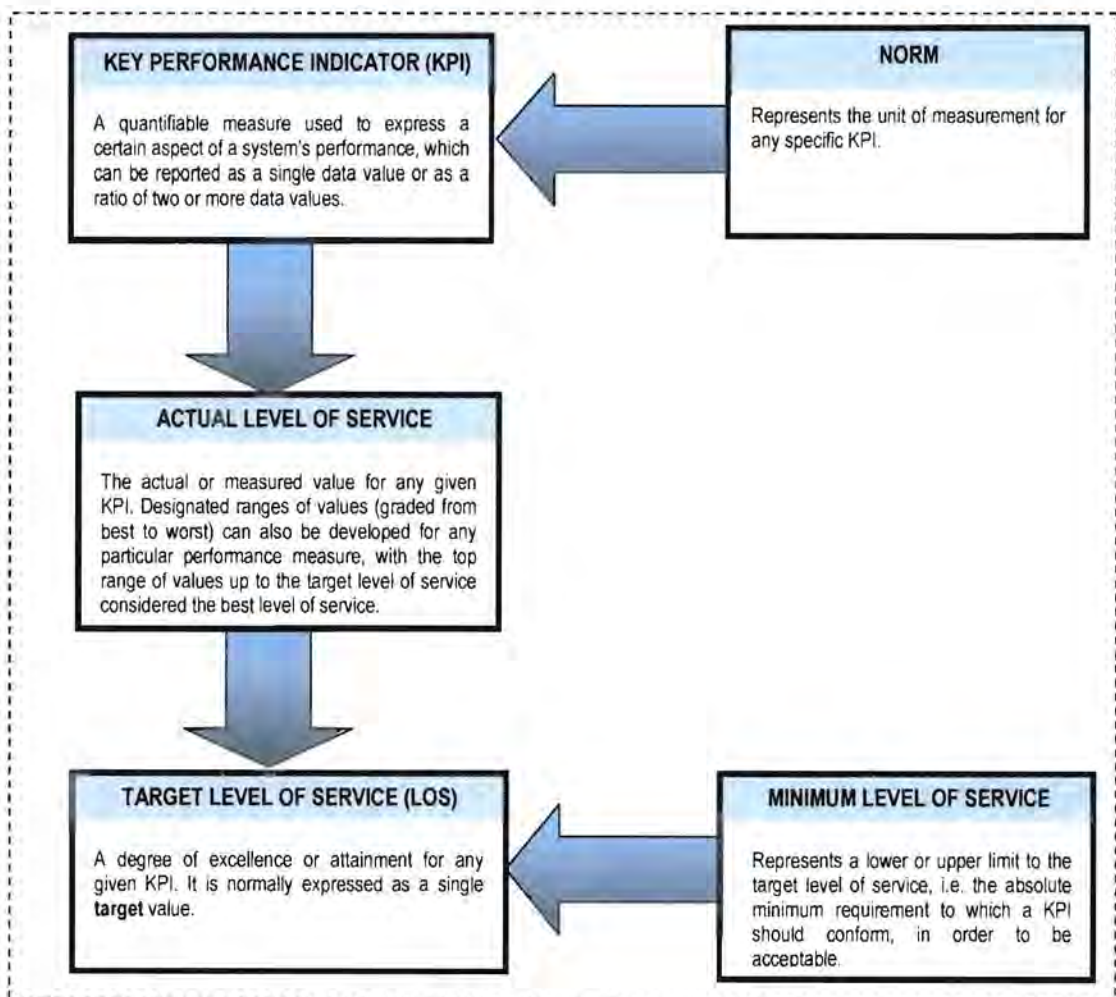


Figure 2: Hierarchy of Definitions

2.2.2 THE PROCESS OF ESTABLISHING KPIs AND LEVELS OF SERVICE

To date, actual public transport levels of service have been variously defined by one or more of the following attributes: speed, travel time, headway, operating ratio, and passenger capacity.

Various authors, for example Botzow (1974), attempted to develop methods of measuring actual LOS based on the system's ability to provide for example, basic accessibility, reasonable travel times and a comfortable ride. To provide a comparison with the highway LOS concept, Botzow (1974) employs six distinct levels of service, namely A through to F (excellent LOS to poor LOS). However, the sources mentioned are outdated and the literature is vague in providing firm principles on which the development of these levels of service is based.

Target LOS can be set typically using two common methods: self-identified target LOS or comparisons to typical target LOS in the industry. Self-identified LOS are based on a combination of current performance, professional judgement and government goals. Customer and community issues can be considered and can be directly linked to customer satisfaction, particularly when the results of a customer satisfaction survey are available. When considering the Gauteng Household Travel Surveys (GDPTRW, 2002), it is possible to compare satisfaction with different characteristics of public transport. The latter will provide an indication of the current LOS, as well as the travel needs, of Gauteng communities.

A comparison to typical industry target LOS builds on the work done by other governments and applies an average or typical target level of service to its own operations. This method has the advantage of being reasonable; the target level of service were not adopted imprudently, but can be compared to what others are doing. However, it fails to consider either the special circumstances that caused the other organisation them to adopt a particular target, or the organisation's own circumstances. It is important to identify definitions used to develop the target LOS. For example, when "on-time" performance is measured, results will be higher if up to 10 minutes late is considered "on-time", rather than no more than five minutes late.

2.2.3 CONSIDERATIONS FOR THE SELECTION OF KEY PERFORMANCE INDICATORS

Reliability of a KPI depends on the quality of the data used to calculate the measure. Also, the methodology used to calculate a KPI should be consistent between reporting periods (Ewing, 1993).

KPIs should be easily understood, readily measured and not too numerous. Equally important, KPIs should follow from established goals and objectives (Giannopoulos, 1989). In deciding which to include in a package designed for a particular operation, two issues should be borne in mind. Firstly, the collection of the necessary data and the calculation of the KPIs are costly in terms of staff, time and resources. Also, KPIs are only as valid as the data and information used to develop them. Secondly, really important aspects of the operation can become submerged under huge quantities of statistical information, especially if the user is not sufficiently selective in deciding where to concentrate attention. Perhaps most importantly, consideration should be given to the purpose for which the specific KPIs are to be used.

Vorster (2000) proposed the development of a strategic monitoring process in Gauteng within the framework as stated below. KPIs need to be:

- specific enough to accurately indicate areas of transport deficiency;
- utilising existing information as far as possible;
- designed in such a manner that they are part of the normal planning process; and
- monitored in the same area repeatedly over time.

A final point is the need to have uniform and comparable KPIs in a wider area, e.g. a region or the country as a whole. Compatibility and uniformity of the KPIs used can provide a useful comparison between municipalities in different areas. These will be the duty of a high-level authority, such as the Gauteng Provincial Department of Public Transport, Roads and Works, to study and impose (Giannopoulos, 1989).

2.3 INTERNATIONAL EXAMPLES OF PERFORMANCE MEASUREMENT

This section of the literature review focuses on a few examples in terms of public transport performance measurement in the international arena. Distinction is made between target public transport LOS (single target values for a specific measure) and the measurement of actual public transport LOS (range of values for a specific measure). A summary of the sources consulted, together with typical target LOS for the KPIs discussed, is provided at the end of this section.

2.3.1 THE HIGHWAY CAPACITY MANUAL

The Highway Capacity Manual (HCM) (Transportation Research Board, 2000) stipulates a number of actual public transport LOS, providing distinction between *availability* and *passenger / convenience* measures. Availability measures include service coverage, service frequency, hours of service, while the convenience measures include passenger loads, punctuality or on-time performance as well as public transport vs. car travel time. Table 1 summarises the range of values for the measurement of actual LOS for the mentioned measures.

Table 1: Measuring of Actual Public Transport LOS from HCM (2000)

KPIs	Actual LOS					
	A	B	C	D	E	F
Availability Measures						
% PT Supportive Area Covered ⁽¹⁾	90-100	80-89	70-79	60-69	50-59	<50
Service frequency (veh/hr)	>6	5-6	3-4	2	1	<1
Hours of service (per day)	>18-24	>16-18	>13-16	>11-13	>3-11	0-3
Convenience Measures						
Bus Passenger loads (pass/seat)	0.0-0.5	0.5-0.75	0.76-1.0	1.01-1.25	1.26-1.5	>1.5
Rail Passenger loads (pass/seat)	0.0-0.5	0.5-0.75	0.76-1.0	1.01-2.0	2.01-3.0	>3.0
%On-time performance (punctuality)	97.5-100	95-97.4	90-94.9	85-89.9	80-84.9	<80.0
Travel time difference (mins)	< 0	1-15	16-30	31-45	46-60	> 60

(1) PT supportive area: the portion of the area being analysed that has a household density of at least 7.5 units per gross hectare or an employment density of at least 10 jobs per gross hectare. Covered area: the area within 0.4 km of local bus service or 0.8 km of a bus way or rail station, where pedestrian connections to PT are available from the surrounding area.

2.3.2 STRATHCLYDE PASSENGER TRANSPORT UNDERGROUND

The Strathclyde Passenger Transport Underground ¹ based in Scotland aims to provide safe and convenient transport between stations. They have set specific performance targets related to frequency, punctuality and reliability. They also aim to ensure that trains and stations are clean and they monitor customer satisfaction through surveys. Performance against the set target LOS are monitored and published every four weeks.

The most prominent target LOS are as follows:

- frequency of trains during peak period = four minutes;
- frequency of trains during off-peak period = six minutes;
- punctuality of trains (within five minutes of scheduled time) = 98.5%; and
- reliability of trains (actual service vs. scheduled service) = 98.0%.

2.3.3 CHILTERN RAILWAYS PASSENGER CHARTER

The Chiltern Railways Passenger Charter (March, 2002) ² is committed to providing a safe, reliable, welcoming and value-for-money service all day, every day. Within the charter, they set out to explain the target LOS (more specifically related to punctuality and reliability) they expect to achieve and how they report on their performance. The charter is reviewed annually in consultation with their passengers.

The most important target LOS contained in the charter are:

- standing time in peak period should be less than 20 minutes;
- punctuality of trains (within five minutes of scheduled time) = 93.0%; and
- reliability of trains (actual service vs. scheduled service) = 99.0%.

¹ www.spt.co.uk/subway/facts03.html

² www.chilternrailways.co.uk

2.3.4 NEW SOUTH WALES TRANSPORT CUSTOMER COMMITMENT

The New South Wales Transport Customer Commitment ³ defines the target LOS that passengers can expect on trains, buses and public ferries. Specific LOS are listed for punctuality, safety, comfort and accessibility, among other measures.

The punctuality LOS are:

- punctuality of trains (within five minutes of scheduled time) = 92.0%; and
- punctuality of buses (within five minutes of scheduled time) = 95.0%.

2.3.5 TRANSLINK

Translink ⁴ is responsible for the integrated rail and bus public transport services in Northern Ireland, with the Passenger Charter committing them to high-quality service. The charter highlights aspects associated with reliability and punctuality, as well as safety and comfort.

The most prominent target LOS are:

- standing time during peak period should be less than 15 minutes;
- reliability of trains and buses (actual service vs. scheduled service) = 99.0%; and
- seat capacity on trains shall not exceed 20%.

2.3.6 BUS PLANNING AND OPERATION IN URBAN AREAS: A PRACTICAL GUIDE

This publication (Giannopoulos, 1989) discusses the subject of performance evaluation, and includes results on a worldwide survey conducted in the late 1980s on the use of KPIs and procedures. This survey involved mailing a simple questionnaire to public transport agencies. The types of KPIs used by agencies varied substantially. Several KPIs and target LOS could be said to be similar, but with some degree of modification. However, these modifications would have to be based on the background data, which did not form part of the survey. No comparisons could thus be made. Some of the most commonly used KPIs such as walking distances, frequencies and passenger comfort are included in the summary provided at the end of this section.

The most prominent KPIs and target LOS are:

- walking distance to bus stops shall be less than 500 metres;
- punctuality of buses (within five minutes of scheduled time) = 98.0%;
- frequency of buses during peak periods shall be between five and 10 minutes, and between 15 and 30 minutes during off-peak periods; and
- loading on buses shall not exceed 130% of the available seating capacity.

2.3.7 SAN FRANCISCO MUNICIPAL RAILWAY DEPARTMENT

The San Francisco Municipal Railway Department ⁵ set target LOS for rail operations, mainly concentrating on system reliability and performance. The following KPIs had specific target LOS to be met by 2004:

- percentage of vehicles that ran on time according to published schedules (no more than four minutes late or one minute early) measured at terminals and established intermediate points (target at 85%);
- percentage of scheduled service hours that were delivered and percentage of scheduled vehicles that began service at the scheduled time (target at 98.5%);

³ www.transport.nsw.gov.au

⁴ www.translink.co.uk/peoplescharter.asp

⁵ www.sfmuni.com/cms/rptpub/documents/svcst011.pdf

- missed service due to either insufficient vehicles or driver unavailability as a percentage of scheduled service hours (less than 1.5%);
- percentage of vehicles that passed published time points during measurement periods unable to pick up passengers due to crowding, without being followed within three minutes or less by another vehicle on the same route with space for all waiting passengers (less than 5%);
- actual headways against scheduled headways on all lines for peak, base, evening and late-night services (operate more than 80% of the time within 30% or 10 minutes of schedule);
- percentage vehicle availability (target at 98.5%) and reliability (mean distance between failure by mode);
- number of passengers carried by mode (increase by 2%); and
- number of crime incidents on vehicles or in facilities (reduction of 5% from previous year).

2.3.8 WEST MIDLANDS

The development of target public transport LOS in the West Midlands, United Kingdom, was part of a strategy to deliver an integrated transport system (CENTRO, 1992). A 20-year Public Transport Strategy provided for the delivery of high-quality public transport services and facilities. Targets and objectives were to be monitored, adopted and updated on an annual basis to reflect customers' changing needs. Target LOS were set for various key strategic areas, including the following:

- opportunity, i.e. accessibility to the network;
- integration of different public transport modes, such as ticketing;
- accessible design, including unaided access for all people;
- affordability, including discounted travel for unemployed people and half-price travel for job seekers;
- trip quality addressing frequency, reliability, travel time, security and comfort; and
- other measures which included customer care, promotion, awareness and responsiveness to complaints and enquiries.

Target LOS had to be updated every five years to reflect customers' changing requirements, while product and service guarantees were to be established.

2.3.9 CHICAGO TRANSIT AUTHORITY

The Chicago Transit Authority's (CTA) mission is to deliver quality, affordable public transport services that link people, jobs and communities (Chicago Transit Authority, 2001). Target LOS lay out a framework for achieving this mission. In addition, they provide a framework for a consistent and fair evaluation of both existing and proposed services. As markets, resources and customer expectations change over time, target LOS are evolutionary by nature. CTA must respond to the changes in order to retain current customers, and achieve and sustain ridership growth.

The main target public transport LOS are:

- walking distance to public transport stops shall be less than 750 metres; and
- frequency of buses and trains during off-peak periods = 30 minutes.

2.3.10 TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

This publication (Texas Transportation Institute, 2000) does not deal with target LOS per se, but rather with the concept of measuring actual LOS. In the early 1980s, the concept of actual LOS was suggested for describing the quality of service offered by public transport (transit). Although this concept has been applied to several case studies in the United States, no generally accepted set of target LOS or evaluative criteria have been developed that can be applied to the public transport in Texas. In response to this problem, the Texas Transportation Institute undertook a research project for the Texas State Department of Highways and Public Transportation and the Urban Mass Transportation Administration. The project was geared towards the development of a LOS concept applicable to the transit systems of Texas. The study involved a literature review of existing LOS models and visits to each of the 19 public transit systems in Texas to discuss techniques used at the time to assess quality measures of transit service. A draft LOS concept was developed in which various KPIs were identified and quantitative LOS values were assigned to each indicator. The key results of this research are documented in Table 2.

Table 2: Summary of Actual LOS Measurement for Public Transport in Texas, USA

Indicator	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Walking distance	< 375ft	376-660	661-1320	1321-2000	2001-3300	3300+
Travel time ratio	1 or less	1.01 – 1.10	1.11 – 1.34	1.35 – 1.50	1.51 – 2.00	2.00+
Transfers	0	1	1	1 or 2	2	3+
Waiting time	0	5	5 to 10	10 or 5	5+	3+
Frequency Peak, mins Off-peak	10 or less 15 or less	11 to 15 16 to 30	16 to 25 31 to 45	26 to 40 46 to 60	41 to 60 61 to 90	60+ 90+
Reliability*	98 to 100	95 to 97	90 to 94	75 to 89	50 to 74	<50
Passenger Density	1 seat/pass; individual separated seats	1 seat/pass; parallel rows of upholstered seats	1 seat/pass; parallel rows of molded seats	Perimeter seating w/ 100 to 110% of seated load	110 to 125% of seated load	125+% of seated load

* % Runs 0 min. early to 5 min. late
Source: Texas Transportation Institute, 2000

2.4 SOUTH AFRICAN EXAMPLES ON PERFORMANCE MEASUREMENT

This section investigates local examples of public transport performance measurement in the context of South Africa.

2.4.1 NATIONAL PASSENGER TRANSPORT CHARTER

The National Department of Transport (NDoT, 2004a) initiated a process in December 2003, which called for the formulation of a Passenger Transport Charter. This was one of the outcomes suggested by the Road to Safety Strategy launched in 2001, and it called for improved road traffic services. The Passenger Rights Charter was aimed at raising public awareness to order to grant various rights to passengers and guarantee certain service levels.

2.4.2 GAUTENG SOCIAL AND QUALITY CHARTER

The Gauteng Social and Quality Charter conducted by the sub-directorate Modal Integration of the Gauteng Provincial Department of Public Transport, Roads and Works (GDPTRW, 2004d) is a negotiated agreement between users and operators of public transport, transport planners, implementers and authorities on social and quality issues pertaining to public transport. The social charter involved a process whereby both existing and potential users, together with other stakeholders, are able to express their views as to what constitutes a viable and affordable public passenger transport system; one which operates in the broader public interest while meeting peoples' needs and requirements. Having established the form such a public transport system should take, the quality charter identified the degree of adherence to agreed target LOS, which are regarded as acceptable. The charter was expected to be completed during 2005.

2.4.3 PROPOSED CAPE TOWN METROPOLITAN INTERIM SERVICE CHARTER

The actual provision of public transport services in terms of routes, frequencies, duration of operations and size of vehicles, has been decided by the individual operators (City of Cape Town, 2001). In the National Land Transport Transition Act 22 of 2000 it is proposed that the authorities take responsibility for the planning of public transport services. One of the initial requirements is a service charter. The Interim Service Charter provides service specifications, which relate to frequencies, as well as details of the trip quality that users can expect.

2.4.4 WHITE PAPER ON NATIONAL TRANSPORT POLICY

The following target LOS form part of the national strategic objectives set for land passenger transport, taken from the White Paper on National Transport Policy (NDoT, 1996):

- the promotion of the use of public transport over the private car in order to achieve a passenger trip ratio of 80:20 respectively;
- to ensure that public transport is affordable, with commuters spending less than 10% of disposable income on transport;
- to improve accessibility and mobility, limiting walking distances to about 1km in urban areas;
- to encourage more efficient urban land use structures, correcting spatial imbalances and reducing travel distances and times for commuting to a limit of about 40 km or one hour in each direction; and
- to ensure that public transport services address user needs, including those of commuters, pensioners, scholars, the disabled, tourists and long-distance passengers.

2.4.5 GAUTRAIN LEVELS OF SERVICE

The Gautrain Rapid Rail Link ⁶ is a state-of-the-art, rapid rail network planned for Gauteng. The rail connection comprises two links, namely, a link between Tshwane (Pretoria) and Johannesburg, and a link between Johannesburg International Airport and Sandton. This modern train will offer international LOS of public transport with high levels of safety, reliability, predictability and comfort. Travelling at maximum speeds of 160 to 180 km/hr it will reach Tshwane from Johannesburg in less than 40 minutes. The minimum frequency between Johannesburg and Tshwane will initially be six trains per hour per direction and it will operate approximately 18 hours per day. Safety and security of Gautrain passengers and other affected parties are of the utmost importance, and will be extended to other

⁶ www.gautrain.co.za

facilities of the services, such as the station precinct and vehicle parking areas. The intention is that the rail link will be open to passengers by 2010.

2.4.6 GAUTENG RAIL PLANNING SUB-COMMITTEE: COMMUTER RAIL PLAN

The Gauteng Rail Planning (GRP) Sub-Committee established a commuter rail plan containing operational norms and LOS, agreed between the South African Rail Commuter Corporation (SARCC) and Metrorail (GPDPTRW, 2003c). Metrorail operates the commuter rail services in Gauteng in terms of a concession agreement with the SARCC. LOS have been specified by the SARCC, and these include the provision of train services, fares, reliability, punctuality, minimum frequency, safety and security levels, and capacity levels with regard to overcrowding.

2.4.7 CITY OF JOHANNESBURG INTEGRATED TRANSPORT PLAN

The City of Johannesburg set out specific policies to improve the public transport service delivery in the Integrated Transport Plan (ITP) of 2003. The strategy supported the following:

- the promotion of higher residential densities to reduce the cost of public transport infrastructure and services, and to reduce travel times;
- a minimum frequency for off-peak services (including weekends and public holidays) of at least one vehicle trip per hour;
- the improvement of accessibility to the city's transport system for people with disabilities, children, sick people and the illiterate, among others; and
- high frequencies for operations on the strategic network – at least every 2-15 minutes during the peak period and every 30-60 minutes during the off-peak period.

2.5 RESUMÉ

Various conclusions can be drawn from the literature on performance measurement and is summarised below.

- The purpose of KPIs, actual and target LOS is “to tell us where we are in terms of where we want to go”. When developing or selecting KPIs, it should be clear what goal(s) the measure will help achieve.
- There is a general consensus that the concept of service quality related to public transport is made up of factors such as accessibility to the service, reliability, convenience, comfort, crowding, safety, speed of travel, frequency of service and directness of route.
- KPIs should be easily understood, readily measured and not too numerous. Equally important, KPIs should follow from established goals and objectives.
- In the selection of KPIs for a particular operation, two issues should be taken into consideration. Firstly, the collection of the necessary data and the calculation of the indicators are costly in terms of staff, time and resources. Secondly, important aspects of the operation can become submerged under huge quantities of statistical information.
- Uniform and comparable indicators in a wider area are important in order to provide a useful comparison between different areas, e.g. a region or the country as a whole.
- Suggestions for specific target LOS can only be made after careful consideration of local conditions and constraints. There can be no target LOS that can be applied universally, because the requirements and conditions of service differ from place to place.
- A need exists for performance evaluation at the operating level, for policy formulation at several levels of government, and possibly for the determination of subsidy levels.

Table 3 provides more details relevant to the sources discussed in the preceding Sections 2.3 to 2.4. The table lists the KPIs and gives typical target LOS values applicable to these measures. A distinction is made between different modes of public transport, while generic LOS applicable to more than one mode are also specified.

Some sources have provided multiple LOS values (as for the measurement of actual LOS), rather than the target LOS, in which case the value corresponding to a level of service E (at which the performance of an operation becomes unacceptable) is shown to allow comparison between the different sources.

Table 3: Summary of KPIs and their Corresponding LOS for both Local and International Public Transport Operations

KPI	General										Bus				Rail			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
	Modal Integration Gauprans	National White Paper	CT Interim Charter	National Passenger Charter	Translink	NSW Transport Customer Commitment	Yvett Midlands UK	Texas State Dept (Transport Initially)	HCM of 2000	Chicago Transit Authority	Gaunpous	San Francisco Railway Dept	Stramcyle Passenger Charter	Children Railways	GRP Commuter Rail Plan	Gratrain		
Walking distance		1000 m	1000 m				700m 400m (1)	670m		750m	500 m							
Waiting time								10mins										
Travel time (mins) or difference in travel time (ratio)		60	< 60 mins				< equiv fuel & parking cost	1.5	45 mins									
Cost of public transport		10%																
Number of transfers			2					2										
Seat availability (standing time in peak)			20 mins		<15 mins									< 20 mins				
Seat capacity (trains)					1.2			1.1	2.0							1.05		
Seat capacity (bus)								1.1	1.25		1.3							
Safety																		
Security						A	B					C		D	E			
Frequency (peak) - Bus			5 mins				30 mins	40 mins	30 mins		5-10 mins							
Frequency (off-peak) - Bus			20 mins				12 mins	60 mins	30 mins	30 mins	15-30 min		4 mins			10 mins		
Frequency (peak) - Train			5 mins				6 mins											
Frequency (off-peak) - Train			20 mins															
Frequency (off-peak) - Train			20 mins															
Taxi feeder frequency (peak)			2.5 mins															
Taxi feeder frequency (off-peak)			10 mins															
Punctuality - Trains (within 5 min of scheduled time)					90%(2)	92.00%	97%					85%(3)	98.50%	93.00%	90-95%			
Punctuality- Bus (within 5 min of scheduled time)					95%(2)	95.00%	97%				98%							
Reliability (actual service provision)					99%		99.70%	50%	85%			98.50%	98%	99%	99-99.7%	99.50%		
Special needs passengers						F	G							H				

- (1) High-density housing - 700m, Rural areas - 400m
- (2) Trains within 10mins of published time, buses within 7 mins
- (3) Trains within 4 mins of published time

NOTES:

- A. CCTV on all buses and trains
- B. Security guard on trains after 7pm
- C. Bus stops in well-lit areas, internal lighting at shelters, help buttons and CCTV, roving staff daily
- D. 5% reduction in incidents/yr
- E. 5% reduction in National Crime Index (number of crime incidents per 100 000 commuter journeys)
- F. All new stations and trains wheel-chair accessible
- G. 25% of buses within 5 years
- H. 2 Car parking bays to be provided for special needs passengers at each station, at no cost
- I. 24hr assistance to special needs passengers

CHAPTER 3

TRAVEL NEEDS OF COMMUNITIES IN GAUTENG

3.1 BACKGROUND

Travel needs should be distinguished from travel demand. Demand is defined as the number of trips that will occur when a given level of transport service is available. The need to travel, however, exists whether or not passenger transport services are available.

Public transport is less convenient than private transport, although it can be seen as an opportunity for those with no transport available. These inconveniences, however, need to be minimised in order for the service to be attractive. These include the following factors:

- public transport service is not instantly available, i.e. there is a waiting time involved;
- in most cases, it does not adhere to specific travel requirements, i.e. it takes one close but not exactly to where one is going; and
- the trip often requires transfers.

In 1994, the National Passenger Panel defined transport problems for the country as a whole. More specific to the province, the Gauteng Household Travel Survey of 2002 invited responses to general problems experienced with the transport system, in addition to testing commuters' attitudes towards public transport services. These two sources have provided a valuable perspective on the wants and needs of commuters in the province, and will, to a large extent, form the basis of the discussion in this chapter.

3.2 MAIN TRANSPORT PROBLEMS IN GAUTENG

The Gauteng Household Travel Surveys (GPDPTW, 2002) found that the following transport problems are most pressing:

- taxi safety and driver behaviour;
- non-availability of public transport;
- cost of taxi services; and
- public transport being too far away.

3.3 DISSATISFACTION RATINGS

The following section draws attention to the reasons why commuters are dissatisfied with the services of the respective public transport modes (GPDPTW, 2002). In addition, it also deals with the reasons why people, who currently make use of other means of transport, would not consider using public transport. It should be noted that only the three characteristics that scored the highest average dissatisfaction rating are pointed out, together with the top two reasons why people are not making use of the public transport system.

3.3.1 RAIL SERVICES

Table 4 illustrates the satisfaction ratings for rail services.

Table 4: Satisfaction with Service Characteristics of Commuter Rail Users

Attribute	% Satisfied	% Dissatisfied	% No Knowledge
Overall quality of service	52	31	17
Distance of train station from home	69	22	9
Travel time by train	73	17	11
Crime at train stations	24	56	20
Safety from accidents	35	43	22
Frequency of trains during peak hours	22	60	17
Frequency of trains during off-peak hours	60	25	15
Punctuality of trains	56	25	19
Train fares	63	22	15

Source: Data from Gauteng Household Travel Survey (GDPTRW, 2002)

The highest level of dissatisfaction is with frequency of trains during peak hours (60%), followed closely by crime at stations (56%). In terms of safety from accidents, 43% of respondents consider it to be problematic.

Non-users of the rail service stated that trains are not available where they stay (33% of non-users), or that stations are too far (23% of non-users).

3.3.2 BUS SERVICES

Table 5 illustrates the satisfaction ratings for bus services.

Table 5: Satisfaction with Service Characteristics of Bus Users

Attribute	% Satisfied	% Dissatisfied	% No Knowledge
Overall quality of service	57	21	22
Distance from your home	63	23	14
Travel time by bus	54	25	20
Crime at bus stops	47	22	30
Safety from accidents	51	21	28
Frequency of buses during peak hours	49	27	24
Frequency of buses during off-peak hours	32	38	31
Punctuality of buses	41	31	27
Bus fares	43	36	21

Source: Data from Gauteng Household Travel Survey (GDPTRW, 2002)

The following characteristics require attention:

- frequency of buses during off-peak hours (38% dissatisfied);
- bus fares (36% dissatisfied); and
- punctuality of buses (31% dissatisfied).

The main reason for not using bus services relates to the fact that bus stops are too far from work (19% of non-users) and that some non-users prefer to walk to work (15% of non-users).

3.3.3 MINIBUS-TAXI SERVICES

Table 6 shows the satisfaction ratings for minibus-taxi services.

Table 6: Satisfaction with Service Characteristics of Minibus-Taxi Users

Attribute	% Satisfied	% Dissatisfied	% No Knowledge
Overall quality of service	48	36	17
Distance from your home	64	27	9
Travel time by taxi	70	20	10
Violence between associations	26	53	21
Crime on the taxis	23	20	57
Crime at the taxi ranks	36	41	23
Safety from accidents	24	59	17
Frequency of taxis during peak hours	56	28	16
Frequency of taxis during off-peak hours	52	29	19
Punctuality of taxis	58	26	15
Taxi Fares	41	45	15

Source: Data from Gauteng Household Travel Survey (GDPTRW, 2002)

The following is a list of attributes with relatively high levels of dissatisfaction:

- safety from accidents (59% dissatisfied);
- violence between associations (53% dissatisfied); and
- taxi fares (45% dissatisfied).

The main reason for not using taxi services is private car usage (39% of non-users). Another argument that was highlighted by non-users is that taxis are dangerous with respect to crime and accidents (13% of non-users).

3.4 PROBLEMS IDENTIFIED BY NATIONAL PASSENGER PANEL

In 1994, the National Passenger Panel (NPP) (NDoT, 1994) identified certain issues in terms of the travel needs of disadvantaged communities. These are presented below.

- Nearly all disadvantaged commuters regularly travelled to work at least five days a week using the same mode of transport.
- 20% of commuters expressed dissatisfaction with their present mode of getting to work. The majority were dependent on public transport, but accessibility was low, especially the accessibility of rail services.
- Vehicle ownership is low among black households. As household income rises above R3 500, vehicle ownership increases and the demand for public transport decreases.
- Those who have access to cars were in favour of using them, primarily for their speed and ability to take commuters door-to-door. However, the high cost of travel was a disadvantage.
- Out-of-vehicle travel times are long. These are longer for buses and trains than for taxis and private cars. Up to 50% of travel time was spent waiting, and walking to and from boarding and alighting points. Commuters were particularly dissatisfied with waiting times.
- Fares were somewhat unaffordable at 9% of personal income in 1994. These were almost double what commuters regarded as affordable (5%). A relatively small proportion of commuters (15%) would be willing to pay more for a premium transport service. Train services were regarded as relatively cheap, while one of the main complaints against taxis was the high fares charged.
- A lack of safety regarding both accidents and crime caused great dissatisfaction among commuters, especially with regard to taxi services. Although taxis travel faster and are more accessible, the violence and reckless driving are a concern. This was the mode used by nearly half of the commuters.
- Crowding and poor levels of service were problems associated with taxis and trains.
- A lack of public transport at night and over weekends did not accommodate those commuters working over weekends and at odd hours.

3.5 RESUMÉ

Table 7 gives a summary of problems highlighted for the different public transport modes.

Table 7: Summary of Public Transport Problems in Gaunteng

Top 3 Service Characteristics with High Dissatisfaction			
	RAIL	BUS	TAXI
1	Frequency of trains during peak hours	Frequency of buses during off peak hours	Safety from accidents
2	Crime at stations	Bus fares	Violence between associations
3	Safety from accidents	Punctuality of buses	Taxi fares
Top 2 Reasons for not Using a Service			
1	Not available	Bus stop too far from work	Use own car
2	Stations too far from home	Walk to work	Safety and security issues

From the Gauteng Household Travel Surveys, the overarching public transport characteristics requiring attention are:

- frequency of service;

- safety and security issues;
- fares, i.e. cost of the service; and
- availability of the service.

Most problems identified by the National Passenger Panel in 1994 are consistent with problems experienced at present, with the following exceptions:

- crowding in taxis and trains;
- out-of-vehicle travel time such as walking and waiting; and
- limited service hours.

CHAPTER 4

DETERMINATION OF KEY PERFORMANCE INDICATORS

4.1 BACKGROUND

This chapter aims to formulate a prioritised list of KPIs. This needs to link with the travel needs of communities as earlier defined. The most pressing transport problems earlier defined relate to:

- frequency of service;
- safety and security issues;
- cost of public transport;
- availability of public transport service;
- crowding in taxis and trains;
- out-of-vehicle travel time; and
- limited service hours.

KPIs based on the needs listed above provide a mechanism to evaluate the performance of the system, and thus target public transport LOS can be developed. The resulting target LOS are defined as a degree of excellence or attainment for any given KPI. These are normally expressed as a single target value. Target LOS can also have minimum levels of acceptability, referred to as minimum LOS, which are lower or upper limits to target LOS.

4.2 THE SELECTION OF KEY PERFORMANCE INDICATORS

4.2.1 GENERAL CONSIDERATIONS FOR THE SELECTION OF KPIs

The following factors draw on various aspects identified in the literature (see also Chapter 2) and should be considered in the selection process.

- KPIs must be easily understood, readily measured and not too numerous.
- They must reflect efficiency of both land use and transportation.
- The collection of data and calculation of the KPIs must not be too costly in terms of time and resources, and must utilise existing information as far as possible.
- The purpose for which KPIs are to be used dictates the selection process.
- KPIs must be applied on a provincial basis - the same criteria must apply regardless of the area in the province which is being monitored.
- KPIs must be specific enough to indicate areas of transport deficiency accurately.
- They must allow repeated monitoring of the same area over time.

When selecting KPIs, the above must be considered. The following section identifies the KPIs conforming to the above, together with typical target values drawn from the international and local examples of public transport performance measurement presented in Sections 2.3 and 2.4 respectively.

4.2.2 SELECTING KEY PERFORMANCE INDICATORS RELEVANT TO GAUTENG

(a) KPIs Required by the National Land Transport Strategic Framework

The National Department of Transport will use key performance indicators (KPIs) to help monitor the implementation of the main policies for land transport, in national, provincial and local spheres.

Two types of KPIs are identified in the National Land Transport Strategic Framework (NLTSF) (NDoT, 1998b). Customer-based KPIs measure the performance of the land transport system from the customer's point of view, and they, therefore, pertain to this study in particular. NLTSF-based KPIs measure the progress of the national and provincial departments of transport and local authorities in implementing the strategies contained in the NLTSF. Provincial departments of transport will be required to report on the KPIs (where appropriate) for their province, within six months after the end of every financial year. Table 8 summarises the KPIs found in this document (NDoT, 1998b).

(b) KPIs as Identified by the Transportation Coordination Committee

The specification document prepared by Work Group 1 of the Transport Coordination Committee (TCC:WG1) for the measurement of KPIs in Gauteng, identified two broad areas for which KPIs have been established (GPDPTRW, 2003b). These areas included customer service KPIs, as well as KPIs for operational system performance. The latter was then broken down into infrastructure, services, vehicle and accident, and financial performance indicators. Only customer service performance indicators, services as well as vehicle and accident performance indicators (as part of operational KPIs) will be considered within the context of this research. A summary is contained in Table 8.

(c) KPIs Resulting from GPMC Study

The Greater Pretoria Metropolitan Council (GPMC) initiated a study in 1998 to determine KPIs for monitoring transport in their area of jurisdiction. The study dealt with the development of KPIs and the resulting LOS. Although applicable to Pretoria, the study serves as a useful reference. KPIs and LOS that resulted from the study will thus be examined as part of this thesis (see Table 8).

(d) Summary of KPIs from Different Sources

Table 8 presents a summary of the preferred KPIs. The indicators are supportive of national and provincial transport policy, as well as the relevant identified transport problems. The table links the KPIs identified by the different sources to the key public transport objectives and user requirements or needs.

Table 8: Comparison of KPIs Addressing Public Transport Needs

No.	Identified Public Transport Problem	Corresponding Public Transport Objective	Key Performance Indicators		
			NLTSF (National)	TCC WG1 (Provincial)	GPMC Study (Local)
1	Services not available	Improved mobility of public transport users (including that of the disabled and learners)			Total public transport route kms per 1 000 population
					Availability of public transport to preferred destination during peak and off-peak hours
2	Long travel times (out-of-vehicle) / stations too far away	Minimise travel distance / time Enhance accessibility to public transport	Average travel time to work for all urban public transport commuters	Average travel time (door-to-door) for work trips by public transport	Percentage of commuters travelling less than one hour to work
			% of rural people living within 2km access to regular public transport services		Percentage of commuters travelling less than 40 km from home to work and vice versa
3	Frequency of trains (Including crowding)	Rail efficiency		Total number of train users	Ratio of number of passengers to available service capacity in peak period
				Total peak period train passenger boardings and average train capacity utilisation per 1 000 population	
4	Frequency of Buses	Bus efficiency		Total number of bus users	Average number of passengers carried per bus per day
				Peak period bus passenger departures, bus capacity utilisation, bus seat capacity per 1000 population	
5	Fares too high	To provide affordable public transport services	Percentage of households spending more than 10% of disposable income on public transport	Average travel cost (monthly) for all trips to and from work	Percentage of commuters spending less than 10% of disposable income on transport to work
				% of public transport commuters spending more than 10% of their disposable income on transport to work	
6	Overall quality of service	Satisfaction of passenger user needs (including the disabled and learners)		No of commuters not making a transfer, making 1 transfer, making 2 or more transfers	Percentage of public transport passengers / users satisfied with travel times, costs, security and safety, by mode
				% of commuters dissatisfied with fares, facilities, safety and security, etc.	
7	Lack of safety and security	Improved transport safety	No. of road fatalities by all modes, and public transport fatalities per 100 million vehicle km	Number of licensed motor vehicles in the different categories	Number of accidents (minor, serious and fatal) per 100 000 vehicles in area, by mode
		Promote personal safety and security		Average age of motor vehicles by capacity for each year since 1996	Number of crimes reported per 1 000 passengers
				Number of all road traffic fatalities, public transport fatalities, and pedestrian fatalities per 100 million vehicle km	

The public transport user requirements or needs discussed earlier in the text (see Section 3.5) can be categorised as follows:

- availability;
- accessibility;

- frequency;
- cost;
- quality of service; and
- safety and security.

Table 9 lists the possible KPIs selected within the scope of these parameters, and is based on the list of KPIs given in Table 8. Preliminary minimum and target LOS are proposed in Section 4.3, based on LOS values taken from the various case studies as presented in the literature review, in addition to consultation with local experts to ensure contextual validity. These minimum and target LOS were re-evaluated once the status quo information on pilot areas had been obtained. Realistic minimum and target LOS can only be established once the base line conditions have been measured.

Table 9: Possible KPIs and Typical Target Levels of Service

No.	Parameter	KPI	KPI Unit	Typical Target Levels of Service	Source
1	Availability	Hours of service availability	Hours / day	Target: 18-24 hrs	TRB, 2000 (HCM)
		Service coverage	% PT supportive area	Target: 90%	TRB, 2000 (HCM)
		Total public transport route kms per 1 000 population	Km per 1 000 population	Urban areas: 2km public transport routes / 1 000 population Rural areas: 0.5km public transport routes / 1 000 population	GPMC, 1998
2	Accessibility	Walking distance to public transport stop	Metres	400m, representing 5 mins walking time	Dept of Environment, 1973 UK Guidelines ⁽¹⁾
		% of commuters travelling less than 40km from home to work and vice versa	% commuters	1 km in urban areas Maximum walking distance not more than 750m 80% of public transport commuters should travel less than 40km from home to work and vice versa ⁽²⁾	NDOT White Paper, 1997 Chicago Transit Authority Service Standards, 2001 GPMC, 1998
3	Frequency	Number of vehicles / hour in: - Corridor routes (bus/train) - Non-corridor routes (taxi)	Vehicles per hour	Target: 12 (1 vehicle every 5 minutes) Target: 6 (1 vehicle every 10 minutes) Target: 3 (1 vehicle every 20 minutes) Target: 2 (1 vehicle every 30 minutes)	City of Cape Town, 2001 (Interim Service Charter)
		Service frequency	Vehicles per hour	Maximum interval between buses and trains less than 30 mins, i.e. 2 vehicles per hour	Chicago Transit Authority Service Standards, 2001
4	Cost	Waiting time	Minutes	Target: 0 minutes ⁽³⁾	Texas TI, 2000
5	Overall quality of service	% of commuters spending less than 10% of disposable income on public transport, and ave travel cost	- % commuters - Rands	90% of commuters should spend less than 10% of disposable income on transport to work	GPMC, 1998
		Punctuality: Arrivals within 5 minutes of scheduled time (late and early)	Ratio	95% >80% of arrivals within 30% or 10 mins of scheduled headway (which	Gautrain Official Website
6	Safety & Security	Standing time in vehicle	Minutes	Max 20 minutes	San Francisco Rail, 2001
		% commuters satisfied with fares, travel times, safety and security, etc.	% commuters	90-95%	San Francisco Rail, 2001
7	Safety & Security	Crowding ⁽⁴⁾ : actual service capacity vs. service schedule exceeded with 5%	Ratio Passenger density	99.5% 1 seat / passenger 130% during peak periods, 135% maximum	Gautrain Official Website Texas TI, 2000 San Francisco Rail, 2001 GPMC, 1998
		Security: Number of crimes per 1 000 passengers	% crimes	5% reduction / annum in crimes reported / 1 000 passengers	San Francisco Rail, 2001
8	Safety & Security	Safety: Number of road fatalities by all modes, and PT fatalities per 100 million veh km	% accidents	5% reduction / annum in accidents / persons injured and killed / 1 000 busses & 10 000 taxis. Rail insignificant for monitoring purposes.	GPMC, 1998

(1) Department of the Environment (1973). Bus Operation in Residential and Industrial Areas. Circular 82/73 United Kingdom.

(2) Greater Pretoria Metropolitan Council (1998). Phase 1 of a Pilot Project on the Assessment of Key Performance Indicators in the Greater Pretoria Metropolitan Council Area. Khuthele Projects. Pretoria.

(3) A target value of 0 minutes for waiting time is not practical in a South African context, but shown here as it is a true reflection of what all commuters expect or want their waiting time to be.

(4) Crowding can also be measured by the percentage of vehicles that pass published time points during measurement periods unable to pick up passengers due to crowding without being followed within 3 minutes or less by another vehicle on the same route with space for all waiting passengers (to be less than 5%) - San Francisco Municipal Railway Department (2001).

4.3 IDEAL PUBLIC TRANSPORT KPIS AND LOS TO BE TESTED

The preceding section lists various possible KPIs and target LOS for each identified user requirement. However, the list is rather extensive and these items will require significant resources to test them all for applicability in Gauteng. With due regard to these and other limitations, it was decided to select a smaller number of ideal KPIs as a starting point. Hence, the following ideal KPIs, together with their corresponding minimum and target LOS, are to be tested for application in Gauteng.

Table 10: Ideal KPIs and Corresponding Minimum and Target Levels of Service

No	Parameter	KPI	Levels of Service (1)		
			Bus	Rail	Taxi
1	Availability	Hours of service	18 (24)	18 (24)	18 (24)
2	Accessibility	Walking distance to public transport	1 000m (500m)	1 000m (750m)	750m (400m)
3	Frequency	Number of departures per hour in peak period	6 (12)	6	12
4		Number of departures per hour in off-peak period	1 (2)	1 (2)	4
5		Average waiting time in peak period	5 mins (2.5)	5 mins	2.5 mins
6	Quality of Service	Percentage capacity utilisation (volume to capacity ratio)	1.00	1.00 (0.90)	1.00
7	Cost	Percentage of income spent on public transport	10%	10%	10%
8	Safety	Reduction in accident ratings per 1 000 commuter journeys (per year)	5%	5%	5%
9	Security	Reduction in crime incidents per 1 000 commuter journeys (per year)	5%	5%	5%

(1) Target levels of service are indicated in brackets.

CHAPTER 5

SEGMENTATION OF PASSENGER MARKET AND SELECTION OF PILOT AREAS

5.1 BACKGROUND

This chapter comprises two components. The first is segmentation of the urban passenger market in Gauteng based on income, travel distance/travel time and the existing mode choice. The market segmentation has been carried out for two reasons. This is to determine whether travel attributes are different for the various segments of the public transport market (e.g. longer walking distances for scholars or low-income users). The second reason is to establish the number of users aspiring to private transport (selective customers) and whether it is feasible to attempt to retain them in the public transport market. The second component is the initial screening of the province to identify pilot areas in which ideal public transport LOS are to be tested.

5.2 NATIONAL PASSENGER MARKET SEGMENTATION

The segmentation of the passenger market by Moving South Africa (MSA) (NDoT, 1998a) was aimed at gaining a better understanding of the characteristics of urban transport travellers and at targeting state expenditure more effectively through strategic adjustments to urban transport systems. The segmentation was based on income, travel distance (time) and the existing mode choice. Table 11 shows the passenger market segments in South Africa in 1996, as well as the projected growth for each market segment.

Table 11: Urban Passenger Market Segments and Projected Growth (South Africa)

% of urban population (1996)	MARKET SEGMENTS	2020 projected % growth
13%	Stranded customers: no affordable transport available 2.8 million in 1996; projected to grow to 3.6 m by 2020	28%
25%	Strider customers: prefer to walk or cycle 5.4 million in 1996; projected to grow to 6.9 m by 2020	28%
19%	Survival customers: captive to cheapest mode of public transport 4.1 million in 1996; projected to grow to 5.1 m by 2020	24%
10%	Sensitive customers: captive to best public transport option 2.1 million in 1996; projected to grow to 2.6 m by 2020	25%
19%	Selective customers: can afford a car but willing to use public transport 5.4 million in 1996; projected to grow to 6.9 m by 2020	39%
14%	Stubborn customers: will only use car 3.0 million in 1996; projected to grow to 5.6 m by 2020	88%

Source: Moving South Africa, 1998

MSA specified that priority should be given to the “stranded” and “survival” customers. These are the customers who have no affordable transport available, or who are captive to the cheapest mode of public transport. From a strategic perspective, MSA was concerned about the transport implications of the high growth rate of the “selective” and “stubborn” customers (growth will amount to 39% and 88% respectively) between 1996 and 2020. The growth in car ownership and usage could have a negative impact on both the urban environment, and also on public transport patronage.

The recommendations of MSA called for the following strategic actions:

- densification of transport corridors;
- optimal deployment of modes to better meet customer service requirements; and
- improved performance levels, i.e. improved operations of urban public transport.

5.3 GAUTENG PASSENGER MARKET SEGMENTATION

TRC Africa, responsible for the national MSA market segmentation in 2000, found that applying the MSA market segmentation (and the resulting assumptions) to Cape Town (and urban areas in general) was unrealistic. To illustrate this, a walk of up to 30 minutes (instead of 20 minutes) was not considered unreasonable by commuters in Cape Town, and therefore TRC Africa developed an alternative segmentation (TRC Africa, 2002). The basis for the alternative segmentation applicable to urban areas, and thus relevant to Gauteng, is as follows:

- Stranded – walking/cycling longer than 30 minutes, but excluding households with monthly incomes in excess of R2 500;
- Strider – anyone who walks or cycles for less than 30 minutes, regardless of income;
- Survival – users of public transport with monthly household income less than R1 500;
- Sensitive – users of public transport with monthly household income between R1 500 and R4 000;
- Selective – users of public transport with monthly household income above R4 000, and those with car availability but earning less than R6 000; and
- Stubborn – users with car available and monthly household income above R6 000.

The market segmentation, initially developed for Cape Town, was applied to commuter trips in Gauteng and is depicted in Figure 3. Figure 3 shows the travel modes used for work trips in each market segment. The public transport market shows no relationship between income group and the mode of transport chosen, as the modal split is relatively similar for all three segments. Taxis appear to be the dominant mode of public transport.

The public transport market comprises 44% of the total market segment (49% of motorised trips). It is evident that only a small percentage of commuters in Gauteng walk (13%), which proves that walking trips do not influence attributes of the commuter market. Commuter trips comprise about 35% of all trips in Gauteng during the morning peak period (GPDPTRW, 2004a).

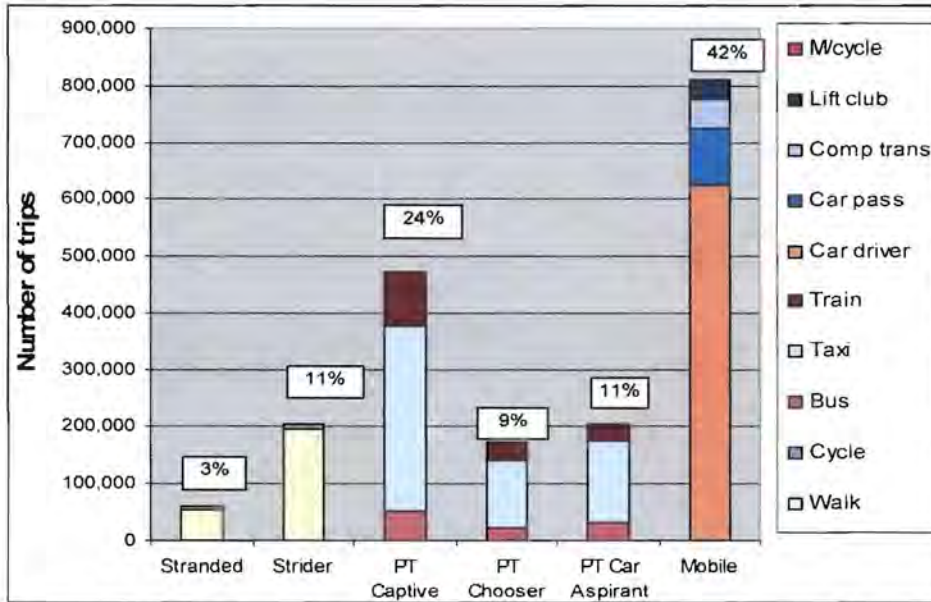


Figure 3: Market Segmentation of Commuter Trips in Gauteng

Source: Data from Gauteng Household Travel Survey (GDPTRW, 2002)

Figure 4 shows the market segmentation for education trips in Gauteng. Education trips constitute the majority of trips in Gauteng, and are estimated at about 47% of all morning peak-period trips (GDPTRW, 2004a). In comparison, commuter trips comprise about 31%, while purposes such as shopping, leisure and other trip purposes account for the remaining 22%. Of all education trips, only 18% can be attributed to public transport modes, while the majority of trips (57%) are non-motorised journeys (55% walking). This means that the majority of scholars either reside within walking distance of their place of education, or face long walking distances to get to school.

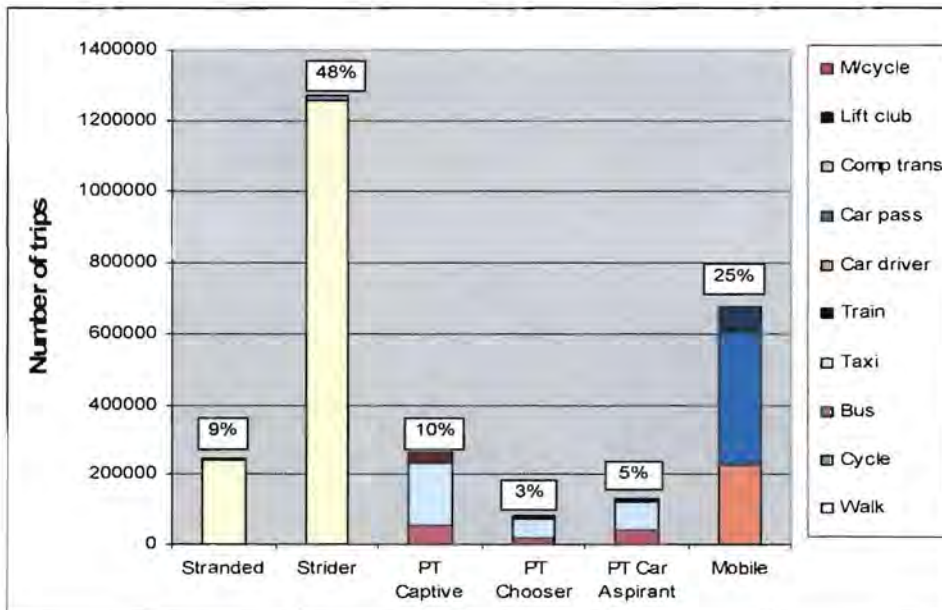


Figure 4: Market Segmentation of Education Trips in Gauteng

Source: Data from Gauteng Household Travel Survey (GDPTRW, 2002)

Based on the market segmentation of passenger trips in Gauteng, the observations listed below can be made.

- The education market segmentation reveals substantial differences compared to the commuter market in Gauteng. The difference in the modal split between the commuter and scholar markets is significant, and cognisance must be taken of this fact when analysing public transport modal operations.
- For both these trip purposes, captive public transport users comprise the majority of the public transport market. Focus must be placed on these users and their needs. This observation is in line with the objectives of this study, i.e. to focus on those users who will benefit the most from improvements to the system.
- "Car aspirant" or selective customers (about to make a shift to private transport) comprise a relatively small segment of the market (11% commuter trips, 5% education trips). In the light of the promotion of public transport, it would make sense to retain this segment to the public transport market, but require further investigation to understand their public transport needs better.
- Likewise, the public transport needs of "stranded" and "strider" customers require further investigation. An improved public transport system ought to serve as an alternative mode of transport for all those not able to afford private motorised transport, including those dependent on walking. This study, however, will not consider the needs of these market segments, as the complexity of these segments calls for further research in itself.

5.4 IDENTIFICATION OF PILOT AREAS

This section focuses on the identification of pilot areas to test the ideal KPIs identified in Chapter 4. It presents base-line data (demographic, socio-economic and transportation characteristics) for the whole province. Much of the data has been summarised in a series of maps and tables. The data will be used to identify pilot areas. Criteria need to be identified that will provide an accurate depiction of the province's travel and socio-economic conditions.

As stated before, this research concentrates particularly on areas that will benefit most from improvements to the system. These areas are characterised by households with low levels of income, where individuals cannot afford motorised transport. As a result, car ownership figures are generally low, meaning that many of these users are captive to public transport modes in order to make travel possible. In light of this, the following criteria were found to be suitable for the analysis of zones in the province:

- average monthly income per household;
- average car ownership per household; and
- percentage of public transport utilisation.

The selection process for pilot areas is schematically shown in Figure 5.

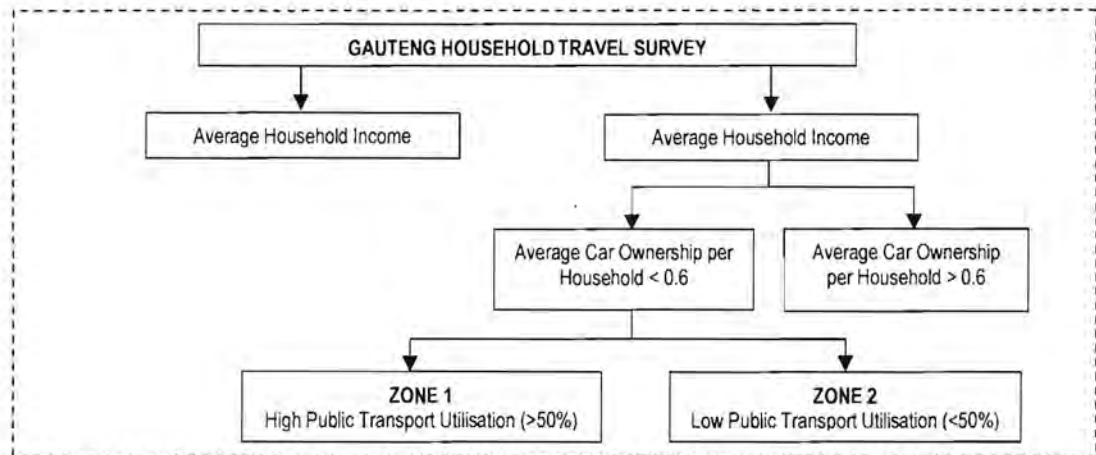


Figure 5: Selection of Pilot Areas Shown Schematically

5.4.1 POTENTIAL ZONES

The demarcation of boundaries was based on the zones used by the various Gauteng transportation models, as well as considering the delineation of the 1996-Census Enumerator Areas (EA's). Approximately 22 000 EA's were converted to 826 traffic zones, which in turn were consolidated into sub-regions. Table 12 allocates the sub-regions to metropolitan areas (GDPTRW, 2004a). Figure 6 maps all the sub-regions in the study area. For the purposes of this research, sub-regions (instead of traffic zones) will be considered as they are representative of communities in the province.

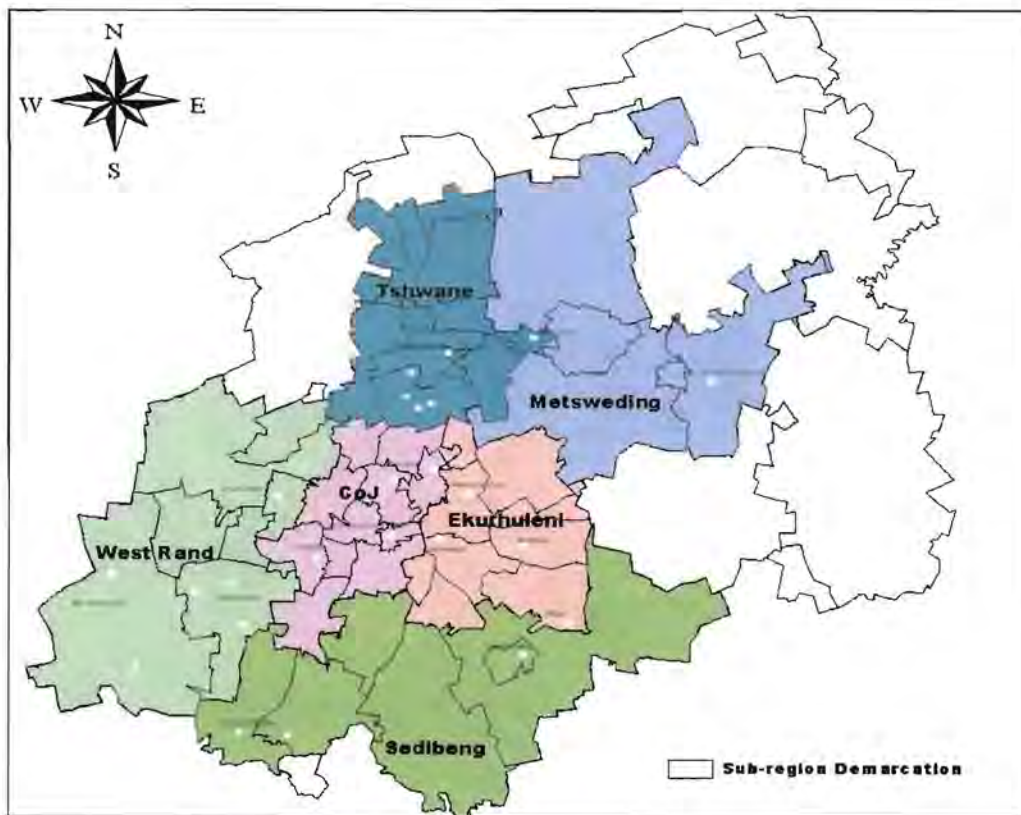


Figure 6: Study Area and Spatial Demarcation of Sub-Regions

Source: Gauteng Household Survey Report, (GDPTRW, 2004a).

Table 12: Sub-Regions per Metropolitan / District Area in Gauteng

Metropolitan / District Area	Sub-Region	
	No	Name
City of Tshwane	1	Temba, Winterveld, Mabopane, Garankuwa
	2	Soshanguve
	3	Akasia / Rosslyn
	4	Rooiwal
	5	Pretoria North
	6	Moot
	7	Mamelodi / Nellmapius
	8	Pretoria East
	9	Pretoria CBD
	10	Pretoria West / Atteridgeville
	11	Centurion
	12	Tshwane West Rural
City of Johannesburg	13	Region 1
	14	Region 2
	15	Region 7
	16	Region 3
	17	Region 5
	18	Region 4
	19	Region 8
	20	Region 9
	21	Region 10
	22	Region 6
	23	Region 11
Ekurhuleni	24	Tembisa / Clayville
	25	Ekurhuleni Rural
	26	Kempton Park / JIA / Boksburg North
	27	Daveyton
	28	Brakpan / Benoni / Springs
	29	Kwalsaduza
	30	Germiston / Boksburg
	31	Alberton
	32	Katorus
	Sedibeng DM	33
34		Lesedi LM Rural
35		Midvaal LM Rural East
36		Midvaal LM Rural West
37		Emfuleni LM Urban (Evaton, VdBP, Vereeniging)
38		Emfuleni LM Rural
West Rand DM	39	Westonaria LM
	40	Merafong LM
	41	Randfontein LM Urban
	42	Randfontein LM Rural
	43	Mogale City LM Urban (Krugersdorp, Kagiso)
	44	Mogale City LM Rural
	45	Gauteng District Management Area (Cradle of Humankind)
Metsweding DM	46	Nokeng Tsa Taemane LM Rural
	47	Nokeng Tsa Taemane LM Urban (Cullinan / Rayton)
	48	Kungwini LM Rural West
	49	Kungwini LM Urban (Bronkhorstspuit, Zithobeni)
	50	Kungwini LM Rural East

Source: Gauteng Household Survey Report, (GDPTRW, 2004a).

5.4.2 ZONE ANALYSIS

Map 1 depicts the utilisation of public transport spatially (GDPTRW, 2002). The regions with the highest utilisation are the Daveyton area, Mamelodi, Soshanguve, Mabopane, Krugersdorp, and Midvaal Rural. These areas have public transport usage in excess of 80%.

In contrast, some of the areas with low utilisation are Pretoria East, Alberton, large parts of the city of Johannesburg and most of the rural areas.

Map 2 illustrates the average household car ownership in the province (GDPTRW, 2002). The greatest concentration of households with very low car ownership (up to 0.4 cars/household) occurs in the south of the province (Westonaria, Emfuleni, etc), in addition to Mamelodi, Ekurhuleni Rural and the north-western areas (Soshanguve, Mabopane, etc.).

Low-income regions are concentrated along the same areas as were identified for very low car ownership above (see Map 3) (GDPTRW, 2002). Most of these regions, such as Soshanguve, Mabopane and Mamelodi, have extremely high public transport utilisation.

In view of the objectives of this study, attention should be given to areas where the greatest need for public transport exists and which will benefit most from improvements to the system, i.e. low-income areas (with low car ownership), where there is a significant dependence on public transport. A weighted-sum evaluation was conducted to identify two areas conforming to the following criteria:

- Area 1: Low-income areas with low car ownership, and with high public transport utilisation;
- Area 2: Low-income areas with low car ownership, and with low public transport utilisation.

The criteria were weighted as depicted in Table 13.

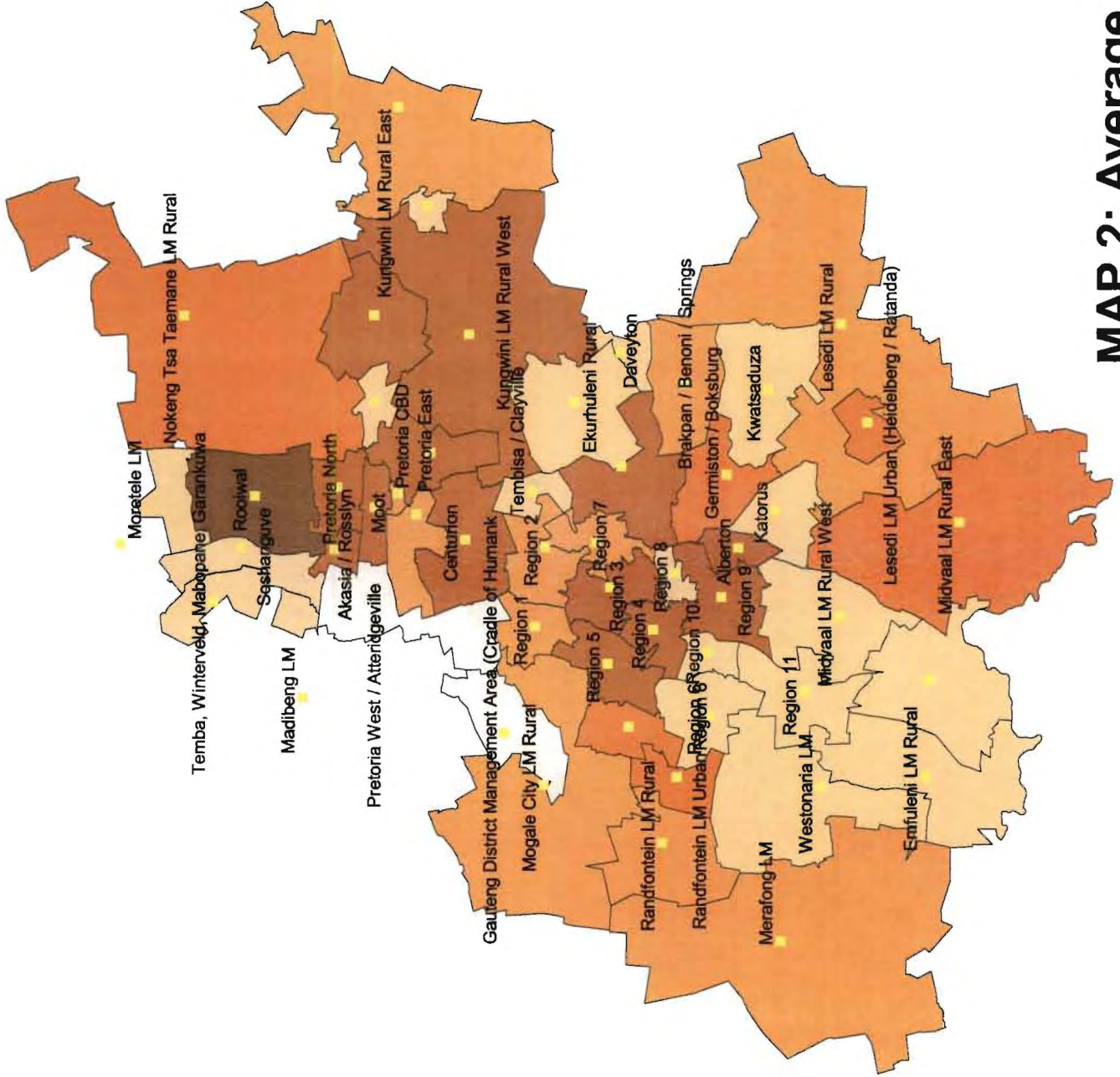
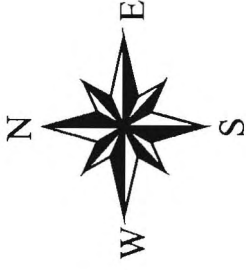
Table 13: Weighting of Criteria for Selection of Pilot Areas

Criteria	Comments	Weighting ⁽¹⁾
Percentage of public transport utilisation	High utilisation ranked higher for area 1 Low utilisation ranked higher for area 2	50 points
Average monthly household income	Low-income areas ranked higher	25 points
Average household car ownership	Low car ownership areas ranked higher	25 points
TOTAL		100 points

(1) Weighting of criteria decided upon in consultation with key transportation experts, Messrs Vorster & Britz (2004).

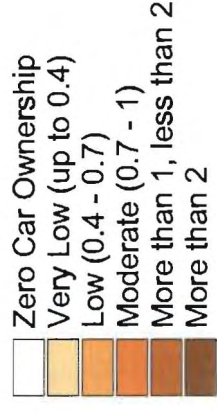
Areas with higher rankings in terms of the criteria listed above, qualify as candidates for possible selection as pilot areas. The detailed analyses are shown in Annexure A.

Based on the results of the weighted sum evaluation, it was decided that priority should be given to **Soshanguve**, which conforms to the criteria set for area 1, and **Brakpan/Benoni**, which conforms to the criteria set for area 2. It should also be noted that each public transport mode is represented in these two areas. This is necessary for the validation of KPIs for each of the different modes. Soshanguve has approximately 30% bus utilisation, 43% minibus-taxi utilisation and 27% train utilisation. The modal split for the Brakpan/Benoni area consists of 7% bus, 79% minibus-taxi and 14% train utilisation (GDPTRW, 2004a). A profile for each of the pilot areas is also provided in Annexure A.

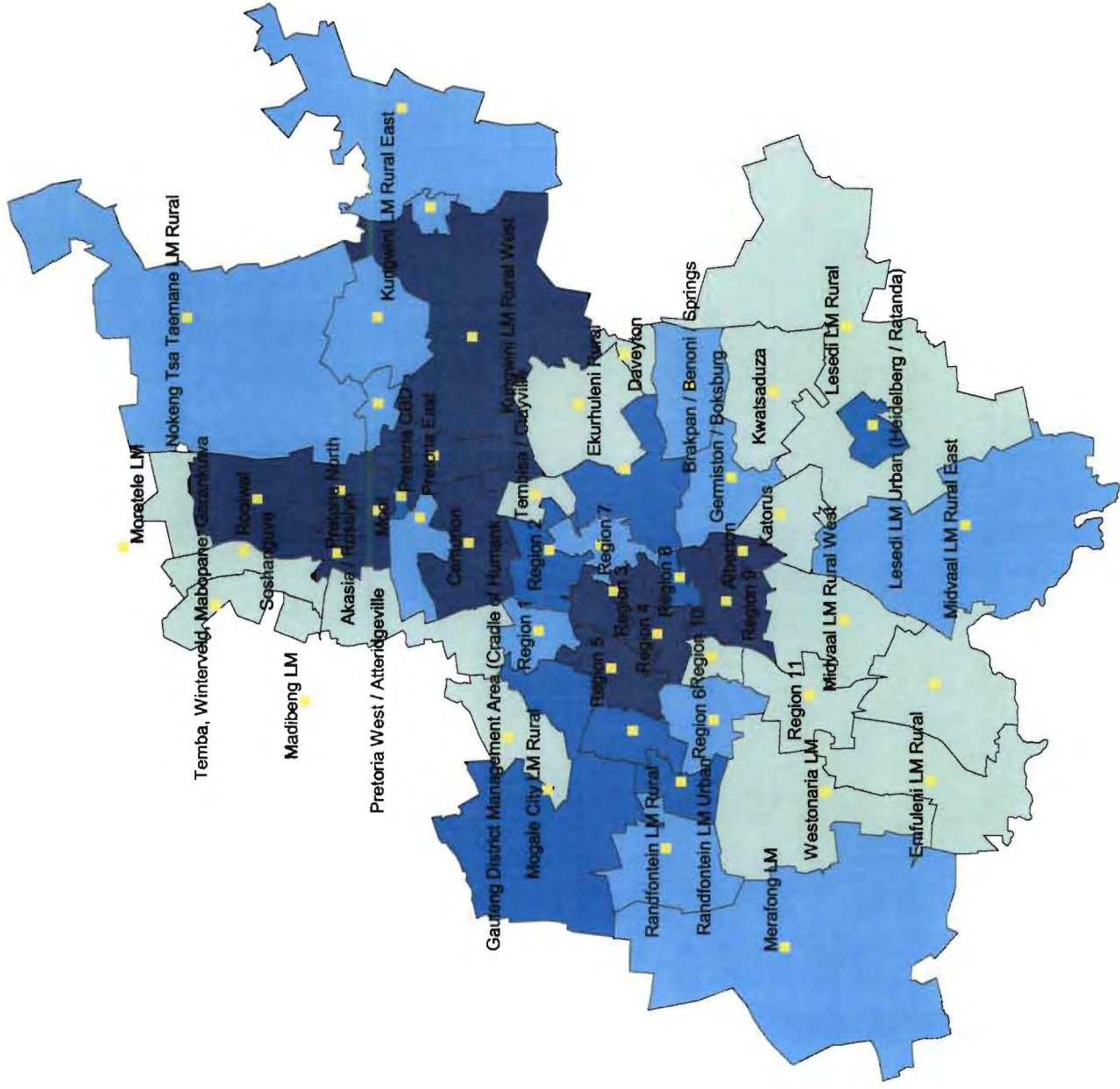
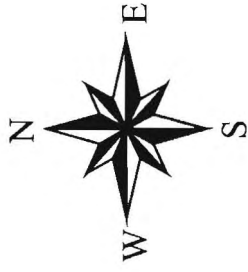


LEGEND

Average Household Car Ownership



MAP 2: Average Household Car Ownership



LEGEND

Average Monthly Income per Household

- Low Income (up to R2 500)
- Middle Income (R2 500 - R4 000)
- Middle Income (R4 000 - R6 000)
- High Income (above R6 000)

MAP 3: Average Monthly Income per Household

CHAPTER 6**STATUS QUO ANALYSIS****6.1 BACKGROUND**

This section tests the proposed ideal KPIs and their corresponding LOS in the pilot areas identified in Chapter 5. As a starting point, the actual LOS of the selected ideal public transport KPIs will be determined collectively for the province, after which the actual LOS will be determined for the pilot areas. Minimum and target LOS are reiterated in Table 14. It should be noted that no status quo data are available for percentage capacity utilisation at a provincial level, or for KPIs related to safety and security in the pilot areas.

Table 14: Ideal KPIs and Corresponding Minimum and Target Levels of Service

No	Parameter	KPI	Levels of Service (1)		
			Bus	Rail	Taxi
1	Availability	Hours of service	18 (24)	18 (24)	18 (24)
2	Accessibility	Walking distance to public transport	1 000m (500m)	1 000m (750m)	750m (400m)
3	Frequency	Number of departures per hour in peak period	6 (12)	6	12
4		Number of departures per hour in off-peak period	1 (2)	1 (2)	4
5		Average waiting time in peak period	5 mins (2.5)	5 mins	2.5 mins
6	Quality of Service	Percentage capacity utilisation (volume to capacity ratio)	1.00	1.00 (0.90)	1.00
7	Cost	Percentage of income spent on public transport	10%	10%	10%
8	Safety	Reduction in accident ratings per 1 000 commuter journeys (per year)	5%	5%	5%
9	Security	Reduction in crime incidents per 1 000 commuter journeys (per year)	5%	5%	5%

(1) Target levels of service are indicated in brackets.

6.2 STATUS QUO FOR IDEAL KPIs IN PROVINCE**6.2.1 WALKING DISTANCE**

Table 15 sets out the perceived walking times from home to train stations, bus stops and taxi ranks, as was recorded as part of the Gauteng Household Travel Surveys in 2002.

The average walking distance for train services is by far the longest and is in excess of 1 000 metres, which is to be expected considering the concentrated and localised distribution of train stations, i.e. the area covered by one station is small. Average walking distances to both bus stops and taxi ranks are below 1 000 metres.

Table 15: Perceived Walking Distance from Home to Public Transport in Gauteng

Public Transport Mode	Minutes Walking to Service	Equivalent Distance (m)
Walking time / distance to train station	15.7 (16.6)	1 230 (1 300)
Walking time / distance to bus stop	6.9 (8.2)	540 (642)
Walking time / distance to taxi rank	7.4 (8.2)	580 (642)

Note 1: Equivalent distance is based on a walking speed of 4700 m per hour (NDoT, 1994a)

Note 2: Walking time and distance for low-income households is indicated in brackets

Source: Gauteng Household Travel Survey Report (GDPTRW, 2004a).

6.2.2 FREQUENCY AND WAITING TIME

Table 16 portrays perceived waiting times at train stations, bus stops and taxi ranks. No information is available for the frequency of public transport modes at a provincial level.

Table 16: Perceived Waiting Time for Public Transport in Gauteng

Public Transport Mode	Waiting Time for Service (minutes)
Waiting time at train station	7.4
Waiting time at bus stop	5.0
Waiting time at taxi rank	5.1

Source: Gauteng Household Travel Survey Report (GDPTRW, 2004a).

The perceived waiting time for train services is on average higher than for buses and taxis. However, all public transport modes have average waiting times of below 10 minutes.

6.2.3 PERCENTAGE INCOME SPENT ON PUBLIC TRANSPORT

Table 17 provides data on the number of commuters spending various proportions of their personal income on public transport.

Table 17: Percentage of Personal Income Spent on Public Transport in Gauteng

Percentage of Income Spent on Public Transport	Percentage of Commuters
1-5 %	17.8 %
6-10 %	22.7 %
11-15 %	19.0 %
16 – 20 %	13.5 %
More than 20 %	27.0 %

Source: National Travel Survey (NDoT, 2004b).

The table shows that approximately 60% of public transport commuters are spending more than 10% of their personal income on public transport.

6.2.4 SAFETY AND SECURITY

(a) Satisfaction Ratings

The following table summarises the satisfaction ratings regarding safety and security for the three public transport modes in the province.

Table 18: Satisfaction Ratings for Safety from Accidents and Security Levels

Public Transport Mode	Safety from Accidents (% satisfied)	Security Levels at Stations and on Vehicles (% satisfied)
Train	35	25
Bus	51	53
Taxi	24	30

Source: National Travel Survey (NDoT, 2004b).

All modes have rather low satisfaction ratings as far as safety from accidents is concerned, with buses perceived to be the safest, and taxis to be the most dangerous. Moreover, security levels are not perceived to be good, with train services receiving the lowest rating, with only 25% of customers considering trains to be secure. Bus satisfaction ratings for both safety and security are nearly double those of the other two public transport modes.

(b) Vehicle Accident Statistics

Detailed information regarding the type/severity of vehicle accidents for a period of four years (2000 to 2003) was obtained from the Directorate Traffic Management in the Gauteng Provincial Department of Community Safety. Figure 7 sets out the number of accidents according to degree of severity involving public transport vehicles for the years 2000 to 2003.

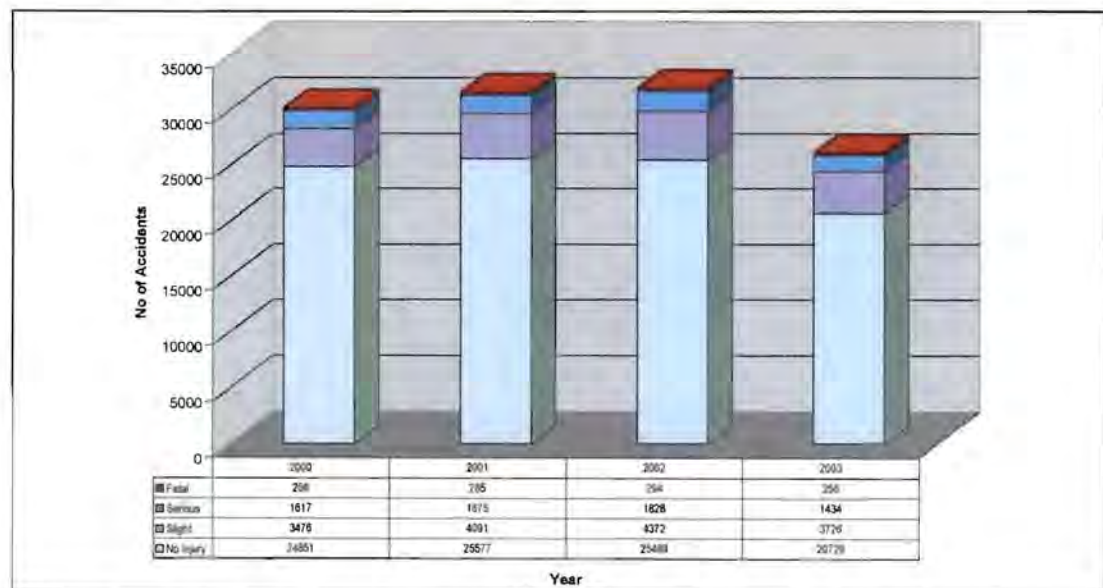


Figure 7: Number of Vehicle Accidents per Year by Degree of Severity

Source: Gauteng Provincial Department of Community Safety (2005).

Accidents involving public transport vehicles amounted on average to approximately 8% of all road accidents per annum. In absolute terms, public transport accidents amounted to about 30 000 accidents per year. It is clear from Figure 7 that the total number of accidents increased from 2000 to 2002, but decreased significantly during 2003 (18%). Approximately 1% of all accidents were fatal, while 20% of all accidents resulted in some form of injury.

Figure 8 indicates the contribution of each public transport mode towards all public transport related accidents (total number of vehicle accidents). The highest number of accidents involved minibus-taxis, and amounted to almost 85% of all accidents.

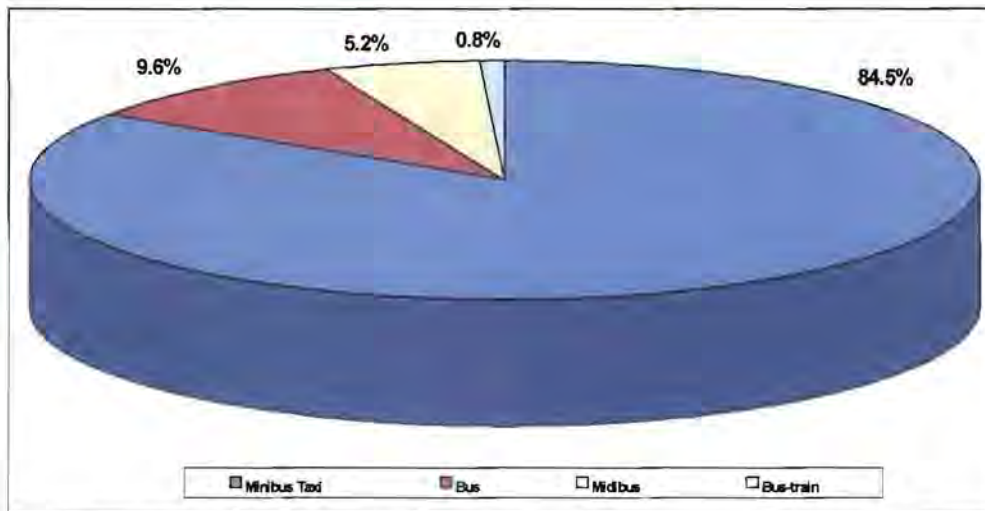


Figure 8: Modal Contribution to Total Public Transport Vehicle Accidents

Source: Gauteng Provincial Department of Community Safety (2005).

(c) Public Transport Vehicle Characteristics

In January 2005, 90 439 minibus-taxis and 9 148 buses were registered in the province, with a year-to-year increase of 2% and 6% for buses and minibus-taxis respectively. Of all vehicles registered on the National Traffic Information System (NaTIS), about 7 844 minibus taxis (9%) and 691 buses (8%) were said to be unroadworthy. This increased by 27% for taxis and by 3% for buses between 2004 and 2005. Unlicensed vehicles amounted to 2 998 for minibus-taxis (3%) and 83 for buses (1%) (NDoT, 2005a).

The average age of all road-based public transport vehicles could be a serious safety concern, with the average for minibus-taxis being 13 years and buses being 10 years. Only 12% of minibus-taxis and 20% of buses are less than three years old (i.e. 88% of minibus-taxis and 80% of buses older than three years). Nearly 64% of minibus-taxis and 50% of buses are older than 10 years. Figure 9 depicts the age profile for all minibus-taxis and buses in the province.

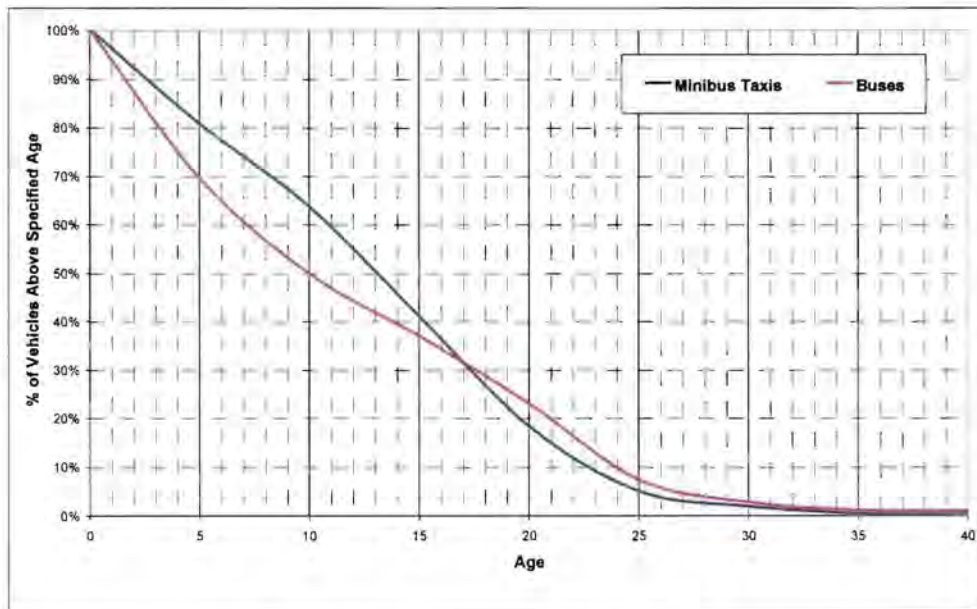


Figure 9: Age Profile of Minibus-Taxis and Buses in the Province

Source: National Traffic Information System (NDoT, 2005a).

6.2.5 OVERALL QUALITY OF SERVICE

Table 19 summarises the findings for overall quality of service for each of the public transport modes.

Table 19: Satisfaction Ratings for Overall Quality of Service

Public Transport Mode	Overall Quality of Service (% Satisfied)
Train	52
Bus	57
Taxi	48

Source: Gauteng Household Travel Survey Report (GDPTRW, 2004a).

The overall quality of service of public transport is considered to be average, with about half of the respondents being satisfied with the current service provision. Once again, taxi services are rated lowest, while bus services are perceived to have a higher level of service compared to those of trains and taxis.

6.3 STATUS QUO FOR IDEAL KPIs IN PILOT AREAS

In order to provide a benchmark for the selected public transport KPIs for each of the three public transport modes, this section determines the status quo for the KPIs in the pilot areas. The viability of the minimum and target LOS can then be tested once current levels of the KPIs have been established.

The market segmentation, as determined in the preceding chapter, will not be applied to establish the status quo of the KPIs. This section will concentrate solely on commuter (work) journeys in the pilot areas.

6.3.1 WALKING DISTANCE

The table below provides perceived average walking distance data for the pilot areas.

Table 20: Perceived Walking Distances to Public Transport in Pilot Areas

Mode	Walking Time (minutes)	Walking Distance (metres)
SOSHANGUVE		
Taxi	8.2	640
Bus	8.5	610
Train	12.9	1 010
BRAKPAN / BENONI / SPRINGS		
Taxi	8.1	640
Bus	10.1	790
Train	20.0	1 570

Walking distance based on an average walking speed of 4 700 m/hr
Source: GDPTRW (2002) and NDoT (1994a)

It is noted that acceptable walking distances prevailed in both pilot areas for taxi and bus services. However, walking distances to rail services exceeded the minimum level of service of 1000 metres in both the pilot areas.

6.3.2 FREQUENCY AND WAITING TIME

The table below provides perceived average waiting time data for the pilot areas, in addition to the average frequency of public transport services during both the peak and off-peak periods, from which actual average waiting times can be calculated.

Table 21: Waiting Time and Frequency for Public Transport in Pilot Areas

MODE	SOSHANGUVE				BRAKPAN / BENONI / SPRINGS			
	Perceived waiting time	Actual avg waiting time ⁽¹⁾	Avg no. of departures / hr (Peak)	Avg no. of departures (off-peak)	Perceived waiting time	Actual avg waiting time ⁽¹⁾	Avg no. of departures / hr (peak)	Avg no. of departures / hr (off-peak)
Taxi	4.0	7.5	8	-	4.2	10.5	6	-
Bus	7.3	-	-	-	6.3	-	-	-
Train	12.9	5.3	6	2 ⁽²⁾	6.8	10.6	3	2 (2)

(1) Calculated from the number of departures in the peak period.

(2) Based on the number of departures in a 24-hour period.

Source: Gauteng Household Travel Survey Report (GDPTRW, 2004a) & Public Transport Information System (GDPTRW, 2004c)

In Soshanguve, perceived waiting times are longer than actual average waiting times, while the opposite holds for waiting times in the Brakpan/Benoni/Springs area. Moreover, actual average waiting times in the latter area are slightly above the proposed level of service of 10 minutes. Only the peak period frequency of trains is below the proposed minimum level of service of six departures per hour, bearing in mind that no information on bus frequencies is available.

6.3.3 PERCENTAGE CAPACITY UTILISATION

The table below provides volume to capacity ratios for the three modes respectively.

Table 22: Percentage Capacity Utilisation (Volume to Capacity Ratio) in Pilot Areas

MODE	Average V/C in AM Peak Period		
	Taxi	Bus	Train
SOSHANGUVE	0.92	0.76 (1)	1.13
BRAKPAN / BENONI / SPRINGS	0.91	-	0.5

Source: City of Tshwane Integrated Transport Plan, 2003/4 to 2008/9 (CTMM, 2003) and Public Transport Information System (GDPTRW, 2004c)

In general, seat capacity does not seem to be problematic, with the exception of rail services in Soshanguve, where the seat capacity of trains is exceeded by 13% during the morning peak period.

6.3.4 PERCENTAGE INCOME SPENT ON PUBLIC TRANSPORT

The table below provides data related to the average monthly expenditure on public transport in the pilot areas.

Table 23: Percentage of Income Spent on Public Transport in Pilot Areas

MODE	Average % Income Spent on Public Transport		
	Taxi	Bus	Train
SOSHANGUVE	8.2%	6.6%	5.3%
BRAKPAN / BENONI / SPRINGS	12.9%	6.2%	4.0%

Source: National Travel Survey (NDoT, 2004b).

Average income spending on public transport per month varies across the different modes of transport in the pilot areas. Public transport expenditure is lowest for train services, which is to be expected. Relative to the target level of service of 10%, commuters in Soshanguve show spending below 10% across all modes, while only taxi services in Brakpan/Benoni/Springs are not within the proposed target.

6.3.5 QUALITY OF SERVICE

The statistics available for the pilot areas on the Gauteng Household Survey database are lacking and, therefore, not sufficient to draw any conclusions on quality of service ratings. The data available for the whole province is, therefore, assumed to hold for the pilot areas as well (see Section 6.2.5).

CHAPTER 7

DEVELOPMENT OF THE STRATEGIC MODEL

7.1 BACKGROUND

This section of the thesis discusses the development of a strategic model to test the appropriateness and cost implications of the recommended public transport LOS. This model aims to predict the effects of improved public transport LOS on passenger demand, as well as the cost of implementing these LOS in Gauteng Province. The effect of a change in LOS can be expressed as a change in one or more service attributes for one or more of the alternatives. This would result in a change in the value (hereafter called utility) a particular consumer places on the affected alternatives (Manheim, 1979), which impacts on the probability of selecting a specific mode (and thus the modal split or ridership per mode).

An improvement in public transport service delivery also has repercussions on the resources consumed. It is generally accepted that an increase in LOS, e.g. an increase in frequency, will result in an increase in the resources required. The model will aim to evaluate how an increase in resources can be offset against an increase in ridership for a particular service. Thus, the challenge remains to develop appropriate demand functions to predict how users will respond to changes in the system, and what the impact on resources will be as a result of the proposed changes to the system.

In this chapter, an overview of the development of the strategic model is provided, setting the framework within which the model will be developed and the key elements to be addressed. The model structure is then elaborated upon, detailing the relationships between different components of the model and the modules within each of these components.

7.1.1 FRAMEWORK

The framework of the model is depicted in Figure 10. These components will be elaborated upon in the rest of this chapter.

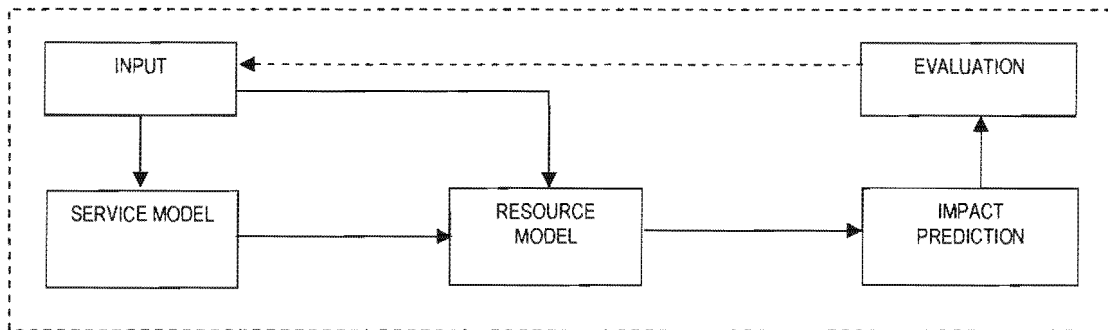


Figure 10: Framework of the Strategic Model

7.1.2 OBJECTIVES

The objectives of the strategic model are as follows:

- the evaluation of impacts on the user, operator and authorities in terms of demand between modes, service levels, resources consumed and monetary impacts such as cost and revenues;
- the testing of sensitivity with respect to change for the identified service characteristics; and
- the determination of investment levels required in order to obtain minimum and target public transport LOS.

7.1.3 KEY ELEMENTS

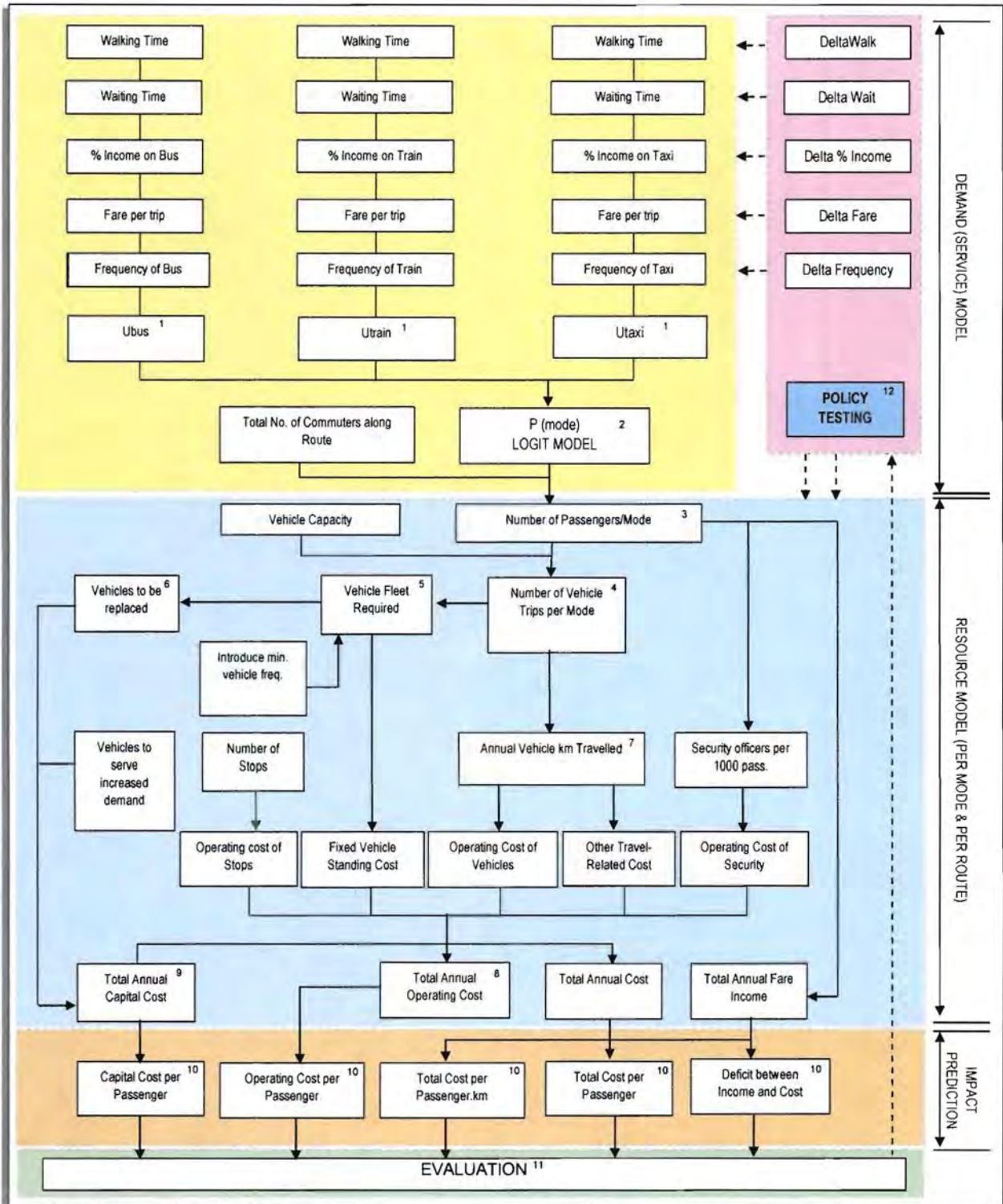
The key elements of the model are set out below.

- The study focuses on the needs of disadvantaged communities, who are in need of public transport services. This market segment forms the basis for the development of the model.
- Initially, the model considers four modes: bus, train, minibus-taxi and car (the latter to place public transport in context).
- The model's primary aim is the prediction of impacts on demand and resources consumed as a result of operational changes, using demand and resource functions.
- The model presents an evaluation of the impacts on the user and operator.
- It also entails the modelling of commuter trips during the weekday morning peak period, adjusted to daily trips and eventually to annual trips.
- The model is developed based on 2004 data, which serves as the base year.
- The following key performance indicators (KPIs) will be tested:
 - walking distance to public transport;
 - waiting time for public transport;
 - frequency (peak and off-peak) of vehicles;
 - cost of (% of income spent on) public transport;
 - percentage capacity utilisation (loading levels);
 - available hours-of-service;
 - safety measures in the form of replacing aged vehicle fleet; and
 - security measures in the form of security guard dispatch on vehicles and at stations.
- Another element is the creation of a corridor model to predict impacts for subsets of O-D pairs in the identified pilot areas.

7.2 OVERVIEW OF THE MODEL STRUCTURE

The model structure is depicted in Figure 11. The numbering in the short discussion below corresponds with the numbering in the figure. Certain points which should be noted are listed below.

1. Utility functions calculate the utility derived from each mode based on attributes such as walking distances, waiting time, cost of public transport and frequency of vehicles.
2. The probability of selecting each mode is calculated based on utility derived from each mode as well as the utility derived from competing modes in the choice set.
3. The probability of each mode is multiplied by the total number of public transport commuters during the AM peak period to obtain the number of passengers for each mode. The model assumes a fixed demand, i.e. users attracted from modes other than public transport are not taken into account. Moreover, in times of economic prosperity, users leaving the public transport market are not accounted for.
4. Based on the vehicle capacity of each public transport mode, the number of vehicle trips required to serve the particular passenger demand is calculated.
5. The critical peak hour passenger volume is calculated in order to determine the vehicle fleet size. The number of passengers is also used to calculate the annual fee income as well as the number of security officers required per certain number of passengers.
6. If any safety measures are introduced, then aging vehicles in the vehicle fleet will be replaced, adding to the capital expenditure of the operator/authority. In the model, no distinction is made between these two bodies. The capital cost of acquiring new vehicles is discounted over the expected lifespan of the vehicle, at a discount rate of 8% per annum.
7. The annual vehicle kilometres are calculated based on the number of vehicle trips per annum, which is then used to calculate the running operating cost of each mode as well as other travel-related expenses which account for costs not included in any of the operating cost components (e.g. start up cost of service change, information provision, etc.).
8. Total annual operating cost is calculated by summing operating cost of stops/stations, fixed vehicle standing cost, running cost of vehicles, other travel-related expenses as explained earlier, and the cost of providing security at stations/in vehicles, and the additional cost of improving on walking distances.
9. Total annual capital costs are calculated by adding the cost of replacing aging vehicles in the fleet and the cost of additional vehicles required due to an increase in the number of peak hour passenger trips. No other capital costing factors are taken into account, as it is assumed that they are already in place (such as ways, termini and existing vehicles). This was confirmed by site visits to the pilot areas.
10. The impact of LOS changes is reported by certain important indicators. These are the calculation of annual number of passengers and number of passenger kilometres to express annual capital, operating and total cost per passenger and per passenger kilometres. The deficit between annual fare income and total annual cost is also reported.



Note: Superscripts correspond with the numbering in the discussion in Section 7.2.

Figure 11: Structure of the Model

11. The proposed service change/s are evaluated by scrutinising the indicators for efficiency and effectiveness.
12. If necessary, policies can be adjusted to produce more cost efficient/cost effective outcomes.

More detail on the above process is provided in Section 7.3.

7.3 DESCRIPTION OF MODEL COMPONENTS

The model has been developed in spreadsheet format comprising the following components:

- Situational Input Sheet;
- Policy Test Input Sheet;
- Service Model;
- Resource Model consisting of one sheet per route (nine routes in total): RM01 – RM09;
- Output Indicators – Tables;
- Output Indicators – Graphs;
- Parameters Sheet;
- Assumptions Sheet;
- Fare Data Sheet; and
- Averages Sheet.

Below follows a description on each of the worksheets in the model.

7.3.1 SITUATIONAL INPUT

The situational input sheet containing the following input information related to the route in general - access to public transport referred to as network level 1; service characteristics along the main corridor referred to as network level 2; and present levels-of-service of the KPIs under consideration. Moreover, the present utility derived from the current service is given, together with the current probability of selecting each mode.

7.3.2 POLICY TEST INPUT

This sheet provides an interface for making changes to the current service provision with respect to the identified KPIs. The values of the policy variables can be changed relative to the base case scenario. The changes can be made by either specifying a percentage change relative to current LOS, or setting a specific target level of service for one of the variables. These changes feed into the service model to predict the resulting modal shifts. To facilitate the specification of the input variables, a user interface was developed for the model, providing linkages between the situational and policy test input, as well as the output tables and graphs.

7.3.3 SERVICE MODEL

The service model calculates the changes in demand as a result of the changes made to the policy variables. This sheet uses the policy test results to calculate a revised utility for the selected mode and the resulting changes in ridership. The revised ridership feeds into the resource model component to calculate the resulting changes in resources consumed, and hence the cost implication of the changes.

Although the original sample dataset (GDPTRW, 2002) from which the parameter coefficients were estimated consisted of 4480 records, only a subset of the sample data (647 records) represents the pilot area that was included in the service model. Utility functions calculate the utility each individual derives from each of the public transport modes. The calculated utility feeds into a logit model function to predict the probability of each mode being selected by the user in question (see detailed explanation further on in this section). The probability of selecting each mode is then calculated as the average probability over all the observations, using sample enumeration.

(a) Utility Functions

The mode-specific utility functions take the following form (linear-in-the-parameters):

$$U = ASC + \beta_1(WD) + \beta_2(WT) + \beta_3(IS) + \beta_4(CU) + \beta_5(F) + \beta_6(HS) + \beta_7(AGE) + \beta_8(SEC) \quad (8-1)$$

Where:

ASC	-	Alternative specific constant
β_1	-	Walking distance (WD)
β_2	-	Waiting time (WT)
β_3	-	Percentage income spent on public transport (IS)
β_4	-	Percentage capacity utilisation (CU)
β_5	-	Frequency of service (F)
β_6	-	Hours of service (HS)
β_7	-	Average age of public transport vehicles (AGE)
β_8	-	Number of security officers per route (SEC).

It is assumed that the decision-making process is made up of the listed attributes (the only attributes of relevance to each decision-maker), and thus determines the choice of mode an individual makes for a particular trip purpose. The commuter will select the mode with the highest utility, i.e. the mode with the best combination of attributes (Ben-Akiva, 1985).

Initially the model included four mode alternatives: bus, train, minibus-taxi and car. All modes are based on the same utility function with coefficients of parameters being generic (the same for all modes), except for the value of the alternative-specific constants (ASC). Note that all public transport alternatives are available to each individual in the dataset, while car is available to those who have chosen it, as well as those who explicitly indicated its availability.

Initial assessment of the dataset indicated that the inclusion of the car mode disturbs the calibration process. Possible reasons for this are suggested below.

- Considering the market segment under discussion, it is questionable whether car is a viable transport option.
- Travel time is not included as a variable (as it was not identified in the needs analysis), but would have contributed significantly to differences in utility between car and public transport.

The car mode was therefore excluded in the further calibration of the model. The exclusion can further be justified by the fact that its inclusion could have resulted in a nested model structure, with added complexity. Moreover, cross-elasticities between car and public transport have been shown to be low especially related to fare and frequency adjustments, and where individuals are captive to public transport. This means that it is unlikely that fare and frequency adjustments in public transport will attract significant riders away from car. Higher elasticities are expected from choice riders, more prevalent among middle and higher income groups (VTPI, 2005). Moreover, studies in the United States (Transportation Research Board, 2003) have suggested that new public transport trips tend to be made more in off-peak periods for non-work purposes than in peak periods for commuting purposes. The latter is the focus of this research. This implies that potential car trips diverting to public transport would be very low.

(b) Logit Model

The utility functions provide input to a Multinomial Logit Model (MNL) which predicts the percentage probability for each mode choice. It takes the functional form (Ben-Akiva, 1985 p.103):

$$P_{iq} = \frac{\exp(\beta \mathcal{G}_{iq})}{\sum_{A_j \in A(iq)} \exp(\beta \mathcal{G}_{iq})} \quad (8-2)$$

It is important to note that in practice β is taken as 1, as it cannot be estimated separately from \mathcal{G} (Ben-Akiva, 1985). The percentage probability is multiplied by the number of commuters generated by the community to calculate the number of passengers per mode (peak period volume V_{mode}).

7.3.4 RESOURCE MODEL RM01 TO RM10

The resource model comprises the following sections for each route:

- calculation of the number of passengers per mode generated by the community;
- calculation of the number of vehicle trips required to serve the passenger demand;
- calculation of the vehicle fleet size based on the number of peak hour vehicle trips;
- calculation of the annual operating cost; consisting of vehicle operating cost (based on the **annual vehicle kilometres travelled** and **fixed vehicle standing cost**), operating cost of the infrastructure (stops and stations), other travel-related cost and annual cost of providing security (if any); and
- calculation of the annual capital cost for the acquisition of new vehicles to serve additional demand or the introduction of new vehicles into the fleet to decrease the average age of vehicles.

The calculations for the resource model are detailed below.

(a) Number of Passengers per mode

The number of passengers per mode is calculated by multiplying the probability of selecting each mode by the total number of passengers along each route during the AM peak period.

(b) Number of Vehicle Trips

The number of vehicle trips during the AM peak period is calculated as follows:

$$T_{am} = V_{mode} / (C * L) \quad (8-3)$$

Where:

- V_{mode} = Peak period volume for the specified mode
 C = Vehicle capacity
 L = Loading factor.

The number of vehicle trips in the off-peak period (including PM) is assumed to be 40% (Del Mistro, 2004) of the total daily trips, i.e.:

$$T_{pm} = T_{am} / (1 - 0.4) - T_{am} \quad (8-4)$$

The number of vehicle trips has been calculated for each hour in the peak period, as this is required in the calculation of vehicle fleet size. The hourly distribution of public transport passengers during the AM peak period is assumed to be as follows (Del Mistro, 2004):
 $(P_{h1}, P_{h2}, P_{h3}) = (45\%, 35\%, 20\%)$.

(c) Vehicle Fleet Size

Vehicle fleet size is calculated based on the premise that enough vehicles should be provided to serve the peak hour demand (Del Mistro, 2004). Vehicle fleet size F is thus calculated as:

$$F = T_{am} * P_h * TT \quad (8-5)$$

Where:

- T_{am} = number of vehicle trips during the AM peak period
 P_h = % of peak period trips in the hour under consideration
 TT = travel time.

Note that:

If $TT < 1$ hr, then $F = T_{am} * P_{h1} * TT / 60$.

If $1 \text{ hr} < TT < 2$ hrs, then $F = (T_{am} * P_{h1}) + [T_{am} * P_{h2} * (TT - 60) / 60]$.

If $TT > 2$ hrs, then $F = (T_{am} * P_{h1}) + (T_{am} * P_{h2}) + [T_{am} * P_{h3} * (TT - 120) / 60]$.

It should also be noted that it is assumed that the vehicle returns empty to the starting point of the route, therefore, no time is lost loading/unloading and stopping on the return journey. The vehicle fleet size is adjusted by 10% to account for a standby fleet in the case of breakdowns (Del Mistro, 2004).

(d) Operating Cost

Calculation of the annual operating cost consists of following elements:

- vehicle operating cost based on the annual vehicle kilometres travelled (AVKT) and fixed vehicle standing cost);
- operating cost of the infrastructure (stops and stations); and
- annual cost of providing security (if any).

The total annual operating cost is the sum of the above. The points below expands on each of the previous components.

- (i) Variable vehicle operating cost (2004) is calculated as the product of AVKT and the unit vehicle operating cost per km. The model uses R4.96/bus.km (Schutte, 2005), R1.98/taxi.km (Schutte, 2005) and R43.02/train.km (R30.33 inflated at 6% per annum from 1998) (Del Mistro, 1998). The annual vehicle kilometres travelled (AVKT) is calculated as:

$$AVKT = D * N_d * V_1 \quad (8-6)$$

Where:

$$\begin{aligned} D &= \text{Distance of the trip} \\ N_d &= \text{Number of service days per year} \\ V_1 &= \text{Trips per day calculated as below} \\ V_1 &= [2PP * (V_{h1} + V_{h2} + V_{h3}) * (1 + F/100)] + [(V_{h4} * SH) * 2]. \end{aligned} \quad (8-7)$$

Where:

$$\begin{aligned} 2PP &= \text{Accounts for 2 peak periods per day (morning and afternoon)} \\ V_{h1,3} &= \text{Number of hourly vehicle trips in peak period} \\ V_{h4} &= \text{Number of vehicle trips in off-peak period (excluding the PM peak)} \\ F &= \text{percentage round trips in peak period based on travel time} \\ &\quad \text{Travel time} < 10 \text{ minutes: } F=100 \\ &\quad \text{Travel time} > 2 \text{ hours: } F=40 \\ &\quad 10\text{min} < T < 2 \text{ hours: } F=0.00568T^2 - 1.284T + 112.26 \\ SH &= \text{Service hours in off-peak period.} \end{aligned} \quad (8-8)$$

- (ii) Fixed vehicle standing cost is estimated at R127 000 for bus, R813 464 for train and R43 000 for taxi (Del Mistro, 2004).
- (iii) The annual operating cost of stops/stations is R654 000/rail station (Del Mistro, 2004) and R500 per bus and taxi stops (assumed).
- (iv) Other travel-related costs include all cost-related issues not accounted for such as operating cost of depots, termini, start-up costs of service changes, information provision, contract management, among other, and are estimated at R1.80/veh.km for bus, R10.00/veh.km for train and R0.10/veh.km for taxi services (estimated).
- (v) The annual cost of providing security is estimated at R36 000/annum per security officer. It should be noted that security is practically non-existent for bus and taxi services, while only minimal for train services. Security is expressed as the number of security officers per 1000 peak hour passengers.

(e) Capital Cost

The capital cost in 2004 for the acquisition of new vehicles is: R800 000/bus (Del Mistro, 2004), R36 million/train set in 2004 (Del Mistro, 1998) and R254 000/minibus-taxi (Del Mistro, 2004). Capital cost of terminals, staging yards, depots and ways is not considered as it is assumed that they are already in place. This was confirmed during site visits to the pilot area. The reader is reminded that this research entails the improvement of the existing service.

(f) Validation

The ability of the resource model component to predict the consumption of resources was evaluated based on a comparison with the public transport costing model developed by

Professor Del Mistro (2004). Table 24 depicts results obtained for a selection of performance indicators using both tools in question. To allow comparison, both models were adjusted to correlate the assumptions made in terms of the basic default parameters. The results are based on a random number of 1000 peak period passengers (daily volume of 2000 passengers), using the minibus-taxi mode over a distance of 50 km.

Table 24: Validation of Resource Model (for Minibus-Taxi)

Indicator	Resource Model Component	Public Transport Costing Model ⁽¹⁾
Passenger km / year (million)	60	60
Annual number of Passengers (million)	1.2	1.2
Annual Operating Cost (Rm)	19.64	20.77
Cost / passenger.km (R)	0.33	0.35
Cost / one-way trip (R)	16.36	17.31

Note 1: Taken from Del Mistro, 2004

The validation was conducted only for taxi services, since the calculations in the resource model are the same for all modes, with only the modal parameters being different for each mode. These results clearly indicate that the resource model is able to predict the order of magnitude of the resulting cost implications realistically. Nonetheless, it should be borne in mind that the absolute values are not significant in this regard, but rather the percentage change with respect to the base case scenario before and after the implementation of service level policies.

7.3.5 OUTPUT INDICATORS – TABLES / GRAPHS

The output sheet provides a summary of the changes that were made to the service levels and gives the resulting cost implications in both tabular and graphical form. The following indicators are shown:

- Passengers per annum (millions);
- Passenger kilometres per annum (millions);
- Cost per one-way trip (Rands);
- Cost per passenger kilometre (Rands);
- Annual fare income (Rmillions);
- Annual operating cost/passenger (Rands); and
- Annual capital cost/passenger (Rands) (if any).

Three graphs are provided which depict impacts on the modal shifts, cost per one-way trip, as well as the annual fee income in relation to the total annual cost before and after policy implementation.

7.3.6 PARAMETERS

The model parameter sheet contains all the default parameter values that are required to perform some of the calculations in both the service and resource models. Table 25 details the default modal parameter values.

Table 25: Default Modal Parameter Values

Modal Parameter	Bus	Train	Taxi
Vehicle standby fleet (% of total)	10%	10%	10%
Average travel speed	50	90	60
Avg time loading/off-loading passengers - sec/stop or pass.	6.5	30	8
Avg time lost through acceleration/decel. - sec/stop	9	53	15
Time to turn vehicle around – min	1	9	0
Vehicle capacity (standing and sitting)	73	2710	15
Average age of vehicles	10	10	13
% of vehicles older than 0 years	100.0%	0.0%	100.0%
% of vehicles older than 5 years	69.5%	0.0%	80.6%
% of vehicles older than 10 years	49.8%	0.0%	63.6%
% of vehicles older than 15 years	36.9%	0.0%	41.0%
% of vehicles older than 20 years	22.9%	100.0%	18.2%
% of vehicles older than 25 years	7.2%	82.8%	4.9%
% of vehicles older than 30 years	2.7%	64.8%	1.8%
% of vehicles older than 35 years	1.1%	44.9%	0.3%
% of vehicles older than 40 years	0.9%	25.3%	0.1%
% of vehicles older than 45 years	0.0%	11.0%	0.0%
Default set at age 50 years	0.0%	0.0%	0.0%
Expected vehicle lifespan (years)	12	30	10

Source: Del Mistro, 2004; NDoT, 2005a and SARCC, 2005.

Apart from modal parameters, the Parameters sheet also contains cost parameters as discussed in Sections 7.3.4(d) and 7.3.4(e) (unit capital and operational cost elements, and fare structures, among other), as well as utility function parameters, which are discussed at length throughout this chapter. The percentage of vehicles older than a specific age is used to calculate the number of vehicles which need to be replaced in line with the revised national Taxi Recapitalisation Programme. Under the new programme, a scrapping allowance is provided for vehicles older than a certain age, amounting to R50 000 (NDoT, 2005b). However, the full cost of acquiring a new vehicle will be considered in the model, as the operator is still responsible for the difference between the scrapping allowance and the cost of a new vehicle (assumed at R186 000) and the model does not distinguish between the operator and the authorities. The vehicle age profile is derived from province-specific data received from the National Department of Transport (NDoT, 2005a) and the South African Rail Commuter Corporation (SARCC, 2005).

7.3.7 ASSUMPTIONS

This sheet contains assumptions mainly related to the service model. Below follows a list of the assumptions made.

- Attribute values for alternatives are missing. Therefore, for each OD-pair, this researcher preferred to replace missing values with the reported average attribute value for each

mode in the dataset. However, these values have been found to be higher (more attractive) than the chosen mode for which the revealed data were available.

- To deal with the above issue, a test was introduced into the dataset to check whether the selected mode is indeed more attractive than the alternatives. If this is the case, then the values of the alternatives are adjusted by introducing a maximum value for a specific attribute in order to make the alternatives less attractive. These maximum values are given below and can be changed if necessary (see Table 26).

Table 26: Maximum Values for Each Variable to Replace Missing Values in Dataset

VARIABLE	BUS	TAXI	TRAIN
Walking time (min)	19	13	25
Waiting time (min)	10	7	10
Fare/trip (Rands)	7	10	5
% Income spent on PT	10.9	10.6	8.5

- All public transport modes are available to each user in the data set.
- Percentage income spent on public transport was calculated based on the income midpoint for each reported income class. As available income data are representative of the year 2002, it had to be escalated until 2004 at an inflation rate of 6% per annum. The cost of public transport is calculated using the formulae determined from regression analysis of the 2004 surveyed cost data. The base-fare equations are as follows:

$$\text{BUS: } y = 0.3193 x^{0.7237} \quad (8-9)$$

$$\text{RAIL: } y = 0.2767 x^{0.5474} \quad (8-10)$$

$$\text{TAXI: } y = 1.1252 x^{0.4674} \quad (8-11)$$

where y represents fare and x represents distance.

7.3.8 FARE DATA

With any increase or decrease in fares, the coefficient of the derived power function changes accordingly, while the exponent of the function stays constant. This sheet lists the resulting coefficient if the fare of public transport is increased or decreased by up to plus or minus 100% from the base fares. In the resource model, the calculation for annual fare income takes cognisance of a change in fares by looking up the corresponding coefficient that is relevant to the percentage change in the fare.

7.3.9 AVERAGES

The Averages sheet contains the weighted average values for each OD pair in order to populate the missing values in the service model. It also contains weighted route-based data (GPDPTRW, 2002) which serves as input to the Situational Input sheet, such as average walking distances, waiting times and income.

7.4 RESUMÉ

This chapter entailed the development of a model that aims to predict impacts of improved public transport LOS on passenger demand, as well as the cost of implementing these LOS (or resources consumed). The model consists of two primary components. A service model predicts the shifts in demand as a result of changes to service levels. This information feeds into a resource model that calculates the resources consumed along a specific corridor. A multinomial logit model was developed to facilitate the prediction of changes to mode utility, and ultimately mode choice probability. Initially, the model considered four modes: bus, train, minibus-taxi and car (the latter to place public transport in context), but it was found that the inclusion of the car mode disturbed the calibration of the model.

The resource model entails the calculation of the number of passengers per mode generated by the community, the number of vehicle trips required to serve the passenger demand, and the calculation of the vehicle fleet size based on the number of peak hour vehicle trips. Based on the **annual vehicle kilometres travelled** and **fixed vehicle standing cost**, the annual running operating costs are calculated. The total annual operating costs consist of the running operating cost of the vehicle, operating cost of the infrastructure (stops and stations), other travel related costs, annual cost of providing security and cost of improving on walking distances (if any). Calculation of the annual capital costs are based on the acquisition of new vehicles in order to decrease the average age of vehicles or to serve additional demand. No other capital cost components (e.g. cost of ways, terminals) are considered, as it is assumed that these are already in place. This was confirmed during site visits to the pilot area.

The model provides the following indicators as output: passengers per annum, passenger kilometres per annum, cost per one-way trip, cost per passenger kilometre, annual fare income, annual operating cost per passenger, and annual capital cost per passenger (if any).

The following chapter discusses the estimation and calibration of the service model.

CHAPTER 8**ESTIMATION AND CALIBRATION OF SERVICE MODEL**

In this chapter, the methodological approach taken for the service model component will be discussed, together with the relevant theoretical issues, the available software applications to carry out complex model estimation tasks, and key statistical tests to be considered. The data source and market segmentation are briefly explained, followed by the estimation and calibration of the service model.

8.1 METHODOLOGICAL APPROACH FOR MODEL ESTIMATION**8.1.1 DISCRETE CHOICE MODELLING**

Discrete choice analysis is the modelling of choice from a set of mutually exclusive and collectively exhaustive alternatives. The analysis uses the principle of utility maximisation, which models a decision-maker to select the alternative with the highest utility among those available at the time the choice is made. The utility of a mode is modelled by constructing utility functions containing parameters for observable independent variables and unknown variables (Hensher, 2003).

In this research, the methodology of discrete choice analysis is applied to travel demand modelling. The probability of choosing a specified alternative is determined by a multinomial logit model, as expressed earlier in equation 8-2.

Utility functions are to be constructed for each of the modes under discussion, in order to predict changes in demand/ridership as a result of changes in the parameter values. The utility function takes a linear form such that (Ben-Akiva, 1985):

$$y = f(x, \beta) \quad \text{or} \quad y = \beta_1 + \beta_2 x + \varepsilon \quad (9-1)$$

Where:

- y - dependent variable (in this case the utility)
- β_1, β_2 - unknown parameters
- x - independent variables (attributes of the service of each mode)
- ε - disturbance term.

It is assumed that the functional form of the model (linear in this case) is known, and thus the task remains to find estimates for the parameters (beta values). Various methods of model estimation are available, although the two most common methods are least squares and maximum likelihood. The following section will provide more detail on the latter estimation method.

8.1.2 MODEL ESTIMATION WITH MAXIMUM LIKELIHOOD

The use of maximum likelihood in model estimation entails the determination of the value of the parameters for which the observed sample is most likely to have occurred. In other words, one needs to find that parameter value that best represents the observed data. The likelihood of the sample based on the parameter θ is (Ben-Akiva, 1985, p.20):

$$\mathcal{L}^* = \prod_{n=1}^N f(y_n | x_n, \theta) \quad (9-2)$$

The most widely used approach is to maximise the logarithm of \mathcal{L}^* rather than \mathcal{L}^* itself. Thus one solves:

$$\max \log \mathcal{L}^* = \max \mathcal{L} = \max \sum_{n=1}^N \log f(y_n | x_n, \theta_N) \quad (9-3)$$

The maximum θ is obtained when the rate of change of $\log \mathcal{L}$ with respect to θ equals 0, and is referred to as the first order condition. One solves for θ , thus producing the MLE for θ , in the following equation:

$$\delta \log \mathcal{L} / \delta \theta = 0 \quad (9-4)$$

The second order condition is to ensure that $\log \mathcal{L}$ is maximised when solving for θ . This condition states that the slope of $\log \mathcal{L}$ near the MLE should be decreasing, i.e. $\delta^2 \log \mathcal{L} / \delta \theta^2 < 0$. The solution to this estimation process can be obtained using various numerical optimisation algorithms e.g. the Newton-Raphson method (Ben-Akiva, 1985). Many software programs are also available to conduct the iterative procedure of the optimisation process. Some of the available applications are discussed in the following section.

8.1.3 AVAILABLE SOFTWARE APPLICATIONS

(a) SPSS

SPSS is a commercial statistical software package which is capable of performing Logit Loglinear Analysis. The logarithm of the odds of the dependent variables is expressed as a linear combination of parameters. The procedure estimates parameters of logit loglinear models using the Newton-Raphson algorithm (SPSS for Windows, 2002). No adequate explanation on the use of the analysis appears to be available. Moreover, the process of numerical maximisation lacks transparency. However, the software may possibly be used to check results obtained by the preferred software package.

(b) DCM for OX

DCM (Discrete Choice Models) is a package, written in Ox programming language, for estimating a class of discrete choice models, including standard binary response models, with notable extensions such as conditional mixed logit, mixed probit, multinomial probit and random coefficient ordered choice models. A user can access the functions within DCM by

either writing Ox programs which create and use an object of the DCM class, or use the program in an interactive fashion (Eklof, 2004). Although little experience in using the Ox programming language is required, the language is not clearly explained in supporting documents. Moreover, the required data structure necessitates significant manipulation of the data and is therefore time-consuming and labour-intensive. It should however be mentioned that the software does make provision for transformation between data structures (single row vs. multiple row), but introduces opportunity for error if the user is not fully familiar with the software.

(c) **BIOGEME**

BIOGEME is a software package designed for the development of research in the context of discrete choice models, and of generalised extreme-value (GEV) models in particular. The software can handle most types of choice models, as mentioned under the description of DCM for Ox. Simulated maximum likelihood estimation is performed in the model estimation process. BIOGEME has the ability to read the data from an Excel spreadsheet, with records presented in a single row structure. Each observation can also be weighted (e.g. a factor to scale the sample data to represent the population as a whole), as well as allowing grouping of the data, i.e. different parameter values can be estimated for different market segments (Bierlaire, 2004). The software is thus perceived to be more user-friendly, with methods of model estimation totally transparent to the user, making it the preferred option for this specific research task.

8.1.4 **KEY STATISTICAL TESTS**

The **t-test** is used to validate whether the mean of a normal distribution equals some given value when the variance is estimated. The selected software provides a one-sample t-test statistic, which compares the sample with the population which it represents, as well as a two-sample t-test statistic, which compares two independent sample means. In a one-sample t-test, the null hypothesis is tested, i.e. that the sample comes from a population with a specified mean. In the case of a two-sample t-test, the significance of the difference between the two means is tested, i.e. the calculated t-value should be greater than the threshold (1.96 for infinite degrees of freedom at the 95% confidence level), in order for the difference between the means to be significant (Ben-Akiva, 1985).

The **likelihood ratio test (LRT)** tests a set of restrictions on the parameters of models estimated by maximum likelihood. A relatively more complex model can be compared to a simpler model to see if it fits a particular dataset significantly better.⁷ It can be used to test the null hypothesis that all coefficients, except for the alternative-specific constants, are zero. The test can also be used to test for non-linearity of the model and for non-genericity of the variables, i.e. proving that a variable does not have the same weight or meaning in all the choice options (Ben-Akiva, 1985).

Rho-square is an index which varies between 0 (no fit) and 1 (perfect fit) in order to compare alternative models. It should be noted that the index is relative to the "market share model" (Ortuzar, 2001, p.247). The test is thus a measure of the goodness-of-fit between the model and the population it represents.

⁷ The LRT is only valid if used to compare hierarchically nested models. That is, the more complex model must differ from the simple model only by the addition of one or more parameters.

Correlation between coefficients, or covariance tests, checks whether two variables are dependent on one another, i.e. a covariance value close to 0 is indicative of independence. Correlation (r) also tests for the relationship between two variables. An r -value close to 0 is indicative of no relationship between the variables, while a value close to +1 or -1 points to a strong correlation between variables (Bierlaire, 2004).

Finally, the validation of the **model structure** entails a comparison of estimation results with those of a generalised model that relaxes the basic assumption that one wants to test (see Section 8.3.4). The following is of more importance (Hensher, 2003):

- specification test for utility function;
- test for violation of Independence of Irrelevant Alternatives (IIA)⁸ assumption; and
- heteroscedasticity of utility functions.

8.2 DATA SOURCE AND SUBSETS OF DATA

The main data source for the development of the strategic model is the Gauteng Household Travel Survey conducted in 2002 (GPDPTW, 2002). The database contains personal and household data on socio-economic characteristics (e.g. dwelling types, income, household size, household structure, formal and informal employed and economic activity) and travel characteristics (trip origins and destinations, travel modes, travel times and travel cost). In this research, data subsets were extracted from the original dataset that conformed to the following criteria:

- areas in the province with an average monthly income lower than R3 000 per month, with an average car ownership lower than 0.6;
- the resulting dataset was divided into two subsets: areas with average public transport usage more than 50%, and usage less than 50%;
- only trips by bus, train and minibus-taxi trips are considered; and
- only commuter trips are considered.

The sample data was generated using the market segmentation procedure as described above. The data can be classified as revealed preference (RP) data. At this point it may be appropriate to mention that it is assumed that the resulting model will be able to *reasonably* predict changes in modal split as a result of changes in the levels of the service attributes, despite the constraints RP which data poses on the analysis. RP data provides little benefit to those who wish to predict market changes prior to changes in the existing service, given its stability to market equilibrium. Furthermore, RP data collection often suffers from invariance of the attribute levels in the market (Hensher, 2003). To predict changes in choice, one requires variation in order to explain variation, which means that an attribute taking on the same value for all alternatives cannot help to explain why individuals make choices in the way they do. RP data often includes variables that do not vary across alternatives (such as socio-economic variables), in addition to failing to provide information on alternatives not chosen.

⁸ If some alternatives are removed from a choice set, the relative choice probabilities from the reduced choice set are unchanged.

8.3 CALIBRATION OF DEMAND MODEL

This section involves the estimation and calibration of parameters for the utility functions in the logit model. The model was calibrated based on its ability to predict the actual modal split in the pilot area as accurate as possible.

8.3.1 INITIAL ASSESSMENT

The dataset in question is a classic case where only attribute values for the selected mode were collected, and not for all modes in the choice set (see discussion of RP data in Section 8.2). Certain assumptions therefore had to be made in order to populate the resulting missing values of the alternative modes in the dataset. Average values of attributes were calculated for each OD pair in the dataset, from the individuals that have selected a particular mode. However, these values have been underestimated as they are representative of the attractiveness of the alternative modes, i.e. they promote a better set of attribute levels than what would be the case if information on non-chosen alternatives was indeed available. Consequently, the resulting dataset implied that the attribute values of the alternatives are more attractive than the actual mode selected in the choice set, in addition to giving rise to wrong coefficient signs for parameters in the utility function.

To overcome the problem, a test was introduced into the dataset to check whether the selected mode was indeed more attractive than the alternatives. If this is the case, then the values of the alternatives were adjusted by introducing a maximum value for a specific attribute in order to make the alternatives less attractive. The results improved significantly. A more suitable approach would have been to synthesise the values for each record in the database, but this approach would have been time-consuming and would not have improved significantly on the accuracy of the dataset, relative to the method deployed.

8.3.2 EVALUATION OF VARIABLES

Table 27 gives the correlation between the potential variables for which data is available, as well as between the potential variables.

Table 27: Correlation between Potential Variables

	Income	Fare/trip	% Income Spent	Walking time	Waiting time	Frequency	Output: No. of trips
Income	1.000						
Fare / trip	0.051	1.000					
% Income Spent	-0.420	0.361	1.000				
Walking time	-0.075	-0.144	-0.024	1.000			
Waiting time	-0.041	0.042	-0.008	0.136	1.000		
Frequency	0.043	0.532	0.175	-0.132	0.064	1.000	
Output: No. of trips	-0.106	0.130	0.107	0.029	0.094	0.141	1.000

It is noted that no strong correlation exists between any of the variables, as the r-values are not approaching one or negative one. However, one would expect a strong correlation

between frequency and waiting time. A possible reason for this may be that the two variables do not share the same dataset. Frequencies were extracted from Current Public Transport Records incorporated into the Public Transport Information System (GDPTRW, 2004c) and existing timetables, while waiting time data was extracted from the Gauteng Household Survey database (GDPTRW, 2002). In addition, it should be noted that waiting time is the perceived time, which may be different from actual waiting time. Moreover, the table does not indicate a strong correlation between fare per trip and the percentage of income spent on public transport either. The effect of income alone on percentage of income spent may be more significant than expected, as is shown by the low correlation (0.051) between income and fare per trip. The table also indicates that walking time has a low correlation (0.029) with the number of trips (or the output), which is an indication that the variable is not significant. Waiting time should therefore be excluded from the model, and be replaced by frequency as a KPI.

The discussion below aims to evaluate each of the potential variables to be included in the model, in terms of its significance, stability of the coefficient value, comparison to other studies, its role in the overall utility function and its monetary value, if applicable. The monetary value of a variable is calculated by taking the ratio of the coefficient of the variable to that of the fare or cost coefficient, and indicates what users would be willing to pay to save one unit of a negative factor to obtain one unit of a positive factor. If a variable is found to be significant for inclusion, graphs are also provided which show the impact of a variable on the mode choice. This discussion refers to Table 28, which lists the most important model estimation runs. Due to a lack of data, safety and security attributes could not be tested for inclusion into utility functions.

Table 28: Model Calibration Results

MODEL		%Income Spent	Fares (R/trip)	Wait (min)	Walk (min)	Frequency (dep/hr)	ASC			REMARKS
							Bus	Train	Taxi	
1	Only PT Modes	Coefficient	-0.061	-0.050	-0.003		0.000	-1.078	2.187	Base Modal Split (B, TR, TX) = (12.76, 21.82, 65.40) ¹ Good fit. VOT for waiting time higher than walking time, would expect VOT for walking to be higher than waiting (PWV Consortium, 2004a), predicts within 3% of actual modal split (B,TR,TX) = (15.03%, 22.67%, 62.30%)
		T-statistic	-3.1	-6.3	-3.2	fixed	-10.8	25.5		
		Value of Time (R)		R 49.01	R 2.60					
2	Only PT Modes	Coefficient	-3.4637	-0.074	-0.003		0.000	-2.658	3.271	Good results, waiting considered more important than walking. Value of walking too low. (B,TR,TX) = (12.66%, 24.74%, 62.60%)
		T-statistic	-22.9	-5.2	-18.4	Fixed	-13.3	14.4		
		Value of time (R)		R 1.29	R 0.06					
3	Only PT Modes	Coefficient	-3.3883	-0.054	-0.408		0.000	-3.613	2.652	Good results. Walking time more significant than waiting, but slightly too high. Predicted modal split good. (B,TR,TX) = (14.23%, 19.30%, 66.47%)
		T-statistic	-19.3	-3.2	-17.1	Fixed	-13.3	10.2		
		Value of time (R)		R 0.96	R 7.22					
4	PT modes	Coefficient	-0.394	-0.071	-0.123		0.000	0.341	1.174	ASCs less dominant, Ratio of Walk to wait = 1.7. Predicted modal split good. (B,TR,TX) = (12.46%, 21.46%, 66.07%)
		T-statistic	-32.4	-11.0	-18.5	Fixed	5.1	2		
		Value of time (R)								
5	PT modes	Coefficient	-0.341	-0.064	-0.227		0.000	0.564	0.885	Walking distance maximum values adjusted from levels in model 4. ASCs less dominant. Ratio of walk to wait = 3.5. Predicted modal split good. (B,TR,TX) = (12.78%, 21.84%, 65.41%)
		T-statistic	-27.7	-9.2	-27.7	fixed	7.7	14.2		
		Value of time (R)								
6	PT modes	Coefficient	-0.062	-0.082	-0.161		0.000	-2.836	3.584	Fare per trip added to model 5. Correlation between income & waiting time fails t-test (1.28). ASCs together with fare per trip rather dominant. Value of time of expected magnitude. Predicted modal split good. (B,TR,TX) = (12.61%, 22.04%, 65.35%)
		T-statistic	-6.1	-6.7	-27.7	fixed	-16.1	17.5		
		Value of time (R)		R 1.45	R 2.87					
7	PT modes	Coefficient	-0.063	-0.081	-0.165		0.000	-2.451	4.654	Frequency added to model 6. ASCs together with fare per trip dominant. Value of time for wait and walk of expected magnitude. Predicted modal split good. (B,TR,TX) = (12.62%, 22.04%, 65.34%)
		T-statistic	-6.4	-6.6	-14.3	fixed	-11.3	10.58		
		Value of time (R)		R 1.46	R 2.95					
8	PT modes	Coefficient	-0.337	-0.064	-0.229		0.000	1.298	3.101	Frequency added to model 5. ASCs dominant again. Ratio of walk to wait = 3.5 Predicted modal split good. (B,TR,TX) = (12.77%, 21.81%, 65.42%)
		T-statistic	-27.3	-9.0	-27.6	fixed	12.5	14.1		
		Value of time (R)								
9	PT modes	Coefficient	-0.062	-0.169	-0.169		0.000	-2.370	4.693	Waiting time excluded from model 8. Predicted modal split good. (B,TR,TX) = (12.68%, 21.57%, 65.75%)
		T-statistic	-6.4	-14.7	-14.7	Fixed	-11.3	11.0		
		Value of time (R)		R 3.04	R 3.04					

Note: Text in bold represents values resulting from the calculation of walking in metres as opposed to minutes, and cost per month as opposed to per trip.
Note 1: Modal split is relative to the sample and not to the population it represents.

(a) Income

Income was included to evaluate the effect it could have on car utility. The variable was successfully included in the Cape Town Multimodal Project (City of Cape Town et al., 2002) where the variable proved to be significant in increasing the utility of the car mode. On the contrary, the GTS2000 Study in Gauteng (PVW Consortium, 2004a) found income to be of very low significance with values in the vicinity of $3.0E-05$ for low-income users. Income is considered a utility (which increases as income increases) and is hence incorrectly represented by a negative sign in the results.

The significance of income however proved to be very low coupled with a low coefficient value. The fact that the variable does not vary across modes (but within modes) could be a contributing factor to its instability. Furthermore, the sample data is representative of only poor people (income less than R3 000), and therefore does not vary significantly. The results clearly show that income should rather enter the utility function taking cognisance of its relationship with cost (i.e. cost/income).

(b) Percentage Income Spent on Public Transport

The variable has proved to be very significant in all model runs. Percentage income spent on public transport is considered a disutility and is hence correctly represented by a negative sign. In models including fare per trip, the coefficient value drops significantly, which may be an indication of the correlation between the two variables. However, the covariance table produced by the software does not provide evidence for the latter with test statistic values in excess of 1.96 at the 95% confidence level. Policies impacting on user cost would therefore have a moderate impact on modal split.

Percentage income spent is rather dominant in most models, except in cases where fare per trip is also included. It is primarily more dominant than both walking and waiting times, but less dominant than the ASCs. Previous studies in South Africa have mainly concentrated on fares (TRC Africa, 2002) as the preferred functional form of the attribute, rather than percentage income spent, hence the value of the parameter cannot be compared to previous estimates.

An attempt was made to depict the impact of the variable on mode choice, but was not found to result in any meaningful insight into the behavior of the variable. The graph appears to be extremely inelastic with a flat slope in the range of possible changes, and will, therefore, not be shown here.

(c) Cost of public transport

Cost of public transport was entered into the utility function deploying two different units: cost per month and cost per trip. The former resulted in a very low coefficient value, while the latter resulted in a very high coefficient value. However, the unit cost per month gave rise to unrealistically high monetary values for waiting time. In contrast, the unit cost per trip resulted in monetary values for waiting time in line with expectations. In both cases, the variable proved to be significant with t-statistics between -3.1 and -25.0.

It should also be noted that cost expressed as fare per trip is more closely comparable with walking and waiting time, as for estimation purposes it is preferred that the contribution of each term and the values of the attributes in the utility function are approximately of the same magnitude. Variables with higher magnitude tend to dominate the estimation

procedure and thereby produce deviating results. The results of model 1 are indicative of that. It was therefore decided to express cost in terms of fare per trip in the remaining models.

The coefficient value of the variable is quite stable around -3.3 with a rather dominant role in the overall utility function. It is obvious that any changes to fares will be very effective in influencing modal shifts. Cost of public transport is considered a disutility and is hence correctly represented with a negative sign.

The following graph, produced using coefficients from model 9, depicts the sensitivity of the demand model to the variable fare per trip and its impact on mode choice.

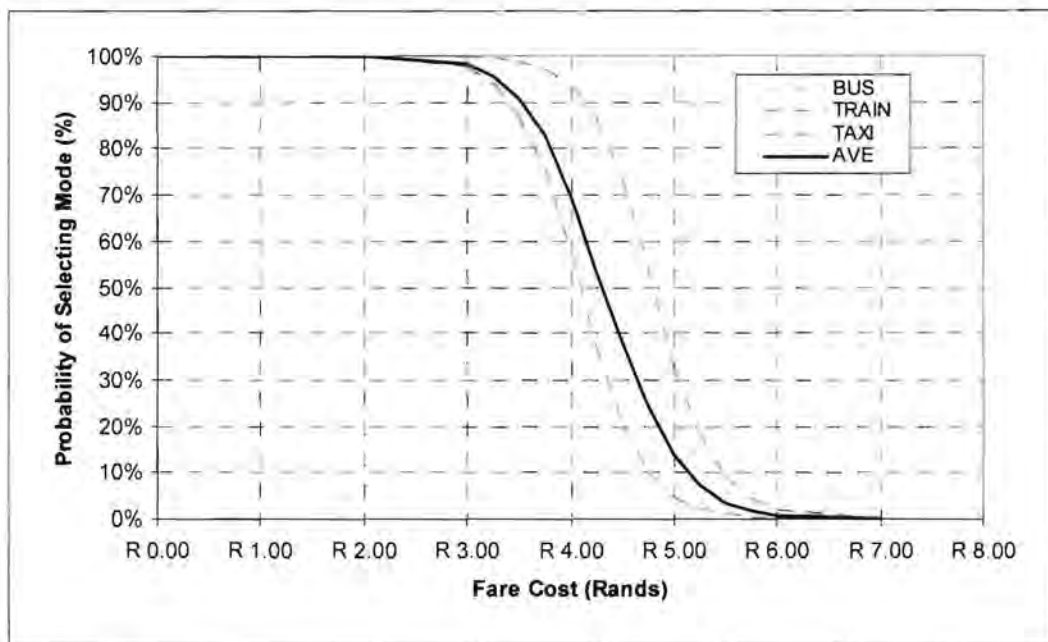


Figure 12: The Impact of Public Transport Fares on Mode Choice

Figure 12 indicates the impact of the variable fare on the probability of selecting any of the public transport modes. The graph is produced by plotting the average probability for each of the three public transport modes against a set fare price. It should be noted that only fare per trip was used to calculate utility, with all other variables excluded from the utility function. The assumption of using an average probability is fair, since the coefficient for the variable is generic (the same for all modes) and the variance in fare per trip between the modes is small. It is clear that the variable of fare is most effective (or most elastic) in influencing mode selection in the range R3.50 to approximately R5.50. Hence policies need to be designed to ensure that proposed changes in fares fall in this range in order to have maximum impact.

(d) Walking Time/Distance

Walking was entered into the utility function deploying two different units: distance and time. The former resulted in a very low coefficient value, while the latter resulted in a very high coefficient value. It was decided to express the variable in time, in order to be more closely comparable with the rest of the parameters in the utility function. The variable proved to be significant with t-statistics between -3.2 and -31.5. The coefficient value of the variable is

quite stable in the range 0.1 to 0.4 expressed in time. Any changes to walking time will be very effective in influencing modal shifts. Walking time is considered a disutility and is hence correctly represented with a negative sign.

Generally, it is expected that waiting time should be weighted lower than walking time. Both local and international studies (Victoria Transportation Policy Institute, 2005) have found that walking time from home is valued higher than waiting time. This is the case in model 6 and model 7 where the value of walking time is approximately double that of waiting time, with values approximated at around R3 per hour. The monetary value of walking time is in the expected range and was validated using the 2004 Gauteng Study (PWV Consortium, 2004a), which estimated the monetary value between R2 and R3 per hour for low-income public transport users. It can therefore be concluded that the monetary value of the variable is realistic.

The following graph, produced using coefficients from model 9, depicts the sensitivity of the demand model to the variable walking time and its impact on mode choice.

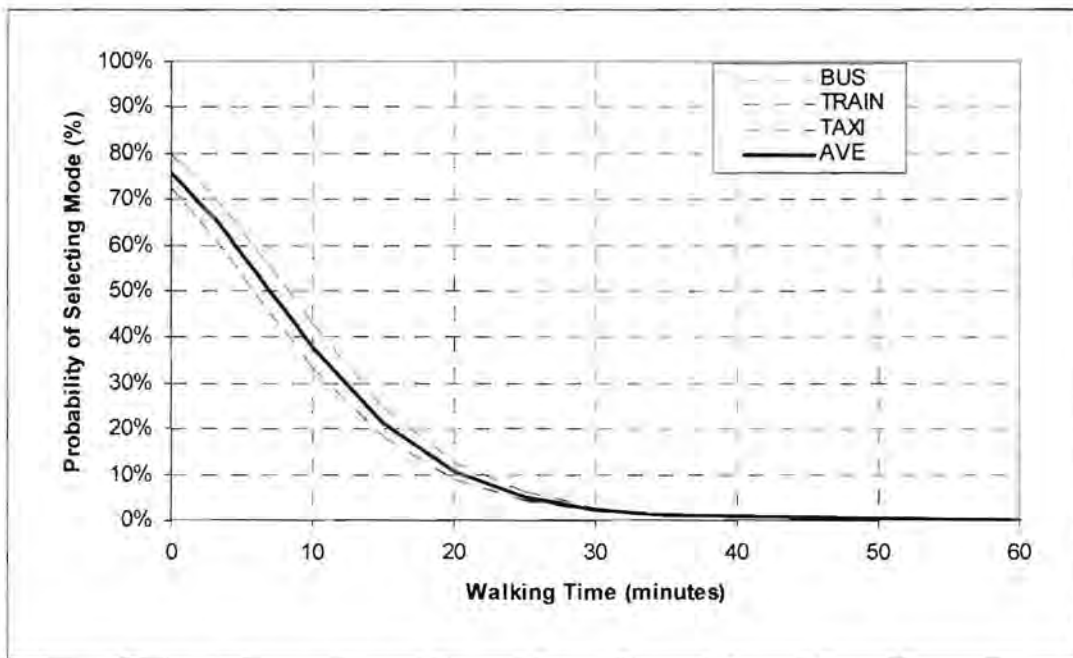


Figure 13: The Impact of Walking Time on Mode Choice

Figure 13 indicates the impact of walking time on the probability of selecting any of the public transport modes. The graph is produced by plotting the average probability over the three public transport modes against a set walking time. The assumption of using an average probability is fair, since the coefficient for the variable is generic and the variance in walking time between the modes is small. It is clear that a change in the variable would be most effective in influencing mode selection in the range zero to approximately 20 minutes. Hence policies need to be designed to ensure that proposed changes in walking time fall in this range in order to have maximum impact.

(e) Frequency of Service

Frequency entered into the database as the average number of departures per hour for each origin zone during the peak period. Since the frequency values of taxi in the dataset was

synthesised, it was decided to exclude frequency of taxi from the utility function. It is assumed that the variable will be taken up by the ASC for taxi. The exclusion is also based on the fact that frequency for taxi is already significantly higher than for the other modes, and therefore does not require any improvements. Subsequently, frequency has been included in all but one utility function. The inclusion of frequency into the utility function did not alter the value of waiting time as significantly as one would have expected. Moreover, the correlation table produced by the software does not provide evidence that the relationship between the two variables is significant (see Table 27). Off-peak frequency data was not available and could thus not be included in the demand model.

The variable has proved to be very significant in all model runs. Frequency is considered to have a positive utility and is therefore of the correct sign. Policies impacting on frequency would therefore have a significant impact on modal split. It is also relatively dominant compared to the out-of-vehicle time attributes as well as the percentage income spent on public transport. Not many studies have addressed frequency as a level of service attribute, as consideration is mainly given to waiting time instead, hence the coefficient value cannot be compared to other estimates.

The following graph, produced using coefficients from model 9, depicts the sensitivity of the demand model to peak period frequency and how the variable impacts on mode choice.

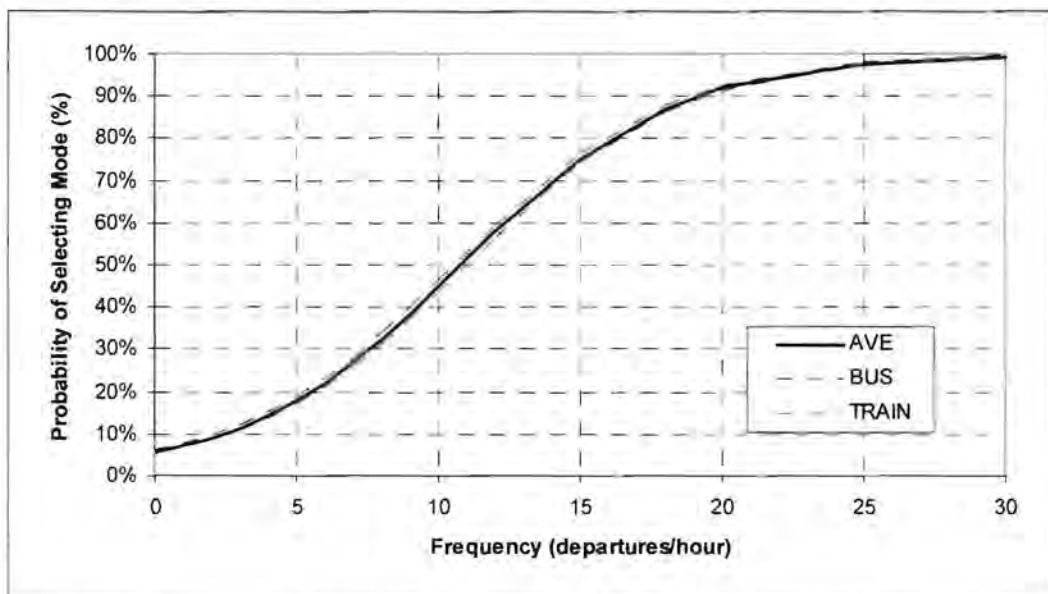


Figure 14: The Impact of Peak Period Frequency on Mode Choice

Figure 14 indicates the impact of peak period frequency on the probability of selecting any of the public transport modes. The graph is produced by plotting the average probability over two public transport modes (bus and train) against a set number of departures during the AM peak period. The assumption of using an average probability is fair, since the coefficient for the variable is generic and the variance in frequency between the modes is small. It is clear that a change in the variable would be most effective in influencing mode selection in the range five to approximately 15 departures per hour. Hence policies need to be designed to ensure that proposed changes in peak period frequency fall in this range in order to have maximum impact.

(f) Alternative Specific Constants (ASC)

As mentioned earlier, the car mode was found to disturb the calibration process and was, therefore, excluded from further calibration of the model. The ASC values consistently express that the minibus-taxi mode dominates both the bus and train mode. This is substantiated by the actual modal split of both the sample data and the population. The train mode is slightly less popular than the bus, as is revealed by the majority of model runs, mainly due to the lack of personal security and often deplorable comfort levels (e.g. crowding). The train mode's higher modal split can be attributed to cheaper fare levels, which were found to be the most important attribute in mode selection.

ASC values reflect factors that were not included in the modelled attributes, together with user's inherent perception of the mode. The constant for bus was set to zero, therefore, ASCs for train and taxi should be seen relative to bus. However, caution should be exercised when considering the potential dominance of the ASC parameters. When these values dominate the contribution of attributes in the utility function, it implies that the ASC seeks to replicate the modal split values. The ASC for taxi in model 7 (with the highest value) contributes on average about 22% to the total utility of the mode. This would obviously be less for the bus and train alternatives, and should therefore not have any serious impact on the explanatory power of the model.

Compared to the 2002 Cape Town study, ASC values were also rather dominating in the overall utility function. ASC value for taxi was more dominant than bus, indicating the same trend. All ASC values are significant as they exceed the t-value of 1.96 at the 95% confidence interval.

(g) Hours of Service

Running a model for hours of service did not produce any significant results. This might have been connected with the fact that the attribute values are entered as constant values (one value for all individuals using of a particular mode) into the dataset for a particular mode, and therefore do not allow for much variation. It should also be noted that the integration of the CPTR dataset (containing the operational data) with the Gauteng Household Travel Survey (containing the demand data) is extremely difficult, as they do not use the same coding. This posed a significant difficulty in analysing the attribute. Time constraints do not allow for any further exploration of this attribute, but may prove to be of importance nonetheless.

8.3.3 CONSOLIDATION OF MODEL CALIBRATION RESULTS

Table 28 summarises the model calibration results. The model was calibrated based on its ability to predict the actual modal split in the pilot area as accurate as possible. Remarks have been made next to each model run to highlight specific issues and concerns related to the model in question (see Table 28). Some conclusions with regard to the calibration results are presented below.

- The rho-square value indicates the "goodness-of-fit" for each model. As can be observed, all models have rho-square values in excess of 0.5, which is considered good.
- It is also noted that most models are capable of predicting the existing modal split quite accurately, with the exception of model 1 which is indicative of a large deviation (maximum difference approximately 3%). These results are considered very good.
- All variables included in the calibration process are significant.
- Although a strong correlation would have been expected between the percentage income spent and fare cost, in addition to waiting time and frequency, the estimation

results did not reflect it. Possible reasons may be the fact that the assumed maximum values for these are not interrelated (as they are based on calculated guestimates) and hence resulted in two unrelated variables altogether.

- The above-mentioned should however be taken cognisance of when policies for LOS changes are tested in the next chapter.
- Adjustment of assumptions for walking time by six minutes produced higher coefficient values for the variable.
- In models 4 and 5, the ASC values are far less dominant. The addition of a fourth variable in model 6 resulted in higher ASC values again. Taxi is consistently more dominant than bus and train, alluding to its dominance and popularity in the market place.
- The ratio between walking and waiting time is acceptable in models 4, 6 and 7. The assumed maximum walking times for the alternatives are at levels six minutes higher than in the other models.
- Model 7 has a good model fit, and indicates the dominance of modes in the expected order, although walking time is valued 3.5 times higher than waiting time. It also predicts the modal split with good accuracy.

It is concluded that model 9 is preferred, since waiting time and frequency are theoretically closely related (although the correlation table does not indicate that). In addition, it seems as if the data related to waiting time is not very accurate. In reality, commuters hardly wait for more than 10 minutes in instances where low frequencies are provided. This is because these commuters are familiar with timetable schedules and therefore arrive at the stop/station shortly before departure. When higher frequencies are provided, arrivals at stops/stations tend to be random, resulting in a more normal distribution of waiting times. The perceived waiting times might therefore not be an accurate depiction of the service currently provided. Based on the 10-minute theory, and from a forecasting perspective, it is more appropriate to include frequency rather than waiting time.

8.3.4 TEST FOR MODEL STRUCTURE/VIOLATION OF IIA ASSUMPTION

Since the model structure being LOGIT was taken as given, the basic assumptions related to LOGIT models need to be adhered to in order for the structure to be valid. It is necessary to test whether the following assumptions are not violated: independence from irrelevant alternatives (IIA), no random taste variations, and no correlation of choice over time (heteroscedacity of utility functions).

Of most importance are the potential limitations of the IIA assumption. If the analysis shows that the information in the observed component of the utility is maximised, resulting in a minimal amount of information in the unobserved component, then any assumption about the error term is likely to be of small consequence (Hensher et al., 2003, p.422). To reduce the impact of IIA violation, Hensher proposes that certain issues need to be adhered to.

- Selection of the most relevant attributes that affect an individual's choice will reduce the likelihood of the error term influencing the predicted choice outcome.
- Measurement of the relevant attributes should be represented as viewed and processed by the individual decision maker (e.g. averaging attributes for a segment in the population is not desirable).
- Socio-economic characteristics should be viewed as proxies for unobserved attributes as they are not sources of utility of an alternative.

- The functional form of the attributes and that of the parameters should be correctly identified, for example some attributes may be better represented as non-linear indicators, or interact with another attribute (e.g. cost over income).

It can be concluded that these conditions are met to a large extent in the resulting model, as is also shown by the contribution of the ASC in the utility function of the selected model (about 22%).

The IIA assumption can also be formally tested by comparing logit models estimated with subsets of alternatives from the universal choice set (Ben-Akiva, 1985, p183). Thus, if a model is correctly specified, one can obtain consistent coefficient estimates (i.e. consistent scale differences) of the same sub-vector of parameters from a logit model estimated ($C \subseteq \hat{C}$) with the full choice set β_C and from a logit model estimated with a restricted choice set $\beta_{\hat{C}}$. McFadden, Tye and Train (1977) developed an approximate likelihood ratio test for the null hypothesis that $\beta_{\hat{C}} = \beta_C$.

$$1/(1-N_1/\alpha N)^{-2[\mathcal{L}_{\hat{C}}(\beta_{\hat{C}}) - \mathcal{L}_C(\beta_C)]} \quad (9-5)$$

where N is the number of observations in the unrestricted choice set estimation, N_1 is the number of observations in the restricted choice set, and one can assume that $\alpha = 1$.

The model structure was validated below using the above formula. The restricted choice set was created by excluding the bus mode from the model estimation process.

$$1/(1-3905/4477)^{-2[-317.3 - 608.9]} = -4563.6$$

It is concluded that the IIA assumption is not violated, since the value obtained are greater than the t-value of 1.96 at the 95% confidence interval. The excluded alternative is shown to be relevant indeed, and thus the multinomial logit model is appropriate for application in this research.

8.4 RESUMÉ

This chapter aimed to describe the methodological approach taken for the service model component, together with the relevant theoretical issues, the available software applications to carry out complex model estimation tasks, and key statistical tests to be considered. The data source and market segmentation were briefly explained, followed by the estimation and calibration of the service model.

The estimation and calibration of the service model posed many challenges. The dataset in question is a classic case where only attribute values for the selected mode were collected, and not for all modes in the choice set. Certain assumptions therefore had to be made in order to populate the resulting missing values of the alternative modes in the dataset. Average values of attributes were calculated for each OD pair in the dataset, from the individuals that have selected a particular mode. Although this is a drawback of the model, the practice of using the average values for alternatives is acceptable in discrete choice modelling. A more suitable approach would have been to synthesise the values for each

record in the database, but this approach would have been time-consuming and would not have improved significantly on the accuracy of the dataset, relative to the method deployed.

Data requirements, availability and quality had its own limitations. This resulted in the successful inclusion of only five attributes, namely percentage income spent on public transport, walking distances, waiting time and frequency. Since waiting time and frequency are theoretically highly related (although a formal correlation test did not indicate that), waiting time was excluded from the final model. The exclusion is based on the fact that the data with regards to waiting time is not very accurate, as the perceived waiting times might not be an accurate depiction of the service currently provided. From a forecasting perspective, it is more appropriate to include frequency rather than waiting time. The variable income was found to produce better results when entering the utility functions as the percentage of income spent on public transport.

The variable fare per trip has the most impact on mode choice probability in the range R3.50 to R5.50, while frequency is most responsive in the range five to 15 departures per hour. Walking time has the highest impact in the range zero to 20 minutes.

A formal statistical test showed that the assumed model structure, i.e. the multinomial logit model, is appropriate for application in this research and that the fundamental assumptions associated with this form of demand model are not violated.

The next chapter deals with the impact of LOS changes on demand and supply, using sensitivity analysis to explore the variables included in the model.

CHAPTER 9**SENSITIVITY ANALYSIS**

This chapter discusses the impact of LOS changes on demand and supply as predicted by the model, addressing sensitivity issues associated with the model and concluding with the formulation of possible policy sets to be tested in the next chapter.

9.1 SENSITIVITY TESTS FOR DEMAND MODEL

In the demand model, any changes in the level of service provided has an effect on the utility of the mode under consideration, as well as the utility of the alternatives in the choice set. As a result, the probability of a particular mode choice will alter, which in turn will alter the ridership of that mode. To test the sensitivity of the service model, each of the input parameters was changed by a certain percentage, while the all other parameters were kept constant at default levels. Table 29 gives the results of the sensitivity tests with respect to each mode, expressed as the percentage change relative to the modal split of the base case scenario, as well as the elasticity of each parameter. Public transport service elasticity is defined as the percentage change in public transport ridership resulting from each 1% change in public transport service, such as price or frequency. A negative sign indicates that the effect operates in the opposite direction from the cause (i.e. an increase in price causes a reduction in travel).

Table 29 shows that a change in fares results in the highest responsiveness in public transport ridership, as indicated by the high elasticity values (>1.0). A reduction in fares is shown to be elastic in all three cases, meaning that a reduction will always result in a higher than proportional change in ridership. The latter is also true for an increase in fares in the case of bus services. Another point of interest is that fare changes are non-symmetric for all three modes, i.e. different elasticity values are reported for the same margin in fare reduction compared to a fare increase. This is due to arc elasticities having a logarithmic distribution, which results in a different gradient for opposing directional movement along the curve. In the case of bus services, the market is more sensitive to a fare increase, while the market is more responsive to a fare reduction in the case of train and taxi services.

Table 29: Demand Model Sensitivity to Change

Parameter Change		% Change in Bus share	% Change in Train share	% Change in Taxi share	Elasticity ¹
Base Case Modal Shares		26.87	29.46	43.67	Default
Bus Parameters	Reduce Walking Distance by 10%	+2.26	-0.88	-0.80	-0.21
	Reduce Waiting Time by 10%	+0.82	-0.29	-0.31	-0.08
	Reduce Fare Cost by 10%	+12.66	-6.71	-3.26	-1.13
	Increase Fare Cost by 10%	-15.28	+6.06	+5.32	-1.74
	Increase Frequency in Peak Period by 10%	+1.75	-0.71	-0.60	0.18
	Reduce % Income Spent on Public transport by 10%	Responsive to a change in fares			
Train Parameters	Reduce Walking Distance by 10%	-0.92	+1.70	-0.58	-0.16
	Reduce Waiting Time by 10% ¹	-0.28	+0.49	-0.16	-0.05
	Reduce Fare Cost by 10%	-5.90	+12.50	-4.80	-1.12
	Increase Fare Cost by 10%	+3.65	-8.02	+3.16	-0.88
	Increase Frequency in Peak Period by 10%	-0.44	+0.73	-0.22	0.08
	Reduce % Income Spent on Public transport by 10%	Responsive to a change in fares			
Taxi Parameters	Reduce Walking Distance by 10%	-1.27	-0.44	+1.08	-0.10
	Reduce Waiting Time by 10%	-0.36	-0.20	+0.36	-0.03
	Reduce Fare Cost by 10%	-17.57	-7.55	+15.90	-1.40
	Increase Fare Cost by 10%	+6.23	+8.99	-9.90	-1.09
	Increase Frequency in Peak Period by 10%	Not to be evaluated – frequency is relative to that of competing modes			
	Reduce % Income Spent on Public transport by 10%	Responsive to a change in fares			

Note 1: Arc elasticities are calculated relative to the mode for which parameters were changed. Arc elasticities are calculated as follows: $e = \Delta \log(\text{Ridership}) / \Delta \log(\text{Attribute})$

Public transport dependent riders, as well as commuter trips, are generally less responsive to price changes compared to choice riders and non-commute trips (Victoria Transportation Policy Institute, 2005). In this research, however, these results show the market segment under consideration as having a significant response to price changes. This is because the market under consideration is limited to public transport modes. Responsiveness to change is higher in a market consisting only of public transport modes, compared to a market consisting of public transport and private modes (Victoria Transportation Policy Institute, 2005).

Reducing walking distances have moderate elasticities ranging between -0.10 and -0.21, as well as an increase in frequency of bus services. Waiting time has a very low elasticity across all modes.

It is noted that an improvement or decline in the service level for a particular mode has the opposite effect on the modal share of the competing modes. This tendency is constant throughout the sensitivity test results. The high market share of taxi means that taxi ridership is in some instances less responsive than the competing modes.

9.2 IMPACT OF SERVICE LEVEL CHANGES ON RESOURCES

Table 30 gives the relationship between changes in LOS and the impact these service level changes would have on resource consumption.

Table 30: Impact of Service Level Changes on Resources/Cost

Change in	Impact on Resources		Impact on Cost	
	Infrastructural	Operational	Capital	Operational
Walking distances	Stop and route spacing	Additional routes to be covered	Cost of additional stops	Cost of additional service
Waiting time	-	Number of departures	-	Cost of additional service
Frequency	-	Number of departures	-	Cost of additional service
Fare levels (% Income spent on public transport)	-	-	-	Impacts on revenue and subsidies
Loading levels	-	Capacity requirements	-	Cost of additional capacity
Safety against accidents	Old vehicles in fleet to be replaced	-	Cost of new vehicles	-
Security against crime	-	Security guard deployment	-	Salaries of guards
Hours of service	-	Additional service	-	Cost of additional service

Below follows a detailed account of the changes indicated in Table 30.

9.2.1 CHANGE IN WALKING DISTANCES

Changes in walking distances (or access time) impact on operational cost and, to a lesser extent, capital expenditure, due to the physical infrastructural intervention required to reduce walking distances. Access time is influenced by the characteristics of the network provided, such as route and stop spacing. It was therefore decided to conduct a spatial exercise, using GIS software, to determine the number of commuters residing (or the amount of urban space) outside a given radius from a public transport stop/station. The operational cost implications are calculated based on the assumptions listed below.

- The area not serviced by a public transport stop/station (i.e. the area outside a given radius from any stop/station), is indicative of the area in need of service provision.
- By calculating the equivalent number of stops/stations required within the area outside the buffered area (by dividing this area by the equivalent area covered by a single stop/station), a cost was deduced which represents the required additional funding to lessen walking distances.
- It was assumed that the number of stops/stations provided is equivalent to the operational expenditure of the service provided at that stop/station.
- Since demand is concentrated along routes already serviced, it was assumed that 50% of the area not covered by public transport had very low population densities and did not need public transport. This assumption attempts to overcome the complexity associated with identifying settlement patterns of public transport users, since there is no single formula to relate the level of density to the most cost effective level of public transport provision (City of Johannesburg Metropolitan Municipality , 2003).
- The capital expenditure as a result of infrastructural intervention is negligible.

The following equations were developed to allocate a percentage increase in operational cost to the resource model, given a decrease in walking distances. The equations were developed so that the operational expenditure would be zero if the walking distances were equal to the current average walking distances in the pilot areas. The equations for calculating a percentage increase in operational cost as a result of a decrease in walking distances are as follows:

$$\text{BUS: } y = (-0.387255x + 272.58745)/100 \quad (10-1)$$

$$\text{TAXI: } y = (-1.560345x + 961.4724)/100 \quad (10-2)$$

where y is the percentage increase in operational cost and x is walking distance (metres).

9.2.2 CHANGE IN FREQUENCY

Changes in frequency result in additional services that need to be provided along a particular corridor. The increase in frequency is taken account of in the resource model by the impact it has on vehicle kilometres travelled. The increase in vehicle kilometres is translated into operational cost to determine the impact on the selected indicators.

9.2.3 CHANGE IN FARE LEVELS (PERCENTAGE INCOME SPENT ON PUBLIC TRANSPORT)

The percentage of income spent on public transport impacts on fare levels in the model. Costing formulae (based on regression analysis of 2004 tariff data obtained from the various operators) are adjusted to take account of reduced or increased fares. An increase in fare levels should be expected to result in some ridership loss, but will provide increased fare revenues. A reduction in fare levels will almost always generate more ridership, but will also result in diminished fare revenues.

9.2.4 CHANGE IN LOADING LEVELS

Changes in loading levels impact on capacity requirements of the current service. To decrease loading levels (i.e. decrease v/c), additional capacity needs to be provided by means of additional departures.

9.2.5 CHANGE IN SAFETY LEVELS

It is assumed that the reduction of the average age of public transport vehicles will impact positively on the overall safety against accidents. To assure a decrease in the average age of vehicles, new vehicles need to be introduced into the system. The acquisition of new vehicles is taken account of in the resource model by including the capital cost of the new vehicles into the total annual cost of the policy change scenario. The scrapping of the aging vehicle fleet is in line with the revised Taxi Recapitalisation Programme launched by the National Department of Transport in 2005 (NDoT, 2005b).

9.2.6 CHANGE IN SECURITY LEVELS

Security against crime can be increased by the provision of visible security at stations and on vehicles. In the model, the number of security officers to be provided is calculated relative to the number of peak hour passengers. It is assumed that, as a minimum, one security guard should be provided per 1000 AM peak hour passengers. Increased security impacts

on the operational cost of providing additional security at stations/on vehicles. The model takes account of additional security by an increase in the annual payroll for security guards.

9.3 SENSITIVITY TESTS FOR RESOURCE MODEL

To test the sensitivity of the resource model, each of the input parameters was changed by a certain percentage, while the all other parameters were kept constant at default levels. Table 31 gives the results of the sensitivity tests with respect to each mode, expressed as the percentage change relative to the monetary implications of the base case scenario, as well as the elasticity of each parameter. As mentioned earlier, elasticity is defined as the percentage change in the consumption or quantity of a good or resource caused by a 1% change in its price or some other characteristic. In the case of fare changes, elasticities are relative to total annual fare income, while elasticities for all other parameters are relative to total annual cost.

Soshanguve is served by only one rail line for movement in and out of the area. In the model, the demand for train services was allocated to only one route to estimate the resource consumption accurately. The cost differential between fare income and total cost is realistic for bus services. Train services are shown to have a surplus, although in reality, this cost differential (or subsidy) amounts to approximately two thirds of the cost for train services and one third for bus services. It should be noted that the high subsidy levels are applicable to the national rail system, and this does not mean that all routes are operating at a loss. It should also be noted that the maintenance of the network is not included in the cost estimate, but may have a significant impact. The model currently estimates subsidies at 36% for bus, and a surplus of 40% for train services with reference to the base-case scenario.

It is noted that the total cost of taxi services has been slightly overestimated. Ideally, fare income and total cost should reach break-even, as the service is not subsidised. The overestimation in cost can be attributed to the depreciation cost component as part of the running costs of the vehicle (R1.98/veh.km). In this regard, the depreciation calculation assumes that new vehicles are acquired, which typically amounts to approximately R180 000. In reality, however, the average age of the taxi vehicle fleet is proof that operators are more likely to purchase second-hand vehicles at a third to half the full price of a new vehicle.

These concerns are not expected have a negative impact on the prediction capabilities of the model, as only relative (and not absolute) changes to the base case are of importance.

Table 31: Resource Model Sensitivity to Change

Parameter Change		% Change in Total Bus Cost / Income	% Change in Total Train Cost / Income	% Change in Total Taxi Cost / Income	Elasticity ¹
Base Case Total Annual Cost (Rm)		65.53	39.33	125.45	Default 1
<i>Base Case Total Annual Fare Income (Rm) ²</i>		<i>41.76</i>	<i>22.02</i>	<i>101.30</i>	<i>Default 2</i>
Bus Parameters	Reduce Walking Distance by 10%	+10.4	0	0	-0.94
	<i>Reduce Fare Cost by 10%</i>	<i>-11.0</i>	<i>0</i>	<i>0</i>	<i>1.11</i>
	<i>Increase Fare Cost by 10%</i>	<i>+10.0</i>	<i>0</i>	<i>0</i>	<i>1.00</i>
	Increase Frequency in Peak Period by 25% (after introduction of minimum frequency)	+17.6	0	0	0.56
	Increase Frequency in Off-Peak Period by 50%	+35.6	0	0	0.44
	Increase Hours of Service by 10%	+0.5	0	0	0.06
Train Parameters	<i>Reduce Fare Cost by 10%</i>	<i>0</i>	<i>-10.0</i>	<i>0</i>	<i>1.00</i>
	<i>Increase Fare Cost by 10%</i>	<i>0</i>	<i>+9.0</i>	<i>0</i>	<i>0.90</i>
	Increase Frequency in Peak Period by 25% (after introduction of minimum frequency)	0	+24.5	0	0.98
	Increase Frequency in Off-Peak Period by 50% (after introduction of minimum frequency)	0	+34.0	0	0.73
	Increase Hours of Service by 10%	0	+0.4	0	0.04
	Reduce Crowding by 10%	0	+11.5	0	-1.03
	Increase Security Officers / Vehicle by 10%	0	+0.10	0	0.01
Taxi Parameters	Reduce Walking Distance by 10%	0	0	+36.9	-2.98
	<i>Reduce Fare Cost by 10%</i>	<i>0</i>	<i>0</i>	<i>-10.0</i>	<i>1.00</i>
	<i>Increase Fare Cost by 10%</i>	<i>0</i>	<i>0</i>	<i>+10.0</i>	<i>1.00</i>
	Increase Frequency by 10%	Not to be evaluated, frequency relative to that of competing modes			
	Increase Hours of Service by 10%	0	0	+0.8	0.08

Note 1: Arc elasticities are calculated relative to the mode for which parameters were changed. Arc elasticities are calculated as follows: $e = \Delta \log(\text{Income or Cost}) / \Delta \log(\text{Attribute})$.

Note 2: Elasticities for the parameters in Italics are relative to Total Annual Fare Income.

A change in fares results in the highest responsiveness to public transport income and cost, as indicated by the unit elasticity values (1.0) in the majority of cases. The positive signs for fare elasticities indicate that the effect on income is in the same direction as the change in fare.

Changes in frequencies have a moderate to high impact on cost, with elasticities ranging between 0.44 and 0.98. An increase in hours of service has had the most significant impact on taxi services (currently having the lowest number of service hours in the model), but a marginal impact nonetheless for all public transport services (elasticities less than 0.1). Related improvements should have a very low impact on cost.

Two additional sensitivity tests were conducted for train services: reduction of crowding and an increase in security. Only train services tend to be overcrowded at this point in time (v/c ratio equals 1.13) during the morning peak period, while security is currently non-existent for the other two modes and the variables were therefore excluded from sensitivity testing for these modes (security can, however, be introduced for the other modes). The model is extremely responsive to a reduction in train crowding, with a 10% reduction resulting in an

approximate 12% increase in cost. On the other hand, the impact of an increase in security is very low.

9.4 FORMULATION OF POSSIBLE POLICY SETS

From the findings in this chapter (i.e. both from the service and resource model), the following policy scenarios appear to have the greatest impact and can be further explored:

- exploration of walking distance ranging from current LOS to target LOS;
- exploration of peak and off-peak frequencies, assuming a fixed level of demand for off-peak frequencies as the variable is not included in the service model; and
- the exploration of fare changes to reduce the cost implications, i.e. maximising total fare income by trading off an increase in fare income, as a result of an increase in ridership, against a loss in ridership as a result of an increase in fares.

The following policy sets are only relevant to the resource model, as these variables are not represented in the service model:

- exploration of train loading levels, with both constant fares and an increase in fares;
- exploration of train loading levels, coupled with changes in frequency;
- exploration of an increase in the available hours of service;
- exploration of safety (from accidents) measures by scrapping aging vehicle fleet; and
- exploration of security measures through the deployment of visible security at stations and in vehicles.

Many of the above policy tests are relevant in an optimisation context, i.e. finding the optimum trade-off between revenue generated and cost implications of single improvements, or a combination thereof. The main objective, however, will be to establish the amount of additional funding required in order to implement the proposed minimum and target LOS. The analysis will be conducted for each mode independently, as the modes are managed and operated in isolation. The decision rule will therefore be to estimate the additional funding needed to be invested into public transport, in order to bring current or actual LOS to minimum or target levels. The remaining policy sets can be explored as part of future research in this field of study.

9.5 RESUMÉ

In this chapter, sensitivity tests were used to express the responsiveness of variables to a given percentage change, also referred to as elasticity. Public transport service elasticity was defined as the percentage change in public transport ridership resulting from each 1% change in public transport service, such as price or frequency.

It was shown that a change in fares results in the highest responsiveness in public transport ridership, as indicated by elasticity values in excess of 1.0. A reduction in fares was found to be elastic in all three cases, meaning that a reduction will always result in a higher than proportional change in ridership. In the case of bus services, the market is more sensitive to a fare increase, while the market is more responsive to a fare reduction in the case of train and taxi services.

In terms of demand, the reduction of walking distances had moderate elasticities ranging between -0.10 and -0.21, as well as an increase in frequency of bus services. Waiting time had a very low elasticity across all modes.

It was shown that the cost differential between fare income and total cost is realistic for bus services. Train services are currently modelled to operate at a profit for the base-case scenario, which can be attributed to the fact that the network maintenance cost is not included in the model. In reality, this cost differential (or subsidy) amounts to approximately one third of the cost for bus services, and two thirds for train services, but the latter is applicable to the country-wide rail network. An overestimation in cost of taxi services can possibly be attributed to an overestimation of the depreciation cost component as part of the running costs of the vehicle. These concerns are not likely to have any negative impact on the model results, as only relative changes to the base case scenario are important.

Sensitivity tests of the resource model showed that a change in fares results in the highest responsiveness to public transport income and cost. Changes in frequencies had a moderate to high impact on cost, with elasticity values ranging between 0.44 and 0.98. An increase in hours of service had a minimal impact on all services, and the measure can, therefore, be implemented at a relatively low cost. The model was found to be highly responsive to a reduction in train crowding, with a 10% reduction resulting in a 12% increase in cost. The impact of an increase in security was found to be insignificant.

The chapter concludes with the formulation of policy scenarios that appear to have the greatest impact and that ought to be explored for high-impact solutions. Most of these policies are related to optimisation techniques and will not be explored as part of this research. The next chapter analyses the deployment of the model in the pilot area of Soshanguve to test the achievement of minimum and target public transport LOS.

POLICY ANALYSIS AND RESULTS

10.1 BACKGROUND

This chapter describes the application of the model developed in Chapter 7 to the pilot area of Soshanguve in Gauteng. The policy sets developed will be applied to the area in order to estimate the impact on demand for those variables successfully included in the service model, as well as the resources required to improve LOS. To summarise, Table 32 illustrates the ideal minimum and target public transport LOS.

Table 32: Ideal Minimum and Target Levels of Service

No	Parameter	KPI	Levels of Service ⁽¹⁾		
			Bus	Rail	Taxi
1	Availability	Hours of service	18 (24)	18 (24)	18 (24)
2	Accessibility	Walking distance to public transport	1 000m (500)	N/A	750m (400)
3	Loading levels	% Capacity utilisation (Volume to capacity ratio)	1.00	1.00 (0.90)	1.00
4	Frequency	Number of departures per hour in peak period	6 (12)	6	12
5		Number of departures per hour in off-peak period	1 (2)	1 (2)	4
6		Average waiting time in peak period	10 mins (5)	10 mins	5 mins
7	Cost	Percentage of income spent on public transport	10%	10%	10%
8	Safety	Maximum age of vehicles in the fleet	10 yrs	30 yrs	10 yrs
9	Security	Number of security officers per 1000 peak hour passengers	1	1	1

(1) Target LOS are indicated in brackets.

Note that the safety and security KPIs had to be changed from what was presented in Chapter 4 (5% reduction in annual accident ratings and crime incidents per 1000 commuter journeys), since no data was available for those KPIs initially selected. Moreover, the preliminary analysis has also indicated that a decrease in walking distances for rail passengers would not be practical, as infrastructure is rather rigid and very expensive to provide. The low number of stations in a given area provides proof in this regard. It would thus be neither feasible, nor cost effective, to provide the necessary infrastructural intervention at the hand of high investments required. Subsequently, it was decided to exclude walking distance LOS for rail services.

The status quo analysis (see Chapter 6) found that the percentage income spent on public transport is within the target of 10%. The variable should be tested for a market segment within the middle-income range, since it did prove to be significant. The same finding applies to minimum walking distances for bus and taxi services, which is within the proposed

minimum level of service. These scenario tests were, therefore, excluded from the analysis conducted for this pilot area.

10.2 DATA REQUIREMENTS, AVAILABILITY AND QUALITY

The results of any quantitative analysis depend on the credibility of the data source. It should be noted that some of the data sources have been found to be rather unreliable in determining actual LOS of the selected KPIs. It should also be noted that the quality of the bus data contained in the PTIS is questionable, and it was decided to seek alternative sources for more reliable data. Subsequently, the respective operators in the pilot areas were approached for the data, although limited information is collected by operators on a regular basis. Hence, only some of the data required for the bus mode was available.

As far as safety and security measures are concerned, it was found that these are areas for which information is significantly lacking. Moreover, it is especially difficult to quantify in monetary terms. For this reason, it was decided to shift the focus away from the pilot areas and rather to focus on data from the province, for which limited safety information is available. Security-related data, however, only exists to a large degree for rail services, and is negligible to non-existent for bus and minibus-taxi services.

The Current Public Transport Records Surveys were conducted only for the AM peak period. The resulting Gauteng Public Transport Information System (GPDPTRW, 2004c) only contains peak period frequency data, and not off-peak frequency. The latter could therefore not be incorporated into the demand model.

Network and operational data for all origin-destination pairs in the pilot area were aggregated into nine routes, as shown in Table 33. The demand for train services was allocated to only one route to estimate the resources consumed accurately, as only one rail line exists for movement in and out of the area.

Table 33: Route Aggregation by Destination from Soshanguve

Route Number	Destinations
1	CBD
2	Temba, Wintersveld, Mabopane
3	Pretoria West, Attendgeville
4	Centurion
5	Johannesburg
6	Internal Trips (i.e. inside regional boundaries of Soshanguve)
7	Ekurhuleni
8	Mamelodi, Pretoria East
9	External Trips (outside of the Gauteng provincial boundaries)

Table 34 provides the data requirements, availability and the available sources that were consulted in order to measure the KPIs in question.

Table 34: Data Requirements and Data Source for Identified KPIs

PARAMETER	KPI	FACTORS AFFECTING PARAMETER	DATA REQUIREMENTS	DATA SOURCE
Accessibility	Walking distance to public transport	Route spacing	Walking time	GHTS, Tshwane ITP
		Spacing between stops		PTIS
Loading levels	Volume to capacity ratio (% capacity utilisation)	Traffic congestion	Number of passengers	PTIS
		Passenger volumes	Number of vehicles	PTIS, Operators
		Alternative modes available		
		Vehicle capacities	Vehicle capacity	PTIS, Operators
Frequency	Waiting time	Traffic congestion	Spacing of stops	PTIS
		Number of stops	Service schedule	PTIS, Operators
	Number of departures per hour	Passenger volumes	Number of stops	PTIS
		Schedule accuracy		
		Operator diligence and availability		
Cost	% of PT commuters spending more than 10% of disposable income on transport to work	Distance travelled	Distances between sub-regions	EMME/2 Modelling Software
		Income level	Fare cost	Costing formulae
		Mode used	Passenger volumes	GHS
Safety	Average age of vehicles in the fleet	Vehicle condition (age)	Vehicle data	NATIS - vehicle registration data
		Stop/station condition	Accident data	Department of Community Safety
		Scheduling speed, incident response time		
Security	Number of security officers per 1000 peak hour passengers	Stop/station design e.g lighting	Crime statistics	Crime Reports
		Presence and location of police, cameras etc.	Number of security officers	Operators
		Presence of crowds		
		Time and day of travel		
		Presence of lighting, cameras etc.		

10.3 MEASURING UNCERTAINTY

In order to quantify the uncertainty associated with the model (or any modelling task for that matter), the Excel add-in tool, @RISK, was deployed to quantify the uncertainties identified in the model, using Monte-Carlo simulation techniques (Palisade Corporation, 2004). By using this procedure, it is no longer necessary to reduce output variables to a single number. Instead, probability distributions are specified for the uncertainty associated with cell values (or the input variables) in the spreadsheet. @RISK uses all this information, along with the Excel model, to provide confidence intervals within which the values of the output variables are likely to fall.

Table 35 lists the input variables that were identified to have an element of uncertainty. The uncertainty was expressed by normal probability distributions, truncated at the most likely minimum and maximum value that the variable can take, and with the mean equal to the value that the variable currently takes in the model.

Table 35: Range of Uncertainty in the Input Variables of the Model

Variable	Range of Uncertainty (min : deviation from mean : max)
% AM passengers in 1st peak hour	-10% : 0% : +10%
% AM passengers in 2nd peak hour	-10% : 0% : +10%
% AM passengers in 3rd peak hour	-10% : 0% : +10%
% Daily passengers in Off-Peak Period	-10% : 0% : +10%
Factor to adjust cost by in order to include walking distances	-20% : 0% : +20%
Number of stops on route	-5 stops : 0 : +5 stops
Distance between origin and destination	-3km : 0 : +3km
Ave travel speed	-10km/h : 0 : +10 km/h
Ave time loading/off-loading passengers - sec/stop or pass.	-2 sec : 0 : +2 sec
Ave time lost through acceleration/decel. - sec/stop	-3 sec : 0 : +3 sec
Time to turn vehicle around - min	-1 min : 0 : +1 min
Unit cost of vehicle	-R10 000 : 0 : +R10 000
Fixed vehicle standing cost - R/veh/annum	-R3 000 : 0 : +R3 000
Variable vehicle operating cost - R/veh-km	-20% : 0% : +20%
Other travel-related cost - R/veh-km	-30% : 0% : +30%
Annual Stop / Station Cost – R	-40% : 0% : +40%
Cost of security officer/annum – R	-15% : 0% : +15%
Fare structure coefficient - R	-10% : 0% : +10%

The following section will discuss the effect of the listed input variables on the identified output variables.

10.4 INFLUENCE OF INPUT ON UNCERTAINTY IN OUTPUT

Figures 15 to 17 illustrate the influence of the most significant input variables on the output variables. The output variables are annual vehicle kilometres travelled (AVKT), cost per one-way trip, annual fare income and the deficit between total income and total cost (or budget deficit). It is important to note that variables with hardly any effect on the output have been omitted from the illustrations. The graphs include those input variables with a percentage change on the influence factor greater than +10% or less than -10%. The input variables listed do not influence all output indicators, and are shown only for those output indicators that were influenced significantly. In addition, for different modes, different input variables are important.

Figure 15 shows the effect of the input variables on output variables for bus services. It is noted that the percentage of passengers in the off-peak period has the strongest influence on all the indicators, followed by the distance travelled between origin and destination. The latter impacts mostly on annual vehicle kilometres travelled (AVKT), and to a lesser extent on fare income. The cost of bus fares seems to have the least impact on those input variables listed in the figure, although it is still considered significant in the bigger scheme of things. The graph also shows that the cost variables, together with the demand variables, have the strongest impact, which is to be expected. The high sensitivity of the distance variable lies in the fact that it impacts strongly on AVKT, and hence on the operating costs.

In the case of train services, it is noted that the distance travelled has the strongest influence on all indicators (see Figure 16). Variable vehicle operating cost, the time taken to turn the vehicle around and other travel-related costs have a strong influence on cost per one-way trip, as well as the deficit between income and cost. It is also noted that the time taken to turn the vehicle around has a negative effect on the amount of AVKT. Moreover, it is not surprising that fare costs impact negatively on annual income generated. Another point of interest is the strong influence of the number of stops, and to a lesser extent the vehicle speed, on the budget deficit. This is an indication that the number of stops can be minimised in order to reduce operational cost.

Figure 17 shows the effect of the input variables on output variables for minibus-taxi services. As for all other modes, the variable vehicle operating cost seems to have a strong influence on the cost per one-way trip and the budget deficit. Fare costs have a significant negative influence on both fare income and, quite surprising, on AVKT. These outputs are positively influenced by the distance traveled, while the increase in cost as a result of decreased walking distances has a strong impact on the cost per one-way trip and the budget deficit.

The higher the sensitivity of the input variables, the greater the impact on the results obtained, and the larger the uncertainty in the results becomes. In order to reduce the sensitivity of these variables, area-specific data should be obtained for operations in the geographical areas in which the model is to be deployed. Uncertainty associated with the input variables stems from the fact that they were based on generic data, and thus the possibility exists that they may take on different values in the area under consideration.

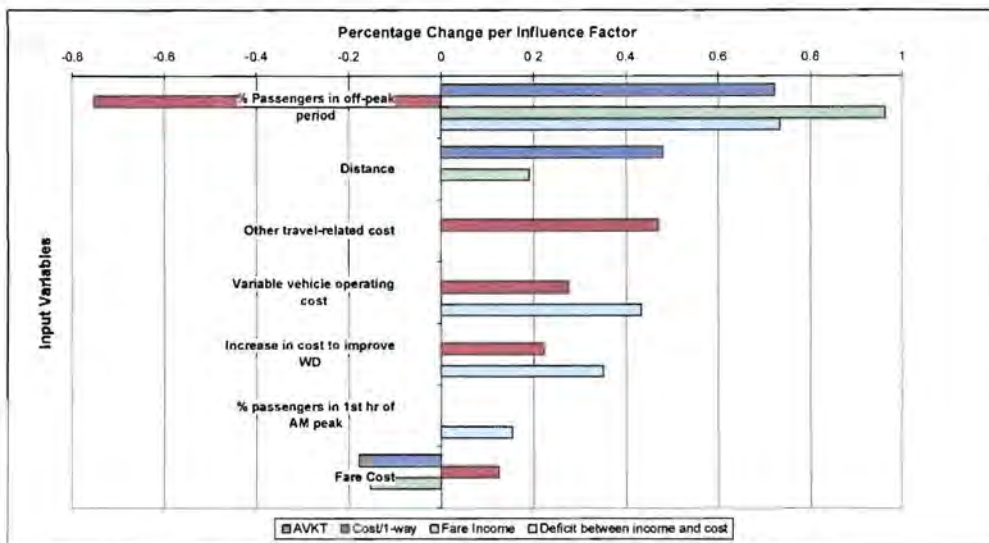


Figure 15: Influence of Input Variables on Output for Bus Services

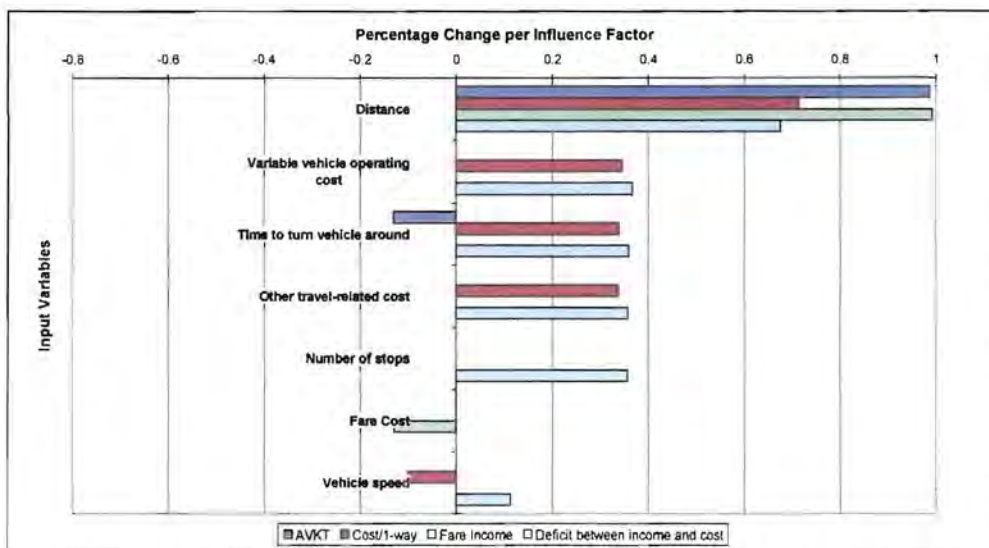


Figure 16: Influence of Input Variables on Output for Train Services

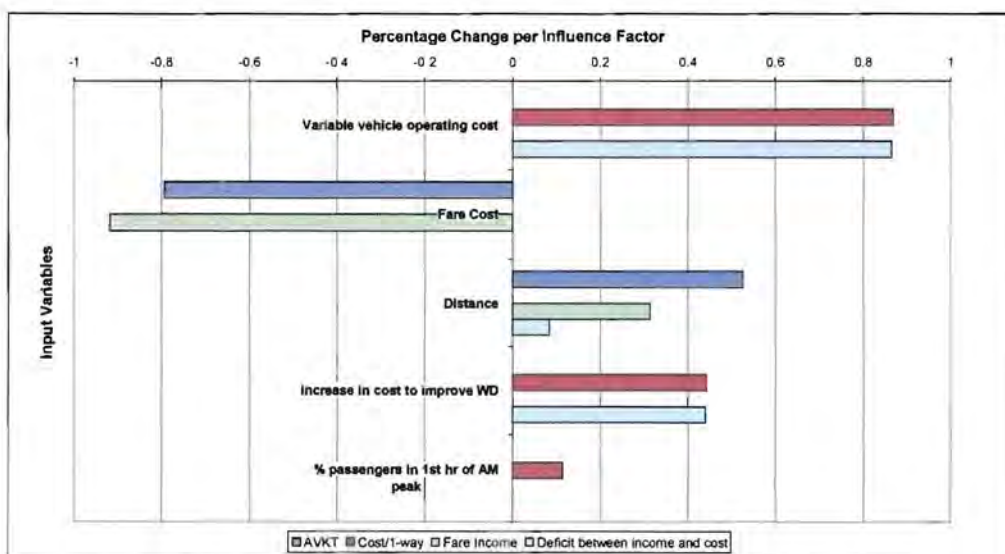


Figure 17: Influence of Input Variables on Output for Minibus-Taxi Services

10.5 IMPROVEMENT OF BUS LEVELS OF SERVICE

The predicted impact of bus LOS changes are summarised in Table 36. For each policy scenario tested, the predicted value for each indicator is given, together with the range of possible values in the 90% confidence interval. The following indicators are listed: cost/one-way trip, annual vehicle kilometres travelled, annual fare income, budget deficit (total and average per passenger) and modal split.

Base values for the indicators are given for purposes of comparison. The base case model produced the following base case values in the pilot area for the indicators under discussion.

- Cost per one-way trip is estimated at R5.16 per one-way trip.
- Annual vehicle kilometres travelled (AVKT) are estimated at 7.231 million km per annum.
- Annual fare income is estimated at R41.3 million per annum.
- The deficit between revenue and costs is estimated at R23.7 million, which translates into an average deficit per passenger trip of R1.89.
- The share of bus transport in the overall modal split is 27.02%.

Before analysing any changes to the demand and resources as a result of higher service levels, it needs to be mentioned that the uncertainty associated with the budget deficit is much higher than cost per one-way trip. These results were obtained by running the base model with the specified uncertainties in the input variables. The results show that the uncertainty associated with the base case scenario is estimated at approximately 10% around the mean (relative to the cost/one-way trip). The uncertainty relative to the budget deficit is about 23% for the base case.

The impact on indicators, as discussed below, is relative to the base case values above. In terms of the impact on **cost per one-way trip**, the points listed below can be inferred.

- The provision of a minimum level of security will result in an increase in the cost per one-way trip from R5.16 to R5.17, a percentage increase of only 0.2%. This measure is likely to have the least impact on cost.
- The implementation of a target peak period frequency of 12 departures per hour will result in an increase of approximately 138% to R12.26 per one-way trip, and is the most expensive measure to implement. In comparison, the implementation of a minimum frequency of one departure per hour will result in an increase of only 16%.
- In order to implement all the proposed minimum LOS, the absolute cost per one-way trip is likely to increase by between R3.5 and R5 per one-way trip, up to between R8 and R11 per one-way trip. This will result in an increase of approximately 80% compared to the current cost of providing the service, relative to the mean (from R5.16 to R9.42).
- In order to implement all the proposed target LOS, the absolute cost per one-way trip is likely to increase by between R11 and R15 per one-way trip, up to between R16 and R21 per one-way trip. This will result in an increase of approximately 260% compared to the current cost of providing the service, relative to the mean (from R5.16 to R18.45).

In terms of average **vehicle kilometres travelled**, the following results can be inferred.

- Measures related to frequency result in the greatest increased travel and, therefore, have the greatest impact on annual vehicle kilometres travelled.
- The implementation of minimum LOS will result in an increase of approximately 64% in annual vehicle kilometres travelled, while the implementation of target LOS will result in an increase of approximately 208% in annual vehicle kilometres travelled.

Table 36: Predicted Impacts of Changes to Bus Levels of Service

Scenario Tested ⁽¹⁾	Confidence Interval	Cost / One-way trip (R)	AVKT (millions)	Annual Fare Income (Rm)	Deficit between Revenue and Cost (Rm)	Average Deficit / pass. (R)	Modal Split ⁽²⁾		
							Bus	Train	Taxi
Base Case	Lower	R 4.64	6.255	R 34.95	R 18.14	R 1.39	27.02%	29.54%	43.44%
	Mean	R 5.16	7.231	R 41.30	R 23.66	R 1.89			
	Upper	R 5.69	8.160	R 47.39	R 29.16	R 2.41			
Min. no. of security officers / 1000 PH pass. = 1 (0.2%)	Lower	R 4.55	6.247	R 34.76	R 16.63	R 1.29			
	Mean	R 5.17	7.261	R 41.50	R 23.81	R 1.89			
	Upper	R 5.85	8.221	R 48.39	R 31.47	R 2.53			
Target service hours = 24hrs (1.4%)	Lower	R 4.59	6.323	R 34.74	R 17.21	R 1.32			
	Mean	R 5.23	7.356	R 41.28	R 24.45	R 1.95			
	Upper	R 5.89	8.316	R 47.94	R 31.86	R 2.59			
Min. off-peak frequency = 1 dep/hr (15.5%)	Lower	R 4.98	7.928	R 35.21	R 22.14	R 1.69			
	Mean	R 5.96	8.780	R 41.51	R 33.63	R 2.68			
	Upper	R 7.07	9.629	R 48.55	R 44.96	R 3.77			
Target max vehicle age = 10yrs (30.0%)	Lower	R 5.88	6.297	R 35.20	R 33.91	R 2.62			
	Mean	R 6.71	7.272	R 41.56	R 43.18	R 3.43			
	Upper	R 7.59	8.199	R 48.16	R 52.53	R 4.31			
Target walking distance = 500m (31.9%)	Lower	R 5.74	6.906	R 38.48	R 34.44	R 2.47	+7.0%	-3.1%	-2.3%
	Mean	R 6.81	7.759	R 44.38	R 47.58	R 3.53			
	Upper	R 7.95	8.667	R 51.04	R 61.72	R 4.65			
Target off-peak frequency = 2 dep/hr (39.3%)	Lower	R 5.99	10.365	R 34.79	R 38.45	R 2.85			
	Mean	R 7.19	11.089	R 41.50	R 49.78	R 3.97			
	Upper	R 8.50	11.701	R 47.97	R 60.92	R 5.17			
Minimum frequency = 6 dep/hr (65.5%)	Lower	R 7.27	9.500	R 35.93	R 53.58	R 3.99	+1.3%	-0.1%	-0.4%
	Mean	R 8.54	10.327	R 41.92	R 66.77	R 5.26			
	Upper	R 9.87	11.196	R 48.48	R 79.59	R 6.57			
Target AM frequency = 12 dep/hr (137.6%)	Lower	R 10.58	15.136	R 44.09	R 116.87	R 7.29	19.2%	-10.6%	-4.7%
	Mean	R 12.26	15.865	R 50.00	R 136.20	R 8.98			
	Upper	R 14.07	16.632	R 56.29	R 155.47	R 10.78			
All minimum levels of service	Lower	R 8.11	11.104	R 35.72	R 66.57	R 4.85	1.3%	-0.1%	-0.4%
	Mean	R 9.42	11.832	R 41.83	R 77.78	R 6.14			
	Upper	R 10.84	12.561	R 48.38	R 89.10	R 7.53			
All target levels of service	Lower	R 15.91	21.741	R 47.38	R 217.70	R 12.69	27.3%	-16.1%	-6.0%
	Mean	R 18.45	22.266	R 53.14	R 244.65	R 15.17			
	Upper	R 21.02	22.814	R 59.77	R 270.89	R 17.72			

(1) For each scenario tested, the percentage increase in cost per one-way trip, relative to the base case, is shown in brackets.

(2) The modal split has been influenced minimally, mainly because the majority of variables could not be included in the demand model.

In terms of average **annual fare income**, the points listed below can be inferred.

- The implementation of a target peak period frequency of 12 departures per hour will result in the largest increase in annual fare income, increasing from R41.3 million to an estimated R50.0 million (21% increase), mainly as a result of a 7% increase in bus riders.

- The implementation of minimum LOS will result in an increase of approximately 1% in annual fare income, while the implementation of target LOS will result in an increase of approximately 29% in annual fare income.

In terms of the **deficit between revenue and cost**, which is indicative of the additional funding required, the following can be inferred.

- In order to implement all proposed minimum LOS, the increase in bus expenditure is likely amount to approximately 230% (more than three times the current expenditure), with the deficit per passenger likely to increase by between R3.50 and R5.10.
- The implementation of all target LOS requires additional investment in bus services of approximately 940% (more than 10 times the current expenditure), with the deficit per passenger likely to increase by between R11.30 and R15.30.

Changes in demand could not be calculated for all proposed measures, as some variables could not be included into the demand model. The changes in modal split change are not the absolute modal split, but are expressed as a percentage change relative to the base case. In terms of the effects on **modal split**, the points listed below can be deduced.

- The implementation of minimum LOS will result in a mere 0.35% of additional bus passengers (1.3% increase relative to base case), although this shift in demand is only as a result of frequency improvements.
- The implementation of target LOS will result in an increase of 27.3% more bus passengers, compared to the base case, mainly as a result of reduced walking distances as well as frequency improvements.
- The results can also be interpreted such that for every 1% of the bus share (relative to the total public transport market), the total cost of providing the service amounts to approximately R2.4 million. With the improvement of service levels to the proposed minimum, the total cost increases to R4.4 million per 1% market share. With the improvement of operations to the proposed target levels of service, the total cost increases to R8.5 million per 1% market share.

The scenarios are ranked by cost in an ascending order. This list can be used to prioritise the implementation of measures should budgetary restrictions pose a problem. The conclusion can be drawn that expenditure will increase significantly for minimal improvements, but for the implementation of target LOS, expenditure will be tremendous and may not be affordable.

10.6 IMPROVEMENT OF TRAIN LEVELS OF SERVICE

The predicted impact of train service changes are summarised in Table 37. For each policy scenario tested, the predicted value for each indicator is given, together with the range of possible values within the 90% confidence interval. Again, base values for the indicators are given for purposes of comparison. The base case model produced the following base case values in the pilot area for the indicators under discussion.

- Cost per one-way trip is estimated at R1.25 per one-way trip.
- Annual vehicle kilometres travelled (AVKT) are estimated at 0.216 million km per annum.
- Annual fare income is estimated at R29.04 million per annum.
- The surplus between revenue and costs is estimated at R11.62 million.
- The share of train in the overall modal split is 29.54%.

The results show that the uncertainty associated with the base case scenario is estimated between 11% and 14% around the mean (relative to the cost/one-way trip) and approximately 18% relative to the budget deficit.

The impact on indicators, as discussed below, is relative to the base case values above. In terms of the impact on **cost per one-way trip**, the following points can be inferred.

- The provision of a minimum level of security will have no impact on the cost per one-way trip. The annual fare income is expected to decrease slightly by R0.02 million. This measure is likely to have the least impact on cost.
- The implementation of a minimum peak period frequency of 6 departures per hour will result in an increase of approximately 256% to R4.45 per one-way trip, and is the most expensive measure to implement.
- In order to implement all proposed minimum LOS, the increase in rail expenditure is likely to amount to approximately eight times the current expenditure, with the absolute cost is likely to increase by between R5.2 and R5.6 per one-way trip. /
- The implementation of all target LOS requires additional rail investment of approximately 12 times the current expenditure (increase of between R11.1 and R11.6 compared to current cost per one-way trip). This will result in an increase of approximately 930% compared to the current cost of providing the service, relative to the mean (from R1.25 to R12.85).

In terms of average **vehicle kilometres travelled**, the points listed below can be inferred.

- Measures related to frequency result in the greatest increased travel and, therefore, have the greatest impact on annual vehicle kilometres travelled.
- The implementation of minimum levels of service will result in an increase of approximately 253% in annual vehicle kilometres travelled, while the implementation of target LOS will result in an increase of approximately 716% in annual vehicle kilometres travelled.

Table 37: Predicted Impacts of Changes to Train Levels of Service

Scenario Tested ⁽¹⁾	Confidence Interval	Cost / One-way trip (R)	AVKT (millions)	Annual Fare Income (Rm)	Deficit between Revenue and Cost (Rm)	Average Deficit / pass. (R)	Modal Split ⁽²⁾		
							Bus	Train	Taxi
Base Case	Lower	R 1.11	0.197	R 28.23	-R 13.57	-R 0.97	27.02%	29.54%	43.44%
	Mean	R 1.25	0.216	R 29.04	-R 11.62	-R 0.83			
	Upper	R 1.42	0.237	R 29.82	-R 9.46	-R 0.68			
Min no. of security officers / 1000 PH pass. = 1 (0.1%)	Lower	R 1.11	0.197	R 28.17	-R 13.39	-R 0.96			
	Mean	R 1.25	0.216	R 29.02	-R 11.59	-R 0.83			
	Upper	R 1.41	0.236	R 29.83	-R 9.51	-R 0.68			
Min service hours = 18 (0.1%)	Lower	R 1.12	0.200	R 28.20	-R 13.39	-R 0.96			
	Mean	R 1.25	0.218	R 29.01	-R 11.57	-R 0.83			
	Upper	R 1.41	0.239	R 29.81	-R 9.46	-R 0.67			
Min loading levels = 1.00 (15.2%)	Lower	R 1.33	0.233	R 28.20	-R 10.30	-R 0.74			
	Mean	R 1.44	0.243	R 29.01	-R 9.02	-R 0.65			
	Upper	R 1.54	0.253	R 29.81	-R 7.69	-R 0.56			
Target loading levels = 1.00 (31.2%)	Lower	R 1.53	0.259	R 28.20	-R 7.54	-R 0.54			
	Mean	R 1.64	0.270	R 29.00	-R 6.15	-R 0.44			
	Upper	R 1.75	0.281	R 29.80	-R 4.79	-R 0.35			
Target max vehicle age = 30yrs (36.8%)	Lower	R 1.54	0.198	R 28.24	-R 7.48	-R 0.54			
	Mean	R 1.71	0.216	R 29.04	-R 5.27	-R 0.38			
	Upper	R 1.91	0.237	R 29.83	-R 2.61	-R 0.19			
Min off-peak frequency = 1 dep/hr (51.2%)	Lower	R 1.76	0.369	R 28.17	-R 4.37	-R 0.31			
	Mean	R 1.89	0.388	R 28.98	-R 2.56	-R 0.18			
	Upper	R 2.06	0.408	R 29.74	-R 0.62	-R 0.05			
Target service hours = 24 (113%)	Lower	R 2.49	0.564	R 28.22	R 6.01	R 0.43			
	Mean	R 2.67	0.592	R 29.00	R 8.23	R 0.59			
	Upper	R 2.87	0.619	R 29.77	R 10.65	R 0.76			
Target off-peak frequency = 2 dep/hr (122%)	Lower	R 2.58	0.589	R 28.22	R 7.23	R 0.52			
	Mean	R 2.78	0.617	R 29.01	R 9.61	R 0.69			
	Upper	R 2.99	0.644	R 29.78	R 12.20	R 0.88			
Min frequency = 6 dep/hr (256%)	Lower	R 4.22	0.667	R 30.17	R 32.07	R 2.16	-3.19%	6.37%	-3.18%
	Mean	R 4.45	0.692	R 30.88	R 35.08	R 2.37			
	Upper	R 4.69	0.717	R 31.60	R 38.13	R 2.58			
All minimum levels of service	Lower	R 6.32	0.886	R 30.14	R 63.27	R 4.25	-3.19%	6.37%	-3.18%
	Mean	R 6.63	0.921	R 30.87	R 67.32	R 4.54			
	Upper	R 6.97	0.956	R 31.63	R 71.87	R 4.86			
All target levels of service	Lower	R 12.26	2.048	R 34.53	R 173.10	R 10.22	-3.19%	6.37%	-3.18%
	Mean	R 12.85	2.130	R 35.30	R 182.27	R 10.76			
	Upper	R 12.46	2.209	R 36.10	R 192.09	R 11.34			

(1) For each scenario tested, the percentage increase in cost per one-way trip, relative to the base case, is shown in brackets.

(2) The modal split has been influenced minimally, mainly because the majority of variables could not be included in the demand model.

In terms of average **annual fare income**, the following is noted:

- the implementation of a minimum peak period frequency of 6 departures per hour will result in the largest increase in annual fare income, increasing from R29.0 million to an estimated R30.9 million (6% increase), mainly as a result of a 6.4% increase in train passengers; and
- the implementation of minimum LOS will result in an increase of approximately 6% in annual fare income, while the implementation of target LOS will result in an increase of approximately 22% in annual fare income.

In terms of the **deficit between revenue and cost**, which is an indication of the additional funding required, the results show that:

- in order to implement all proposed minimum LOS, the increase in rail expenditure is likely amount to approximately 680% (nearly eight times the current expenditure), with the deficit per passenger likely to increase by between R5.20 and R5.60; and
- the implementation of all target LOS requires additional rail investment of approximately 1150% (nearly 12 times the current expenditure), with the deficit per passenger likely to increase by between R11.20 and R12.00.

As mentioned before, changes in demand could not be calculated for all proposed measures, as some variables could not be included in the demand model. The changes in modal split change are not the absolute modal split, but are expressed as a percentage change relative to the base case. In terms of the effects on **modal split**, certain facts can be deduced.

- The implementation of minimum LOS will result in a 6.4% increase in train passengers (relative to base case), although this shift in demand is only as a result of frequency improvements. The same increase in passengers can be expected for the implementation of target LOS.
- For every 1% of train share (relative to the total public transport market), the total cost of providing the service amounts to approximately R0.6 million. With the improvement of service levels to the proposed minimum, the total cost increases to R3.1 million per 1% market share. With the improvement of operations to the proposed target LOS, the total cost increases to R6.9 million per 1% market share.

The scenarios are ranked by cost in an ascending order. This list can be used to prioritise the implementation of measures, should budgetary restrictions pose a problem. Again, expenditure will increase significantly for minimal improvements, but for the implementation of target LOS, expenditure will be tremendous and may not be affordable.

10.7 IMPROVEMENT OF MINIBUS-TAXI LEVELS OF SERVICE

The expected impact of minibus-taxi service changes are summarised in Table 38. For each policy scenario tested, the predicted value for each indicator is given within a 90% confidence interval. The following indicators are listed: cost/one-way trip, annual vehicle kilometres travelled, annual fare income, budget deficit (total and average per passenger) and modal split.

Base values for the indicators are given for purposes of comparison. The base case model produced the following base case values in the pilot area for the indicators.

- Cost per one-way trip is estimated at R6.16 per one-way trip.
- Annual vehicle kilometres travelled (AVKT) are estimated at 46.79 million km per annum.
- Annual fare income is estimated at R101.03 million per annum.
- The deficit between revenue and costs is estimated at R24.92 million, which translates into an average deficit per passenger of R1.22.
- The share of minibus-taxi in the overall modal split is 43.44%.

The results show that the uncertainty associated with the base case scenario is estimated at 8% around the mean (relative to the cost/one-way trip) and approximately 35% relative to the budget deficit.

In terms of the impact on **cost per one-way trip**, the following can be concluded:

- The provision of a minimum level of security will result in an increase in the cost per one-way trip from R6.16 to R6.20, a percentage increase of only 0.9%. This measure is likely to have the least impact on cost.
- The implementation of a target walking distance of 400 metres per hour will result in an increase of approximately 125% to R13.82 per one-way trip, and is the most expensive measure to implement.
- In order to implement all proposed minimum LOS, the increase in minibus-taxi expenditure is likely to amount to approximately double the current expenditure, with the absolute cost is likely to increase by between R1.30 and R1.50 per one-way trip. This will result in an increase of approximately 22% compared to the current cost of providing the service, relative to the mean (from R6.16 to R7.49).
- The implementation of all target LOS for minibus-taxi requires an additional investment of approximately 10 times the current expenditure. An increase of between R10.1 and R12.4 per one-way trip, compared to the current cost per one-way trip, is envisaged. This will result in an increase of approximately 181% compared to the current cost of providing the service, relative to the mean (from R6.16 to R17.35).

In terms of average **vehicle kilometres travelled**, it can be inferred that the implementation of minimum LOS will result in an increase of approximately 21% in annual vehicle kilometres travelled, while the implementation of target LOS will result in an increase of approximately 35% in annual vehicle kilometres travelled.

Table 38: Predicted Impacts of Changes to Minibus-Taxi Levels of Service

Scenario Tested ⁽¹⁾	Confidence Interval	Cost/One-way trip (R)	AVKT (millions)	Annual Fare Income (Rm)	Deficit between Revenue and Cost (Rm)	Average Deficit / pass. (R)	Modal Split ⁽²⁾		
							Bus	Train	Taxi
Base Case	Lower	R 5.68	43.934	R 95.46	R 15.95	R 0.77	27.02%	29.54%	43.44%
	Mean	R 6.16	46.787	R 101.03	R 24.92	R 1.22			
	Upper	R 6.65	49.309	R 105.85	R 34.21	R 1.69			
Min no. of security officers / 1000 PH pass. = 1 (0.9%)	Lower	R 5.34	44.030	R 95.63	R 8.11	R 0.40			
	Mean	R 6.20	46.723	R 100.87	R 25.75	R 1.26			
	Upper	R 7.05	49.241	R 105.79	R 42.40	R 2.08			
Min service hours = 18hrs (3.1%)	Lower	R 5.45	45.672	R 95.36	R 10.83	R 0.54			
	Mean	R 6.34	48.445	R 100.96	R 28.60	R 1.40			
	Upper	R 7.22	50.908	R 105.65	R 46.03	R 2.26			
Target service hours = 24hrs (4.8%)	Lower	R 5.58	47.102	R 95.44	R 13.21	R 0.64			
	Mean	R 6.45	49.853	R 100.86	R 30.67	R 1.50			
	Upper	R 7.36	52.459	R 105.78	R 48.93	R 2.41			
Min off-peak frequency = 4 dep/hr (5.2%)	Lower	R 5.57	47.006	R 95.03	R 13.26	R 0.65			
	Mean	R 6.47	49.869	R 100.83	R 31.28	R 1.53			
	Upper	R 7.43	52.483	R 105.67	R 50.30	R 2.45			
Min peak frequency = 12 dep/hr (10.5%)	Lower	R 5.92	47.632	R 95.42	R 20.09	R 0.98			
	Mean	R 6.79	50.324	R 101.03	R 37.89	R 1.85			
	Upper	R 7.73	52.864	R 105.90	R 56.41	R 2.76			
Max vehicle age = 10yrs (27.9%)	Lower	R 7.03	44.051	R 95.47	R 42.85	R 2.10			
	Mean	R 7.87	46.727	R 100.90	R 59.75	R 2.93			
	Upper	R 8.74	49.329	R 105.79	R 77.78	R 3.80			
Target walking distance = 400m (124.6%)	Lower	R 11.65	46.270	R 100.38	R 141.05	R 6.70	-5.51%	-1.62%	4.53%
	Mean	R 13.82	48.811	R 105.40	R 189.27	R 8.87			
	Upper	R 16.15	51.240	R 109.91	R 239.18	R 11.17			
All minimum levels of service	Lower	R 6.95	54.062	R 95.29	R 41.29	R 2.02			
	Mean	R 7.49	56.725	R 101.06	R 52.02	R 2.55			
	Upper	R 8.08	59.379	R 105.74	R 63.30	R 3.10			
All target levels of service	Lower	R 15.75	60.403	R 100.49	R 231.11	R 10.83	-5.51%	-1.62%	4.53%
	Mean	R 17.35	62.972	R 105.52	R 265.27	R 12.42			
	Upper	R 19.02	65.400	R 109.74	R 302.11	R 14.08			

(1) For each scenario tested, the percentage increase in cost per one-way trip, relative to the base case, is shown in brackets.

(2) The modal split has been influenced minimally, mainly because the majority of variables could not be included in the demand model.

In terms of average **annual fare income**, two points can be inferred.

- The implementation of a target walking distance of 400 metres will result in the largest increase in annual fare income, estimated at 4%, mainly as a result of a 4.5% increase in minibus-taxi passengers.
- The implementation of all minimum LOS will practically have no impact on annual fare income, while the implementation of all target LOS will result in an increase of approximately 4% in annual fare income.

In terms of the **deficit between revenue and cost**, which is indicative of the additional funding required, it is concluded that:

- in order to implement all proposed minimum LOS, the increase in minibus-taxi expenditure is likely to amount to approximately 108% (more than twice the current expenditure), with the deficit per passenger likely to increase by between R1.20 and R1.40; and
- The implementation of all target LOS requires additional minibus-taxi investment of approximately 950% (nearly 10 times the current expenditure), with the deficit per passenger likely to increase by between R10.10 and R12.40.

Changes in demand could not be calculated for all proposed measures, as some variables could not be included in the demand model. The changes in modal split change are not the absolute modal split, but expressed as a percentage change relative to the base case. In terms of the effects on **modal split**, two points can be deduced.

- The implementation of target LOS will result in an increase of 4.5% more minibus-taxi passengers, compared to the base case, mainly as a result of improved walking distance levels of service. Demand changes as a result of the implementation of minimum LOS could not be estimated at this stage.
- For every 1% of minibus-taxi share (relative to the total public transport market), the total cost of providing the service amounts to approximately R2.9 million. With the improvement of service levels to the proposed minimum, the total cost increases to R3.4 million per 1% market share. With the improvement of service levels to the proposed target LOS, the total cost increases to R8.2 million per 1% market share.

Again, the scenarios are ranked by cost in an ascending order. Introducing a minimal level of security is estimated to be the cheapest improvement to taxi services, while reducing the target walking distance to 400 metres is expected to have the highest impact on cost. This list can be used to prioritise the implementation of measures, should budgetary restrictions pose a problem. Expenditure will increase moderately for minimal improvements, whereas the implementation of target LOS will require tremendous expenditure and may, therefore, become unaffordable.

10.8 RESUMÉ

In this chapter, the model developed in Chapter 9 has been applied to public transport operations in the selected pilot area of Soshanguve in Gauteng. The model has been used to present a precise prediction of the impact of suggested minimum and target public transport LOS on demand and supply (or cost). The reader is reminded that the focus is on disadvantaged communities dependent on public transport, with low monthly income and low car ownership. This investigation is, therefore, not representative of the total public transport market in the province.

An important drawback of the model at this stage is its inability to predict demand changes due to improvement in those attributes not included in the demand model, such as safety and security issues, off-peak frequency and hours of service. This is mainly as a result of insufficient data. This has resulted in an underestimation of possible shifts in demand. In addition, the possible demand shifts from private vehicles are not included in the model, although it is unlikely that this shift will be significant.

Moreover, the significant influence of fare costs on demand is not reflected in the results, as expenditure on public transport for the market segment under consideration was found to be within the target of 10% and was, therefore, excluded from the analysis. Nonetheless, the cost implications of improved levels of service can be offset against an increase in fares. The model can, therefore, be used to obtain the maximum possible increase in fares, before the loss in ridership becomes significant. Ultimately, the objective function would be to maximise total fare income by trading off an increase in fare income, as a result of an increase in ridership, against a loss in ridership as a result of an increase in fares. Optimisation, however, will not be explored as part of this research. Walking distances for bus and taxi services were also found to be within the proposed minimum level of service, and were, as a result, excluded from analysis in the selected pilot area.

There is a marginal uncertainty associated with the base model. This is due to the uncertainty in the input variables, such as the aggregation of travel distances to centre-to-centre distances between sub-regions, application of generic cost-related input variables, assumptions made in terms of densification patterns of demand, and the application of generic peaking profiles for demand during the AM and off-peak periods.

With these limitations in mind, the findings presented in this chapter can be summarised in the points below.

- Tested improvements to public transport are listed in an ascending order by cost and can be used to prioritise implementation of measures.
- The highest change in demand occurred for the implementation of target bus LOS (increase in passengers of 7.4%).
- The most cost effective measure across all modes is the introduction of a minimum level of security, equal to one security guard per 1000 peak hour passengers.
- The introduction of acceptable levels of frequency during the AM peak period has proved to be most expensive in the case of bus and train services, while the reduction of walking distances are most expensive in the case of minibus-taxi services.
- The implementation of the suggested **minimum LOS** will require investments in the order of **three times** the current expenditure for bus, **eight times** for train and **double** the current expenditure for taxi services.
- The implementation of the proposed **target LOS** will require investments in the order of between **10 and 12 times** the current expenditure across all modes.
- It is possible that the cost implications may have been overestimated, as they do not take cognisance of the increase in ridership as a result of the majority of the suggested improvements.
- Relative to every 1% in public transport market share, expenditure will increase by between R2.9 and R4.1 million per 1% share for minimum LOS, while for the implementation of target levels of service, expenditure will increase by between R6.9 and R8.2 million per 1% share, and may not be affordable across all modes. However, the improvement of public transport operations may still be an option, if the alternative is to build more roads for cars, encouraging congestion that would ultimately impact negatively on the economy and the environment.

CONCLUSIONS AND RECOMMENDATIONS

The objectives of this research were to develop appropriate public transport KPIs and LOS, to test the practicality of formulated KPIs and LOS and to establish the additional investment levels required to address the backlog within the public transport system in Gauteng. This chapter brings together all the underlying issues in achieving these objectives, from which conclusions will be drawn and recommendations made for possible future research areas related to the topic. This thesis will conclude with:

- a discussion on the process pursued and reflecting on the findings of the research;
- conclusions with regards to the objectives of the research, as well as its shortcomings; and
- recommendations for the implementation of findings and for future research.

11.1 DISCUSSION

Public transport operations in South Africa, and in particular Gauteng Province, are riddled with problems. The service is characterised by poor performance, most evident in late arrivals, over crowdedness, and non-availability outside peak hours, among other. Although national and provincial policies and legislation in South Africa have begun to address these issues, very little has been done up to now towards the implementation of these policies. This is due, inter alia, to the authorities' limited knowledge as to what levels of public transport service are appropriate, in addition to the extent of the actual needs of public transport in the province.

- In addressing the problems facing public transport users, a good understanding of the problem is required. In doing so, this research endeavoured to find answers to the questions set out below.
 - *Is there any public transport service available and is it possible to gain access to it?*
An investigation into the main transport problems facing communities in Gauteng found that the service is available in most areas in the province, but that potential users are not using the systems because of difficulties in accessing it. The daily hours within which the service is available are generally limited.
 - *How frequent are the services provided?*
Although peak period frequency is not cited as a problem by commuters, off-peak frequency ranges from being generally low to the service being completely unavailable outside peak hours.
 - *Is the service affordable?*
Users expressed dissatisfaction with regard to current fare levels for bus and taxi services. Approximately 60% of commuters spend more than 10% of their personal income on public transport.

- *What level of service can be expected?*
High levels of dissatisfaction in terms of the quality of service provision are evident across all modes. Crowding and poor levels of service with regard to safety and security are especially associated with taxi and train services. Overall, the level of current or actual public transport operations is poor. New proposed LOS are shown in Table 39 below.
- *What are the demand and cost implications of providing an improved service?*
This question encapsulates the essence of this research and in answering it, the reader must be provided with insight into the process leading up to it. What will now follow, is the basis on which the results were developed and allows for a cautious interpretation of the results.

This research placed emphasis on the provision of public transport services, firstly in Gauteng Province only, and secondly, in areas where the greatest need exists and that will benefit most from improvements to the system. These are communities with low average monthly household income and who are captive to the public transport system. Hence, the findings of the research are limited to this market segment.

11.2 CONCLUSIONS

• The conclusions are aimed at addressing the objectives as set out at the start of this research. This section first looks at the development of appropriate public transport KPIs and LOS, then at the testing of the proposed KPIs and their corresponding LOS for appropriateness in the context of Gauteng, and lastly at the impact of applying these LOS to passenger demand and cost.

The Development of Public Transport KPIs and LOS

In the absence of generally accepted levels of service, it is not possible to measure the adequacy of current public transport operations in Gauteng Province. It is therefore necessary to understand the prevailing existing situation fully and build on the problem areas resulting from such an analysis. The needs analysis culminated in the identification of KPIs to provide a mechanism for the measurement of public transport performance. To summarise, problems facing public transport commuters relate to availability and accessibility, service capacity, frequency of the service, cost, safety and security. Taking cognisance of these priority areas, an extensive literature review, based on local and international experience in public transport performance measurement, revealed that the following minimum and target levels of service are relevant for each of the public transport modes.

Table 39: Proposed Minimum and Target Levels of Service

No	Parameter	KPI	Levels of Service ⁽¹⁾		
			Bus	Rail	Taxi
1	Availability	Hours of service	18 (24)	18 (24)	18 (24)
2	Accessibility	Walking distance to public transport	1 000m (500)	N/A	750m (400)
3	Service capacity	% Capacity utilisation (Volume to capacity ratio)	1.00	1.00 (0.90)	1.00
4	Frequency	Number of departures per hour in peak period	6 (12)	6	12
5		Number of departures per hour in off-peak period	1 (2)	1 (2)	4
6		Average waiting time in peak period	10 mins (5)	10 mins	5 mins
7	Cost	Percentage of income spent on public transport	10%	10%	10%
8	Safety	Maximum age of vehicles in the fleet	10 yrs	30 yrs	10 yrs
9	Security	Number of security officers per 1000 peak hour passengers	1	1	1

(1) Target LOS are indicated in brackets.

The actual levels of these ideal KPIs indicate that the proposed levels of service are, in general, realistic and achievable in the context of Gauteng. This emanates from the status quo findings that are presented below.

- Walking distances for train services are by far the longest and are the only mode for which walking distances exceed the proposed minimum level of service of 1000 metres. However, walking distance levels of service for rail services can not be considered, due to the rigid nature of rail infrastructure and costly infrastructural intervention required.
- All modes have average waiting times less than the proposed minimum level of 10 minutes.
- Although approximately 60% of public transport commuters spend more than 10% of personal income on public transport, the average spending is estimated at only 1.1% above the required level of service.
- Nearly 64% of minibus-taxis and 50% of buses are older than its expected lifespan of 10 and 12 years respectively. The vehicle age and unroadworthiness are major contributing factors to public transport accidents.

As a general rule, KPIs and their corresponding LOS cannot be applied uniformly, but should be established based on the specific socio-economic, land-use and travel needs of the geographical area or region in question. Hence, the proposed minimum and target LOS had to be tested for their appropriateness and applicability in the context of Gauteng.

Testing the Proposed Public Transport KPIs and LOS

The testing of the proposed KPIs and LOS necessitated two processes: firstly, the selection of a pilot area in which the proposed KPIs and LOS could be tested, and secondly, the development of a strategic model to determine the demand and cost implications of the recommended public transport LOS.

The process leading up to the identification of a pilot area entailed a scrutiny of the average monthly household income, average household car ownership and percentage public transport utilisation figures of sub-regions in the province. The area of Soshanguve was

selected as the preferred pilot area, together with the Brakpan/Benoni area, although time constraints prevented the testing of an improved service in the latter area.

The strategic model that was developed consists of two components: a demand model that predicts the impacts of improved public transport LOS on passenger demand, as well as a resource model able to estimate the cost of implementing improved LOS in the Province.

The estimation and calibration of the demand model posed many challenges. The assumptions made in terms of missing values for the alternatives in the choice set were a major drawback. The limitations imposed by the non-availability of quality data posed a major barrier to the inclusion of all identified attributes in the demand model. Another important drawback of the model at this stage was its inability to predict demand changes due to improvement in those attributes not included, such as safety and security issues, off-peak frequency and hours of service. This resulted in an underestimation of possible shifts in demand.

The impact of the variable fare per trip on passenger demand was found to be greatest in the range R3.50 to R5.50, for peak period frequency in the range five to 15 departures, and for walking time in the range zero to 20 minutes across all modes. This finding is reiterated as it provides a useful indication of where the focus for policy changes should be placed, for the market segment in question. Moreover, fares per trip was shown to have the most significant impact on demand, with elasticity values in excess of one. Caution should be exercised when designing policies involving public transport fares for the low-income market.] The significant influence of fare costs on demand is not reflected in the results, as expenditure on public transport for the market segment under consideration was found to be within the target of 10% and was therefore excluded from the analysis. The same applies to walking distances for bus and taxi services, which were also found to be within the proposed minimum LOS and were excluded as a result.

There is a marginal uncertainty associated with the base model. This is due to the uncertainty in the input variables, such as the aggregation of travel distances to centre-to-centre distances between sub-regions, the application of generic cost-related input variables, assumptions made in terms of densification patterns of demand, and application of generic peaking profiles for demand during the AM and off-peak periods. However, this should not cast doubt on the results obtained from the model, as only relative changes from the base case scenario are of importance.

Impact of Applying LOS on Demand and Cost

An important question remains unanswered - what are the demand and cost implications of providing an improved service? The predicted impact on demand and cost due to changes in public transport levels of service are set out in Table 40.

Table 40: Predicted Impact of the Improvement of Public Transport LOS

MODE	Policy Tested	Impact on Cost / One-way	Impact on Budget Deficit	Impact on Modal Split ⁽¹⁾
BUS	Base Model Values	R 5.17	R 14.7 m	27.02%
	Minimum Levels of Service	+ 80%	+ 230%	+ 1.3%
	Target Levels of Service	+ 260%	+ 940%	+ 27.3%
TRAIN	Base Model Values	R 1.25	- R 11.6 m	29.54%
	Minimum Levels of Service	+ 430%	+ 680%	+ 6.37%
	Target Levels of Service	+ 930%	+ 1150%	+ 6.37%
MINIBUS-TAXI	Base Model values	R 6.17	R25.2 m	43.44%
	Minimum Levels of Service	+ 20%	+ 110%	-
	Target Levels of Service	+ 180%	+ 950%	+ 4.53%

(1): Modal split changes are expressed as a percentage change relative to the base modal split values.

The implementation of the proposed minimum LOS will require investments in the order of approximately three times the current expenditure for bus services, eight times for train services and double the current expenditure for taxi services. The implementation of target levels of service will require investments in the order of between 10 and 12 times the current expenditure. The impact on modal split (demand) is minimal, although the improvement of bus operations to the proposed target LOS is expected to have the most significant impact.

The most cost effective measure across all modes is the introduction of a minimum level of security, equal to one security guard per 1000 peak hour passengers, and it is expected that the measure will have a significant influence on possible demand shifts, although it could not be proven. Henceforth, the demand model needs a major overhaul to better predict changes in ridership due to each improvement to the system.

The most important conclusion is that the improvement of public transport levels of service to the set target may be unaffordable, due to tremendous increases in cost. Minimum levels of service for bus and minibus-taxi services are more achievable in light of their impact on cost. However, the improvement of public transport operations may still be an option, if the alternative is to build more roads for cars, encouraging congestion that would ultimately impact negatively on the economy and the environment.

11.3 RECOMMENDATIONS

- About a quarter of the commuter market is captive to public transport, therefore, most of the users in this market segment are likely to use the service regardless of the level of service provided. The challenge lies in retaining those customers who exercise a conscious choice to use the service above private transport, although they can afford the latter. These users can be expected to have different needs to those who are captive to the system, and should be analysed as part of future research. This research can be extended to include stubborn users with a lower income who willingly make use of private transport
- It is recommended that the proposed minimum and target levels of service be implemented, prioritising the implementation process using the order of measures in Table 41 (see also

Tables 36 to 38). These tables list the tested improvements to public transport in an ascending order by cost.

Table 41: Recommended Prioritised List for Implementation of Proposed LOS

Priority	Bus Levels of Service	Train Levels of Service	Minibus-Taxi Levels of Service
1	Min. no. of security officers / 1000 PH pass. = 1	Min no. of security officers / 1000 PH pass. = 1	Min no. of security officers / 1000 PH pass. = 1
2	Target service hours = 24hrs	Min service hours = 18hrs	Min service hours = 18hrs
3	Min. off-peak frequency = 1 dep/hr	Min loading levels = 1.00	Target service hours = 24hrs
4	Target max vehicle age = 10yrs	Target loading levels = 1.00	Min off-peak frequency = 4 dep/hr
5	Target walking distance = 500m	Target max vehicle age = 30yrs	Min peak frequency = 12 dep/hr
6	Target off-peak frequency = 2 dep/hr	Min off-peak frequency = 1 dep/hr	Max vehicle age = 10yrs
7	Minimum frequency = 6 dep/hr	Target service hours = 24hrs	Target walking distance = 400m
8	Target AM frequency = 12 dep/hr	Target off-peak frequency = 2 dep/hr	
9		Min frequency = 6 dep/hr	

The cost implications of improved levels of service can also be offset against an increase in fares. The model can, therefore, be used to obtain the maximum possible increase in fares, before the loss in ridership becomes significant. Ultimately, the objective function would be to maximise total fare income by trading off an increase in fare income, as a result of an increase in ridership, against a loss in ridership as a result of an increase in fares. Optimisation was not part of this research and is suggested for future research.

In applying discrete choice modelling techniques, more accurate data on alternatives in the choice set ought to be found, either by tailored stated preference surveys, or by synthesis of the data on a discrete level. Efforts should also be streamlined towards the inclusion of all variables tested in the service model, as well as the inclusion of the car mode to explore the possible ridership changes resulting from the improvement in, and promotion of, public transport. Improvements on the data availability and quality will also reduce the uncertainty surrounding the input variables in the model, and subsequently enhance the credibility of the results obtained from the model.

The sensitivity of some of the input variables was found to be high, which in turn had a significant impact on the results obtained, increasing the uncertainty associated with the results. This sensitivity can be reduced by obtaining area-specific data for operations in the geographical areas in which the model is to be deployed. The uncertainty associated with the input variables stems from the fact that they were based on generic data, and thus the possibility exists that they may take on different values in the area under consideration. It is also worth repeating that the results are relevant to the low-income market segment with high public transport utilisation. Additional research should also be done for the low-income market with low public transport utilisation, as there is an obvious need for the improvement of the service.

The list of KPIs and corresponding minimum and target LOS presented in this research should be debated among the relevant stakeholders. The cost implications of the proposed LOS can then be refined to distinguish between the cost to the operator and the authority, as well as allowing for the inclusion of subsidies.

CHAPTER 12

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Annexure A

Evaluation for the Selection of Pilot Areas & Pilot Area Profiles

EVALUATION FOR THE SELECTION OF PILOT AREAS

(WEIGHTED SUM METHOD)

Metro-politan Area	Sub-region Number	Description of Sub-Region	INDICATORS				EVALUATION TO IDENTIFY AREA 1					EVALUATION TO IDENTIFY AREA 2				
			% Public Transport	% Private Transport	Ave HH Car Ownership	Average HH Income	% Public Transport	Ave HH Car Ownership	Average HH Income	TOTAL	RANK	% Public Transport	Ave HH Car Ownership	Average HH Income	TOTAL	RANK
WEIGHT			50	25	25	100	50	25	25	100	50	25	25	100	50	
Ekurhuleni	24	Tembisa/Clayville	86%	14%	0.19	R 1,486.07	42.8	22.9	22.0	87.7	5	7.2	22.9	22.0	52.0	40
	25	Ekurhuleni Rural	71%	29%	0.19	R 1,691.73	35.5	22.9	21.6	79.9	11	14.5	22.9	21.6	59.0	22
	26	Kemptonpark, J.A, Boksburg	16%	84%	1.40	R 5,748.20	8.2	9.4	13.3	30.9	35	41.8	9.4	13.3	64.5	8
	27	Daveyton	86%	14%	0.31	R 2,026.21	43.2	21.5	20.9	85.6	7	6.8	21.5	20.9	49.2	45
	28	Brakpan/Benoni	35%	65%	0.58	R 2,860.52	17.3	18.5	19.2	55.0	28	32.7	18.5	19.2	70.4	4
	29	Kwatsaduza	77%	23%	0.32	R 2,028.99	38.6	21.5	20.9	80.9	10	11.4	21.5	20.9	53.8	35
	30	Germiston/Boksburg	47%	53%	0.74	R 3,576.13	23.3	16.7	17.7	57.8	27	26.7	16.7	17.7	61.1	16
	31	Alberton	10%	90%	1.61	R 6,805.52	4.8	7.0	11.2	23.0	38	45.2	7.0	11.2	63.4	12
	32	Katorus	89%	11%	0.13	R 1,482.22	44.6	23.5	22.0	90.1	3	5.4	23.5	22.0	50.8	41
	13	Region 1	65%	35%	0.48	R 2,895.28	32.3	19.6	19.1	71.0	17	17.7	19.6	19.1	56.4	30
	14	Region 2	55%	45%	0.62	R 5,005.97	27.7	18.0	14.8	60.6	25	22.3	18.0	14.8	55.2	34
15	Region 7	58%	42%	0.60	R 3,522.55	28.8	18.3	17.8	65.0	21	21.2	18.3	17.8	57.3	25	
16	Region 3	5%	95%	1.92	R 11,533.71	2.6	3.5	1.6	7.6	47	47.4	3.5	1.6	52.5	39	
17	Region 5	6%	94%	1.71	R 12,305.07	3.0	5.9	0.0	8.8	45	47.0	5.9	0.0	52.9	38	
18	Region 4	17%	83%	1.29	R 8,589.04	8.3	10.6	7.5	26.5	36	41.7	10.6	7.5	59.9	20	
19	Region 8	63%	37%	0.33	R 4,008.99	31.3	21.3	16.9	69.4	18	18.7	21.3	16.9	56.9	29	
20	Region 9	13%	87%	1.38	R 8,357.02	6.7	9.6	8.0	24.3	37	43.3	9.6	8.0	60.9	17	
21	Region 10	72%	28%	0.27	R 2,481.67	36.2	22.0	20.0	78.1	13	13.8	22.0	20.0	55.8	32	
22	Region 6	73%	27%	0.24	R 2,703.13	36.4	22.3	19.5	78.2	12	13.6	22.3	19.5	55.4	33	
23	Region 11	59%	41%	0.34	R 2,216.73	29.3	21.3	20.5	71.0	16	20.7	21.3	20.5	62.5	13	
Metsweding	46	Nokeng Rural	13%	87%	0.71	R 3,348.78	6.6	17.1	18.2	41.9	34	43.4	17.1	18.2	78.7	2
	47	Nokeng Urban	30%	70%	1.15	R 3,189.92	15.0	12.2	18.5	45.6	31	35.0	12.2	18.5	65.7	6
	48	Kungwini Rural West	7%	93%	1.82	R 8,071.04	3.4	4.7	8.6	16.7	39	46.6	4.7	8.6	59.9	19
	49	Kungwini Urban	40%	60%	0.38	R 3,145.81	20.2	20.8	18.6	59.6	26	29.8	20.8	18.6	69.2	5
	50	Kungwini Rural East	50%	50%	0.59	R 3,728.86	25.2	18.4	17.4	61.1	23	24.8	18.4	17.4	60.7	18
Sedibeng	33	Lesedi Urban	37%	63%	0.78	R 5,539.77	18.6	16.2	13.7	48.6	30	31.4	16.2	13.7	61.4	14
	34	Lesedi Rural	53%	47%	0.57	R 1,791.81	26.4	18.6	21.4	66.4	20	23.6	18.6	21.4	63.6	10
	35	Midvaal Rural East	40%	60%	0.79	R 3,797.24	20.0	16.2	17.3	53.5	29	30.0	16.2	17.3	63.5	11
	36	Midvaal Rural West	95%	5%	0.01	R 932.13	47.5	24.9	23.1	95.5	2	2.5	24.9	23.1	50.4	42
	37	Emfuleni Urban	63%	37%	0.40	R 2,127.98	31.3	20.5	20.7	72.5	14	18.7	20.5	20.7	59.9	21
	38	Emfuleni Rural	73%	27%	0.07	R 758.26	36.4	24.2	23.5	84.1	9	13.6	24.2	23.5	61.3	15
	1	Tembar/Wintersveid/Mabopane	88%	12%	0.18	R 2,005.28	44.0	23.0	20.9	87.9	4	6.0	23.0	20.9	49.9	44
	10	Pta West, Atteridgeville	60%	40%	0.52	R 3,468.35	30.2	19.2	18.0	67.3	19	19.8	19.2	18.0	57.0	28
Tshwane	11	Centurion	6%	94%	1.69	R 9,798.72	3.1	6.1	5.1	14.4	43	46.9	6.1	5.1	58.1	24
	2	Soshanguve	87%	13%	0.21	R 2,080.79	43.4	22.6	20.8	86.8	6	6.6	22.6	20.8	50.0	43
	3	Akasia/Rosslyn	11%	89%	1.73	R 10,627.85	5.4	5.7	3.4	14.5	42	44.6	5.7	3.4	53.7	36
	4	Roosval	2%	98%	2.24	R 8,884.75	1.0	0.0	6.9	8.0	46	49.0	0.0	6.9	55.9	31
	5	Pta North	9%	91%	1.74	R 9,320.91	4.5	5.6	6.1	16.2	41	45.5	5.6	6.1	57.1	26
	6	Moot	9%	91%	1.87	R 8,570.02	4.6	4.1	7.6	16.3	40	45.4	4.1	7.6	57.1	27
	7	Mamelodi	85%	15%	0.23	R 2,850.10	42.5	22.4	19.2	84.2	8	7.5	22.4	19.2	49.1	46
	8	Pta East	7%	93%	1.93	R 10,752.28	3.4	3.5	3.2	10.0	44	46.6	3.5	3.2	53.2	37
	9	Pta CBD	55%	45%	0.43	R 4,405.17	27.3	20.2	16.1	63.5	22	22.7	20.2	16.1	58.9	23
	39	Westonaria	58%	42%	0.29	R 1,799.57	29.1	21.8	21.3	72.2	15	20.9	21.8	21.3	64.0	9
Westrand	40	Merafong	46%	54%	0.57	R 2,772.39	22.8	18.6	19.4	60.8	24	27.2	18.6	19.4	65.1	7
	42	Randfontein Rural	11%	89%	0.52	R 2,789.98	5.6	19.2	19.3	44.1	33	44.4	19.2	19.3	82.9	1
	44	Mogale Rural	23%	77%	0.67	R 4,255.30	11.3	17.6	16.4	45.2	32	38.7	17.6	16.4	72.6	3
	45	Cradle of Human Kind	100%	0%	0.00	R 1,281.74	50.0	25.0	22.4	97.4	1	0	25	22.39592	47.39592	47

NOTES:

Top 10 rankings for low-income, low car ownership and high public transport utilisation sub-regions

Top 10 rankings for low-income, low car ownership and low public transport utilisation sub-regions

PILOT AREA PROFILES

SOSHANGUVE

Description: The area of Soshanguve is found in the northern region of the City of Tshwane Metropolitan Municipality. Soshanguve is considered a previously disadvantaged area, with a severe lack of economic activity in the area.

Population: 34,950

Area size: 170.11 km²

Population Density: 2045/km²

Number of commuter trips in AM peak period: 56,225 (walking excluded)

MODAL SPLIT:

BUS	TAXI	TRAIN
30.7%	42.6%	26.7%
14,467	20,112	12,582

PRIVATE	PUBLIC
16.1%	83.9%

PUBLIC TRANSPORT SERVICE PROVIDERS:

MODE	OPERATOR	SERVICE				BUDGET	
		Days Per Week	Service Hours	Annual Trips	Annual Vehicle miles	Operating Budget	Capital Expenses
RAIL	Metrorail	7	18	-	-	-	-
BUS	Putco Soshanguve	7	-	-	-	-	-
TAXI		7	-	-	-	-	-

INCOME PER CATEGORY:

Income Group	Ave Income	% Of Commuters
Low	R2,080	30.8%
Medium		67.8%
High		1.4%

PILOT AREA PROFILES

BRAKPAN / BENONI / SPRINGS

Description: The Brakpan/Benoni/Springs Area is found in the south-eastern region of the Ekurhuleni Metropolitan Municipality. The area is characterised by a mix of economic activity catering for a population from all walks of life.

Population: 195 750

Area size: 261.65 km²

Population Density: 748/km²

Number of commuter trips in AM peak period: 46,161 (walking excluded)

MODAL SPLIT:

BUS	TAXI	TRAIN
7.0%	78.7%	14.3%
530	5,952	1,081

PRIVATE	PUBLIC
71.1%	28.9%

PUBLIC TRANSPORT SERVICE PROVIDERS:

MODE	OPERATOR	SERVICE				BUDGET	
		Days Per Week	Service Hours	Annual Trips	Annual Vehicle miles	Operating Budget	Capital Expenses
RAIL	Metrorail	7	-	-	-	-	-
BUS	Brakpan Bus services	5	14.5	-	-	-	-
TAXI		7	-	-	-	-	-

INCOME PER CATEGORY:

Income Group	Ave Income	% Of Commuters
Low	R2,860	39.7%
Medium		51.2%
High		9.1%