INTELLIGENT TRANSPORT SYSTEMS FOR SOUTH AFRICA

IMPACT ASSESSMENT THROUGH MICROSCOPIC SIMULATION IN THE SOUTH AFRICAN CONTEXT

Marianne Vanderschuren

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DISSERTATION

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the doctor's degree at the University of Twente,
on the authority of the rector magnificus,
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on account of the decision of the graduation committee,
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Born on the 6th of July 1966
in Kerkrade, the Netherlands

This PhD dissertation has been approved by the promotor:
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Putt's Law

Technology is dominated by two types of people:
those who understand what they do not manage,
and those who manage what they do not understand.

Archibald Putt

In memory of my beloved father
who inspired me to study transport engineering

Preface

When I accepted a post at the University of Cape Town, one of the requirements was to undertake PhD research. Although I had been involved in research with regards to Intelligent Transport Systems since 1996, I did not originally anticipate pursuing this interesting research field in a country such as South Africa. Nevertheless, several people and institutions encouraged me to research the potential for Intelligent Transport Systems in South Africa. Four years later, hoping that results are as interesting for them as they are for me, I thank everyone for their interest and encouragement.

I am indebted to my supervisor, Professor Martin van Maarseveen, for his guidance and lasting belief in me. Our first interaction was in 1990, just after you left and I joined TNO Inro. Over the years, our paths kept crossing. Knowing I was looking for a job outside of the Netherlands, it was you in 2000, who alerted me to the job possibility in South Africa. When I left the Netherlands, neither of us expected that you would become my supervisor, as we expected the research needs in South Africa, to fall outside the scope of the University of Twente. I am happy to say that we were both proven wrong. Although the road was bumpy at times, I have enjoyed the interaction with you, not only with respect to this dissertation. I hope we will be able to strengthen and grow our collaboration in the future.

If I have been successful in conducting the research reported upon in this dissertation, this is not the least due to of interaction with my colleagues in the Civil Engineering Department, and the Urban Transport Research Group at the University of Cape Town. You listened to my struggles, advised me and kept me sane at times. I owe a lot to you all. I need to mention one of you by name; Cheryl Wright. Besides the times at the University, you came to the Netherlands with me during my sabbatical, assisted with editing and looked after my children. I would not have been able to do it without you.

The funding of my PhD research has been challenging at times. Unfortunately, it was not possible to include all research ideas, due to a lack of financial resources. Nonetheless, I will be forever grateful to the National Department of Transport which funded me as a staff member of the Southern Transport Centre for Development. Without this financial support, this dissertation would not exist.

Several institutions and companies have provided me with data. I would like to thank Innovative Traffic Solutions (Pty) Ltd (a South African consulting firm); in particular, Jaco de Vries and Dr. van As, for sharing their knowledge of the Ben Schoeman Highway with me. I would also like to mention the South African Road Agency Pty Ltd (SANRAL), MIKROS (a South African traffic count specialist) and the City of Cape Town for the information they have provided. In addition, I would like to thank Agnes McNamara from AGMAC Consulting cc for supervising the data collection and processing on the N2 near Cape Town.

Many students at the University of Cape Town have played a role during the conducting of this research. Many 2005 third year civil engineering students assisted during the data collection in Cape Town. Students, such as Sirin Galaria, Nico-Tom Pen and Jaap Vreeswijk (international affiliates from the University of Twente) have contributed to specific details in this dissertation. Lavancia Ngwenya, Bhekumuzi Dlamini and Dave O'Reilly deserve a word of thanks for their assistance during the attempt to include a mesoscopic simulation model in this dissertation. Last, but certainly not least, I need to express my gratitude towards Michel Muberuka, who was involved in the majority of inputs and outputs generated for/by the microscopic model applied in this dissertation. I know the results were as fascinating to you as they were for me and I look forward to reading your analysis and interpretations.

The final editing was done by Nicole Chidrawi. I thank you for your cooperation, patience with me and all text suggestions made. I also would like to express my thanks to Esther Speelman for editing the Dutch summary. Moreover, a word of appreciation is needed to everyone who contributed to the cover picture. I do think it captures the differences and challenges we are facing in this country on a daily basis.

Over the last five years I have made many friends in South Africa. You have all, in your own way, contributed to this dissertation. The times we had coffee and 'braais' and you showed an interest in my work, the special events you invited me to (i.e. the Muslim wedding, Barmitzvah and 21st birthday within the coloured community), which has increased my interest in the different cultures within this country, and the personal warmth you have shown, have all contributed to the final product in front of you.

Finally I would like to communicate my deepest gratitude and love to my family. Angus, I thank you for your endless belief in me, for the extra time you spent with the kids and all support given, including the production of some of the graphs and for putting up with me when I was negative and unfair. I could not have done it without you. In addition, I need to thank my two children, Eric and Lara. Although not consciously, you have made sure that I did not forget that there is more to life. I hope you will one day look at this document with pride, as you played a role in your own innocent way.

Marianne Vanderschuren
Cape Town, July 2006

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Chapter 1

Introduction

Transport improvements undoubtedly promote economic growth and social development by increasing mobility and improving accessibility to people, resources and markets. There have, however, been some concerns about the effect of (improved) transport systems on sustainable development. Several impacts of traffic and transport, and the associated costs, can be distinguished, such as economic, social and environmental impacts, for both current and future generations. Sustainable urban transport development can only be achieved if full account is taken of all aspects (Zuidgeest, 2005).

As sustainable development claims to integrate economic, social and environmental sustainability, so too does sustainable transport development. With respect to economic sustainability, transport should (CST, 1997):

- provide cost-effective transport services and infrastructure,
- be financially affordable (to each generation), and
- support vibrant, sustainable economic activity.

This implies that financial resources should be allocated to parts of the transport system that create or improve transport services in support of human potential in the area. Improved services can occur with regards to public, as well as private transport. Improved public transport services include aspects like more routes, better vehicles, higher frequencies and reliability. Private vehicle improvements include more reliable road systems, i.e. a reduction of congestion.

With regards to social sustainability, transport systems should:

- meet the basic human needs for health, comfort, convenience and safety, and
- allow and support development of communities and provide for a reasonable choice of transport services.

This refers to an equitable improvement of standards of living and quality of life, by making transport available to all members of society. Moreover, a reduction of road accidents and fatalities is part of social sustainability.

With respect to environmental sustainability, transport systems should:

- make use of land in a way that has little or no impact on the integrity of ecosystems,
- use energy sources that are essentially renewable or inexhaustible,
- produce no more emissions and waste than the transport system's carrying capacity, and
- produce no more noise than an acceptable threshold of noise pollution.

This refers to high density, sustainably planned cities, demand management towards public transport and the management of traffic flows to reduce unnecessary and stop-and-go driving.

Several international studies imply that Intelligent Transport Systems (ITS) have multiple benefits. It has been indicated that they, among others, assist to reduce congestion, improve road safety, reduce fuel consumption and improve the public transport reliability. An extensive and critical review of ITS systems will be included in this dissertation.

It needs to be mentioned that most ITS studies have been carried out in the developed world. It is, therefore, necessary to investigate the transferability of ITS systems to South Africa. As human behaviour and perceptions are essential ingredients of traffic flows, as well as the acceptance of ITS systems, these will also be investigated.

1.1 Background

In order to understand the existing transport system structure, the structure of South African cities must be understood; it is very different from other cities around the world due to its political situation.

During the apartheid era, Whites[1] used to stay in the developed areas, close to all facilities, whereas African Blacks used to stay in townships[2] away from the developed areas. Public transport, mainly in the form of busses, was used to act as a commuter service to take African Blacks to their workplace early in the morning and bring them back in the evening. Travel, other than for work purposes, was not allowed.

Since the end of the apartheid era, there are no longer restricted areas based on racial classification. Thus, freedom of movement has become possible and mobility for all people must be encouraged. This brings with it the increased demand for transport.

---

[1] The South African government currently differentiates between Whites, African Blacks, Coloureds and Indians.

[2] Townships were not considered part of the city, although a big proportion of the population stayed there.

The current land-use is intensifying the inherited dormitory townships and long travel distances by locating the new low-cost housing far away from the urban centres and existing transport infrastructure. Thus, the provision of low-cost housing and access to opportunities for all is a controversial issue. This results in the increase of the already high average (commuter) distances.

On top of unsustainable land-use patterns, it appears that housing densities have dropped in all major South African cities. As an example, Cape Town has experienced significant growth over the last century. Nevertheless, the density decreased over the last 100 years from 115 persons per hectare in 1904 to 39 persons per hectare in 2000 (Gasson, 2002).

An economic upswing has been experienced in South Africa over the years and the government has worked hard to encourage economic investment and activity. Unfortunately, not everybody is benefiting from this positive economic trend.

Many urban poor, living on the outskirts of the cities, cannot afford to travel to economically active areas. Those who can are dependent on public transport, which generally has a low service level. In many cases, informal minibus taxis provide the only public transport available. Many vehicles used in this informal system appear to be unroadworthy. For those who cannot afford the minibus taxis, the only option is walking. Walking distances for this part of the population are, therefore, large.

The wealthy urban inhabitants are part of a first-world economy. Transport supply is mainly based on the US network example. Private car ownership is high and public transport is not considered an option. Highways and secondary roads provide access to all parts of the city. Moreover, it is expected that private cars will play an even greater role in the future. For the past 18 months, South Africa has had record car sales. Every month the amount of new vehicles sold is higher than the month before. The high fuel prices, which are also occurring in South Africa, do not seem to have an effect on car sales. This trend does re-emphasise the need for safe and efficient road systems.

All in all, it can be concluded that South African cities are not sustainable and transport is unaffordable for many. The level of service of public transport is poor and certainly not comfortable, convenient or safe. As mentioned, many do not have a choice. Finally, the high private car dependency has resulted in unsustainable situations with regards to congestion, emissions and noise pollution.

Government is planning several steps to improve the situation. With regards to land-use problems, the corridor approach is being adopted. Selected axes (corridors) will get better public transport. Moreover, land use densities will be increased and economical activity will be promoted.

Another important action on the government's agenda is the re-capitalisation of the minibus taxi industry. The industry will be formalised via a permit system. Vehicles that are currently unroadworthy will be replaced by new ones. Better driver training is also part of the plan.

Government hopes that a better public transport service will encourage the urban wealthy to use the service. Nevertheless, government realises that many will still use their private vehicles. Improvement of roads is, therefore, also needed. One way to do so is through technology.

Larger South African cities use advanced traffic control systems to improve road traffic system performance. The arrival of vehicles is measured at (major) traffic lights. This traffic demand information is provided to a central computer, which optimises green times.

With regards to the highway network, ITS are being investigated in South Africa. Variable Message Signs (VMS) to inform road users are available in eThekweni (Durban) and the Huguenot tunnel (near Cape Town). Furthermore, a large-scale pilot with regards to incident management is planned for the Ben Schoeman Highway (BSH).

Based on the ex ante studies done for these projects, it can be concluded that the knowledge about current driving behaviour, as well as the reaction of South Africans to ITS systems, is limited.

The rising interest in Intelligent Transport Systems has lead to the establishment of the South African Society for Intelligent Transport Systems (SASITS). SASITS was established on 20 March 2001 and includes members of the public and private institutions as well as the education sector.

1.2 Objectives

Research with regards to ITS has been limited in South Africa. The rising interest and investment in ITS warrants a closer look at the field and the potential benefits for South Africa. The main objective of this dissertation is to investigate if ITS measures are beneficial for South Africa. Several questions need to be answered before this main question is addressed.

The research questions are formulated as follows:

1. Is South Africa’s transport system, as well as related problems, similar to those of the developed world (chapter two)?
2. Would South African society accept new technological solutions (chapter two)?
3. Is South African (driving) behaviour different from driving behaviour found in developed countries (chapter two)?
4. Which benefits of ITS have been established in the developed world (chapter three)?
5. Which ITS measures are potentially beneficial to South Africa (chapter three)?
6. Is it possible to use developed world models to investigate ITS measures in South Africa (chapter four)?
7. What data needs to be available to use developed world models in the South African context (chapter five)?

8. How can differences in driving behaviour be included in transport models (chapter six)?
9. What is the magnitude of impacts of potential ITS measures in the South African context (chapter seven)?
10. Is the magnitude of impacts of ITS measures in South Africa different to international experiences (chapters four and seven)?
11. Should ITS measures be implemented in the South African context (chapters four, seven and eight)?

1.3 Scope and limitations

Section 1.1 provides a first impression of South African society. It is clear that many South Africans are dependent on public transport, including informal minibus taxis. The service level of public transport is generally low and calls for improvement. ITS systems are one of the options available to improve safety, security, punctuality and the information level of public transport.

Originally, the aim was to investigate the potential benefits of ITS for public transport, as well as private vehicles. With regards to public transport, a plan was developed to use the shuttle service (Jammie Shuttle), operating at the University of Cape Town (UCT), as a pilot. Unfortunately, despite several efforts, funding for the implementation of the pilot plan was not available. A public transport pilot study is, therefore, not included in this dissertation.

South Africa has a long history of Advanced Traffic Controllers on secondary roads. It was, therefore, decided to exclude this part of the ITS field from this dissertation.

The focus of this dissertation is on improving the utilisation of South Africa's highway system. ITS measures that have proven to be successful in other countries are researched in the South African context. Two corridors in different parts of South Africa have been selected.

Funding to test ITS measures in practice are lacking. It is, therefore, necessary to use transportation models to estimate the potential effects of ITS measures. The original aim was to use two different models to investigate the effects of ITS measures in the South African context. South Africa has little experience with transport models, other then macroscopic models. A comparison of the advantages and disadvantages of a mesoscopic and a microscopic model was planned. Moreover, the plan was to compare the estimated benefits of ITS measures to establish the robustness of modelling results.

The mesoscopic simulation model DynaMIT was purchased from the Massachusetts Institute of Technology (MIT) in Boston (US). After 10 months of intensive work trying to run this mesoscopic model, including efforts to encourage the developers of the model to solve software problems, the idea to include this model in the dissertation had to be abandoned.

The microscopic transport model that has been purchased for the modelling of ITS measures in the South African context is Paramics. Paramics was purchased from Quadstone, Edinburgh (UK). Although Paramics is a complex model, it has been possible to use the model. Results presented in this dissertation are based on calculations with the microscopic simulation model Paramics.

Models that include driving behaviour, imported from other countries, cannot directly be used in the South African context due to behaviour differences. Thorough calibration, including differences in driving behaviour, needs to take place. Originally, it was assumed that South African researchers would have investigated differences in driving behaviour between South Africa and other parts of the world, or at least have analysed the characteristics of South African driving behaviour. This assumption was proven to be wrong. No information with regards to driving behaviour characteristics was found in literature. In this thesis, general South African behaviour characteristics have been investigated and translated into driving behaviour. The information collected via this ‘detour’ was used to calibrate Paramics for the South African context.

1.4 Approach

This dissertation consists of 15 steps that have been partly carried out in parallel. These steps are:

1. **Familiarisation with the focus area**: South Africa is the area of interest in this dissertation. As a Dutch citizen, living in South Africa for just a few years, it was necessary to get to know the country, culture and specific transport related challenges.
2. **Investigation of the ITS field in general**: A broad understanding of the available ITS measures is needed.
3. **Scan of national and international experiences**: To be able to select ITS measures that might be of benefit in the South African context, knowledge with regards to promising measures is needed.
4. **Identifying modelling requirements**: The fact that ITS measures are investigated in this dissertation through ex ante evaluation imposes the need to identify the requirements for the models used.
5. **Model selection:** Based on the requirements, a selection of transport models was made. At the start of the study, it was decided to use two different models in order to be able to analyse the robustness of modelling results.
6. **Investigation of existing data**: Other researchers/consultancies might have collected data required for the selected models. An inventory of existing data was carried out.
7. **Case selection**: Based on step six, it was concluded that sufficient data is available for one corridor, the Ben Schoeman Highway (BSH). This corridor was, therefore, included in this dissertation. A second corridor, the N2 near Cape Town, was selected based on the interest of the municipality to implement ITS measures.
8. **Data collection**: Data for the BSH, collected for other purposes, was made available. For the N2, only an old Origin-Destination (OD) matrix was made

available. Moreover, maps providing contour lines were used, and data (traffic counts, road lay-out etc.) was collected at the beginning of 2004.

9. **Development of input files**: All collected and existing data was translated into input files required for the models.
10. **Testing of the models:** Using the files developed in step nine, the running of the transport models was carried out. It appeared to be impossible to run one of the two models. Unfortunately, this model had to be excluded from this dissertation study.
11. **Calibrating the model:** Different parameter settings were tested and compared to actual data collected for the two corridors. A final set of parameter settings was selected. It appeared that the settings for the BSH and the N2 were slightly different.
12. **Selection of scenarios:** Based on the information collected in step three a selection of three scenarios was made. These scenarios are:
    - Bus/High Occupancy Vehicle (HOV) lanes,
    - Homogenising traffic flows and
    - Ramp metering.
13. **Calculating the scenarios:** Several settings for each scenario were calculated for the BSH, as well as the N2.
14. **Analysing the results:** Analysis of the results for the different scenarios was carried out.
15. **Report writing:** The findings of step one to 14 were described. This dissertation is the final product.

1.5 Content

This dissertation has nine chapters. Chapter two provides a broad description of South Africa. The chapter starts with a summary of the topography and demography. It then provides a view on land-use patterns and the influence of the apartheid era. A description of the transport supply and demand is followed by a section on one of South Africa’s major transportation challenges: road safety. The chapter continues with a description of (public) transport and ITS policies. It then provides an extensive description of behavioural and cultural differences in South Africa, and ends with a view on technology acceptance.

Chapter three provides an overview of ITS systems. Firstly, the goals of ITS systems are given, followed by a description of different types of ITS systems. European and US ex ante and ex post studies, provide a robust estimate of ITS benefits. Moreover, a limited amount of South African ex ante studies are summarised and compared with the international findings. This chapter, finally, provides results for Cost-Benefit Analysis (CBA) studies with regards to ITS.

The next chapter (four) focuses on modelling traffic flows. It first provides an overview of the different levels on which models operate. Thereafter, it provides a summary of modelling principles; the four-stage model, followed by longitudinal and lateral driving behaviour. The chapter continues with a comparison of different models, including a comparison of input and output variables. Chapter four finalises with the selection of models to be used in this study.

The next step in this dissertation is the selection of the case studies (chapter five). It was established that a lot of data was collected for the BSH. It was, therefore, decided to include the BSH in this dissertation. It was established that no other corridor was available, for which data was available. Based on interests by the City of Cape Town, as well as the convenient location, the N2 near Cape Town was selected as the second corridor. A description of both corridors is included in the chapter.

Chapter six provides the calibration results. The chapter starts with theoretical background including: speed, volume, headway, Time-To-Collision (TTC) and shockwaves. A selection of calibration criteria, based on the theory as well as available data, follows. The chapter then provides an overview of parameters included in microscopic simulation models, followed by a description of the parameters included in Paramics. A link is established between general behaviour information, described in chapter two, and driving behaviour in microscopic simulation models. This link guides the changing of Paramics parameters during the calibration process until the final levels for each selected parameter is established.

In chapter seven the ITS scenarios are calculated. Three ITS measures: a bus- and High Occupancy Vehicle (HOV) lane, homogenising traffic flows via speed limits using VMS, and ramp metering is calculated for both corridors: the BSH and the N2. Volumes, lane distributions, travel time, speed, TTC and headways are compared to actual data.

This dissertation ends with a chapter (eight) summarising the conclusions, based on the different chapters included in this dissertation, followed by recommendations for the future.

Chapter 2

Transportation in the South African context

2.1 Background

Transport plays a vital role in the social and economic facets of a society. This is no different for South Africa. There is a strong interaction between land-use patterns, the economy and transportation systems. Moreover, there are also negative impacts related to transportation. In this chapter the following questions will be answered:

- Is South Africa's transport system, as well as related problems, similar to those of the developed world?
- Would the South African society accept new technology solutions?
- Is South African (driving) behaviour different from driving behaviour found in developed countries?

2.1.1 The topography and demography of South Africa

South Africa is a big country with a diverse physical environment. The country's total land area amounts to 1 219 912 square kilometres. South Africa's physical geography is dominated by one physical feature: a massive escarpment that runs right around the subcontinent, dividing a thin coastal strip from a huge plateau. This escarpment is clearest in the East, where it is marked by the spectacular Drakensberg Mountains (Ballard, 1998).

The very discovery of the southern African shores by European mariners is linked to a transport event, indeed to one of the great transport calamities of all times: when the Turks conquered the Byzantine empire, culminating in the fall of Constantinople in

1453, they cut the trade routes along which caravans had moved, since time immemorial, to supply the people of Europe with treasured goods of “the East”, notably spices. Immediately the race started to find an alternative route for this lucrative trade. The Portuguese were particularly enterprising and sent their mariners out in search for such a route. In 1498 Vasco da Gama discovered a passage around the southern tip of Africa, thus securing for his country the treasured prizes of the East (Muller, undated).

Once regular shipping was established, there was an obvious need for staging points along the route of the gruelling 18-months’ voyages. The Portuguese and the Dutch established such places along the shores of southern Africa. The best known of these is Cape Town, which was founded in 1652, right at the southern tip of the continent. The sole reason for Cape Town coming into being, and its principal purpose for at least the first two centuries, was to serve as a halfway station between the West and the East (Muller, undated).

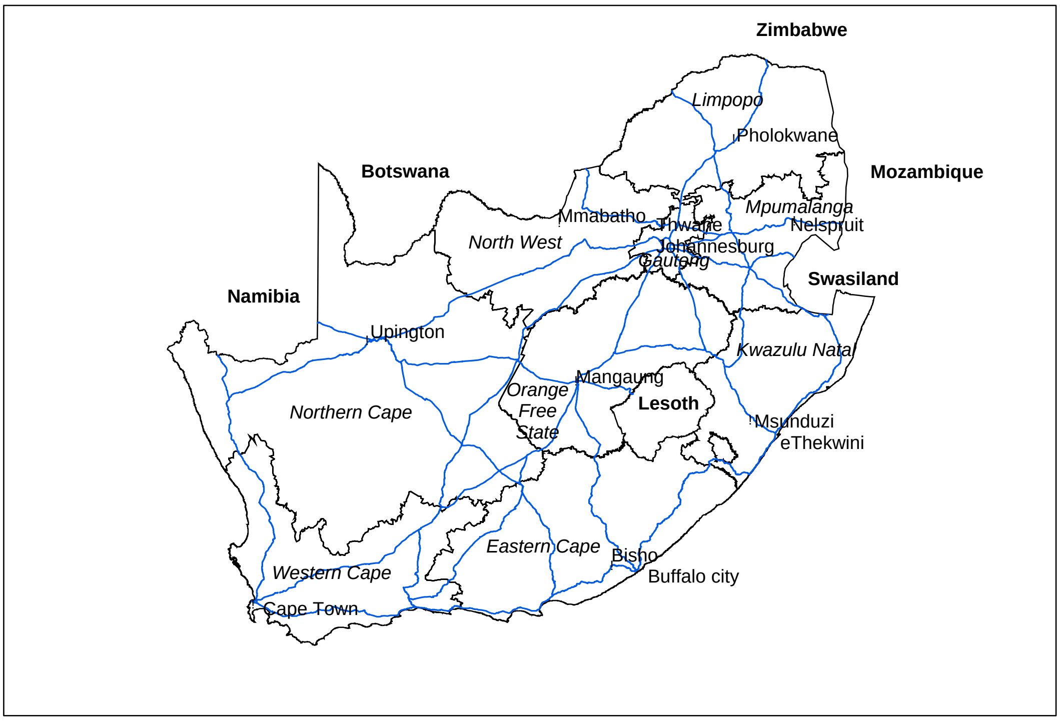

Figure 2.1 Map of South Africa’s provinces, main cities and the highway system[1]

The South African road network started in Cape Town. Land surveyors slowly ‘worked their way’ inland through often difficult terrain. It was Pieter Potter who discovered the first Roodezand pass in 1658. Since then, people like Governor Sir Lowry Cole, John Montagu, Charles Michell and Andrew and Thomas Bain (the first of numerous father-

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[1] The names of the following South African cities have changed: Buffalo city (previously East London), eThekwini (previously Durban), Mangaung (previously Bloemfontein), Msunduzi (previously Pietermaritzburg), Nelson Mandela Metropole (previously Port Elizabeth), Polokwane (Pietersburg) and Tshwane (previously Pretoria).

and-son teams to serve civil engineering in South Africa with great distinction) have built the most beautiful passes. In the Western Cape, travellers can still witness these incredible engineering works. The South African highway system and the main cities are provided in figure 2.1.

The South African population consists of four different races: Black Africans, Coloureds, Indians/Asians and Whites. The total population is 44.8 million people of which the majority are Black Africans (35.4 million). Table 2.1 provides an overview of the number of people per racial group.

Table 2.1 Race and gender distribution of the South African population (Census 2001)

Racial groups	Male	Female	Total
Black African	16 887 831	18 528 321	35 416 152
Coloured	1 920 430	2 074 075	3 994 505
Indian/Asian	545 018	570 410	1 115 428
White	2 080 727	2 212 904	4 293 631
Total	21 434 006	23 385 710	44 819 716

Source: www.statssa.gov.za

The South African population consists of several different ethnic groups. South Africa's different languages are closely related to various cultural differences. All in all the country has 11 official languages: Zulu, Xhosa, Swazi, Ndebele, Sotho, Tswana, Pedi, Venda, Tsonga, Afrikaans and English.

Figure 2.2 provides an overview of the most important languages in the different parts of South Africa. It needs to be mentioned that the coloured community in the Cape Province has Afrikaans as their first language, although this was not the traditional language of the ancestors of these people.

The South African population is very young. More than 60% of the inhabitants are under the age of 30 (see figure 2.3). Although this might seem a healthy age structure, HIV/AIDS is reducing the number of inhabitants of working age, resulting in many children and pensioners without any, or with very limited, support.

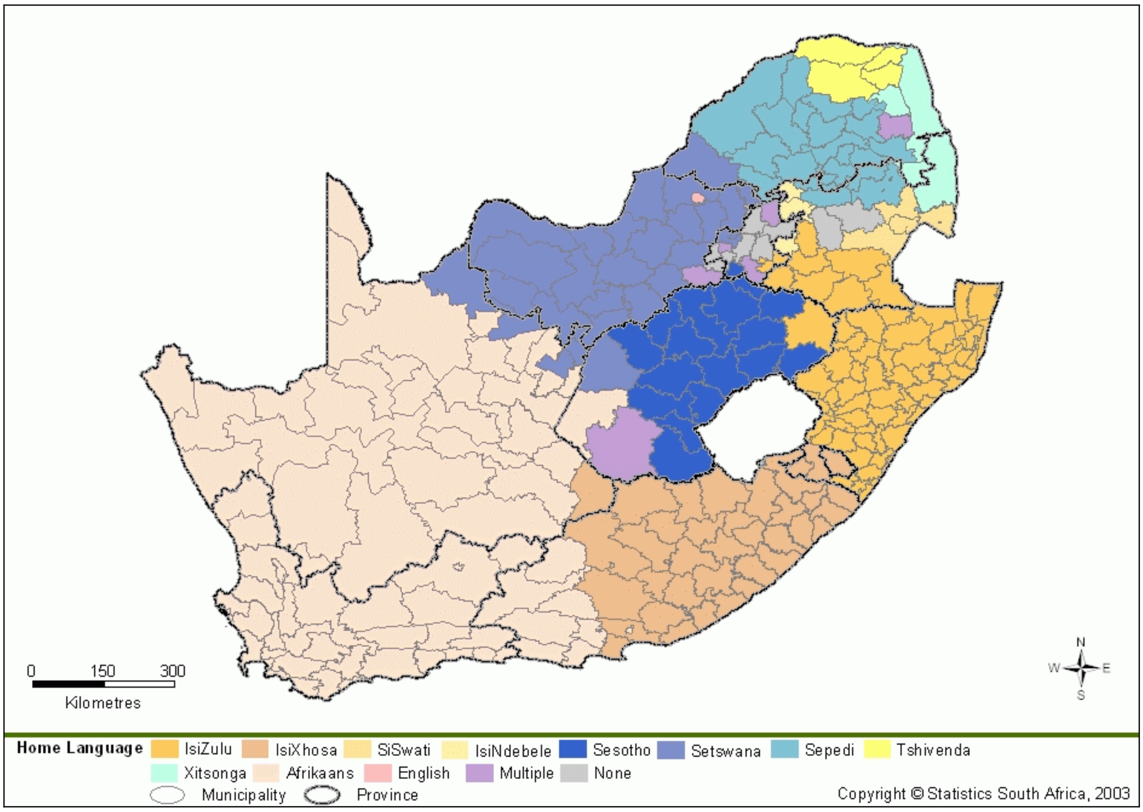

Figure 2.2 ***Distribution of languages in South Africa***

Source: www.statssa.gov.za

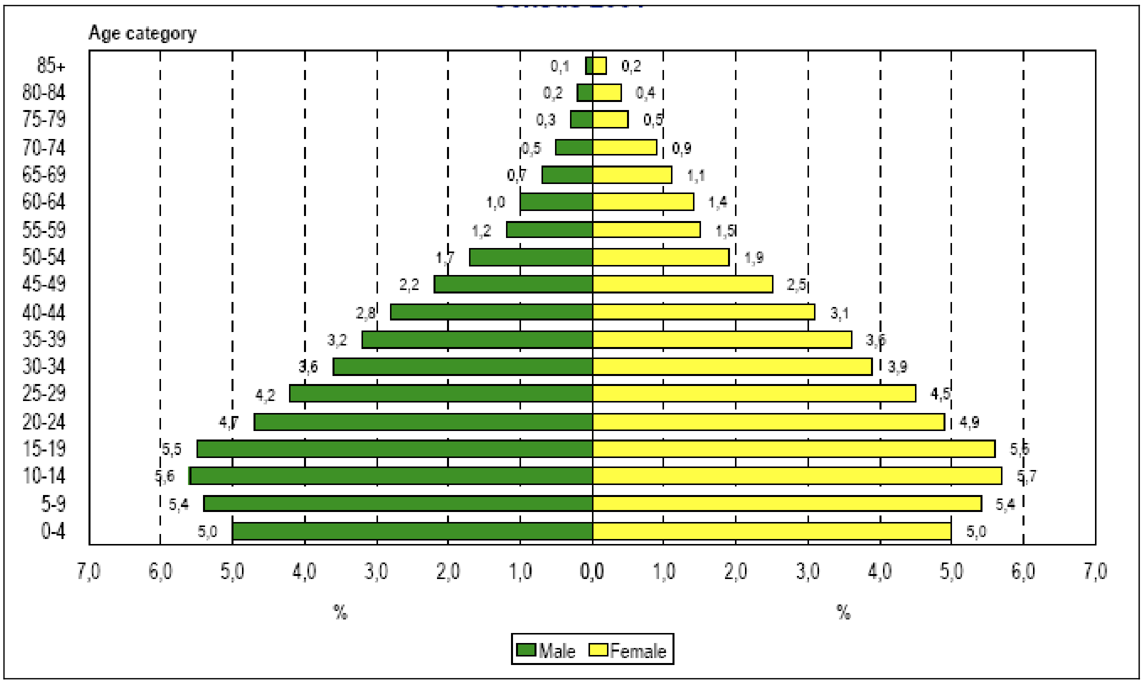

Figure 2.3 ***Age and gender distribution of the South African population (Census 2001)***

Source: www.statssa.gov.za

2.1.2 South Africa's land-use patterns

The main parameter characterising the form of a city is its density, which has significant effects on travel distances and the modal split. The overall characteristics of American and Australian cities are low densities of population and jobs. Planners have investigated several growth patterns for cities over the years. In literature (Newton and Manins, 1999), at least six urban growth theories (figure 2.4) can be found, of which examples exist around the world.

The business-as-usual city

In the business-as-usual city, new developments occur rather autonomously in any open space. From a transport planning point of view, transport infrastructure (in particular the road network) develops along the predict-and-provide method: supply follows demand. Business-as-usual cities generate dispersed settlements and long travel distances. Provision of public transport in this type of city is difficult. The private car has, therefore, a prominent role. This approach is not considered to be sustainable.

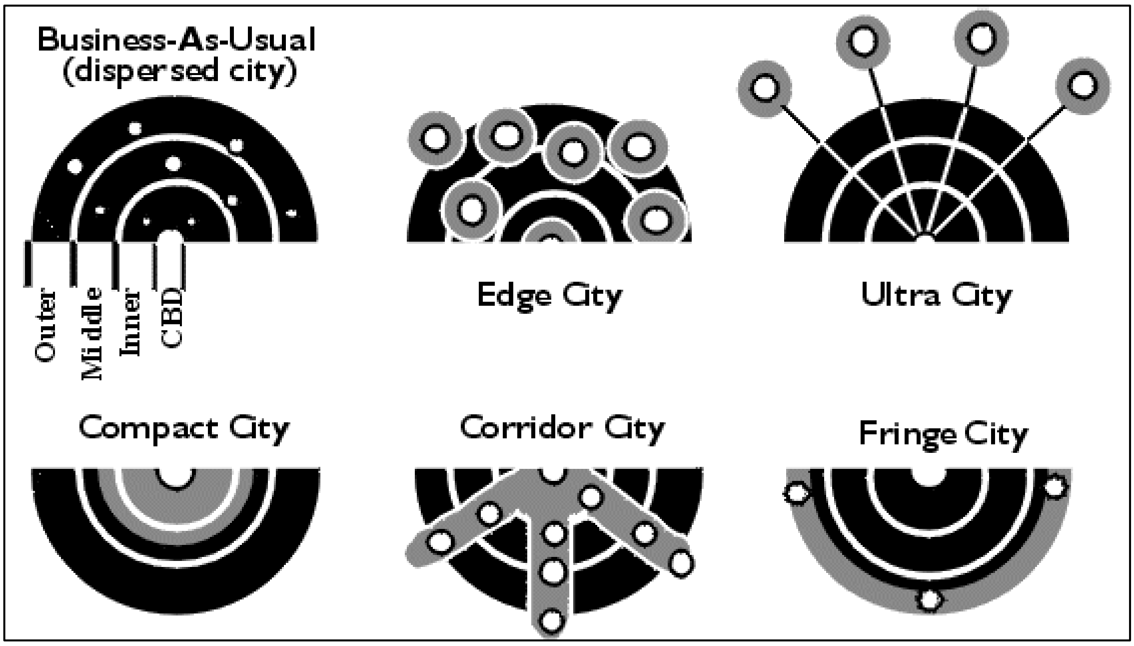

Figure 2.4 Growth patterns for cities around the world
Source: Newton and Manins, 1999

The edge city

The edge city features growth in population, housing density and employment at selected nodes and increased investment in freeways linking these nodes. The edge city is considered more sustainable than the business-as-usual city, as the nodes provide higher levels of services closer to home and, therefore, decreased travel distances. The main negative aspect is the distribution of activity nodes, limiting the possibilities for viable public transport. Most edge cities can be found in America. Local densities in these cities are higher than in the business-as-usual city. Nevertheless, the overall densities of cities are still low.

The ultra city

The ultra city features growth in regional centres within a 100 kilometres of the central business district. High-speed trains link the regional centres to the heart of the city. Although high-speed trains are a sustainable mode of transport, the ultra city development itself is not considered sustainable. Valuable open land is used for development, which could have been realised in (or closer to) urban areas.

The compact city

Compact cities utilise open spaces within the city. An increase in the population is realised within existing suburbs, therefore the densities increase. In general, compact cities are considered to be a sustainable way of extending cities and public transport is generally a viable option.

The corridor city

The corridor city tries to avoid the negative impacts of the edge city. Growth arises from the central business district and existing radial links (public transport) are upgraded. The corridor city is considered to be a sustainable city.

The fringe city

The fringe city has its growth predominantly on the outskirts. Large Australian cities are known to have distinctive rural-urban fringes and densities are low.

During the apartheid era (1948-1990), South African cities were also developed as fringe cities. Whites stayed in the developed areas, close to all facilities, while Blacks lived in the townships[2] away from the developed areas. Public transport used to act as commuter service to take Blacks to their workplace early in the morning and bring them back in the evening (Vanderschuren and Galaria, 2003).

Figure 2.5.a illustrates an example of the South African city structure. The northern parts of the diagram represent the areas where the wealthy urban live. The bulbs on the southern parts of the diagram represent the townships where the male workforce used to live (women often stayed behind in the homelands). The green areas were buffers creating a planned mobility barrier. The poor Black and Coloured workforce was not allowed to move out of their district on their own. As mentioned, people were transported for work purposes only.

With the end of apartheid, there are no longer restricted areas based on racial classification. Thus, freedom of movement has become possible and mobility for all people is encouraged. This brings with it the increased need for transport (Vanderschuren and Galaria, 2003).

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[2] These areas were not considered part of the city though a big portion of the population lived there.

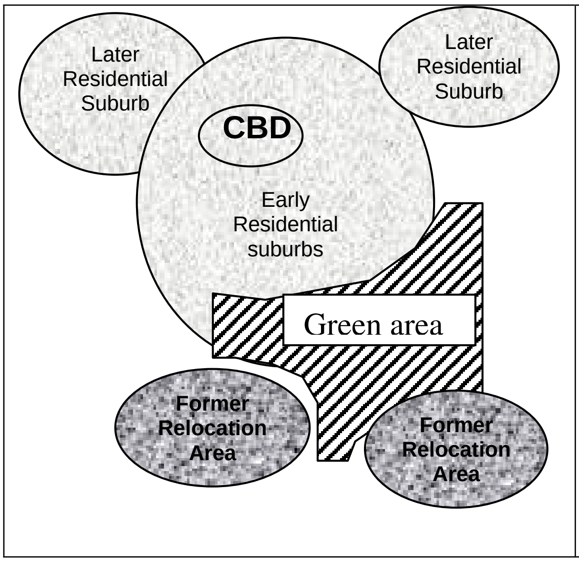

Figure 2.5.a Traditional SA city

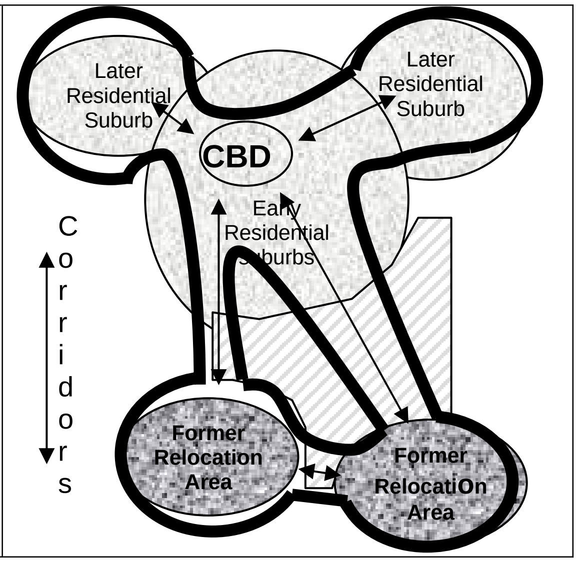

Figure 2.5.b SA corridor planning

The South African National Department of Transport (NDoT) has adopted the corridor city approach (Minister of Transport & Department of Transport, 1999) as its focus (see figure 2.5.b). Considering the historical layout of South African cities, this appears to be a sustainable way forward.

Unfortunately, the starting point for the new (democratic) government is difficult. On top of unsustainable land-use planning during the apartheid period, the general trend in South African cities was a reduction of densities. In Cape Town, for example, densities decreased over the last 100 years from 115 persons per hectare in 1904 to 39 persons per hectare in 2000 (Gasson, 2002).

Densities obviously vary for different agglomerations in South Africa. Figure 2.6 provides an overview of the densities per region. The figure clearly shows that Gauteng (Johannesburg and Tshwane), Cape Town and eThekwini have the highest densities.

As mentioned, densities in South African cities have been declining. Lower densities generally lead to larger distances travelled. Figure 2.7 shows that European cities and Singapore have a structure that reduces the need for motorised travel (even if the densities for the total agglomeration of Madrid and Paris are low). The main reason is that non-motorised travel is much more common in Europe than in other parts of the developed world, due to the more compact way of building. Moreover, Europe traditionally provides non-motorised transport infrastructure, which is often lacking in other parts of the developed world.

In New York, the average motorised trip is about five kilometres longer than in European cities. South African cities show even longer average motorised trips of up to 22 kilometres. It is clear that land-use patterns created during the apartheid era have had a negative impact on transportation; i.e. the need for motorised travel is unsustainably high.

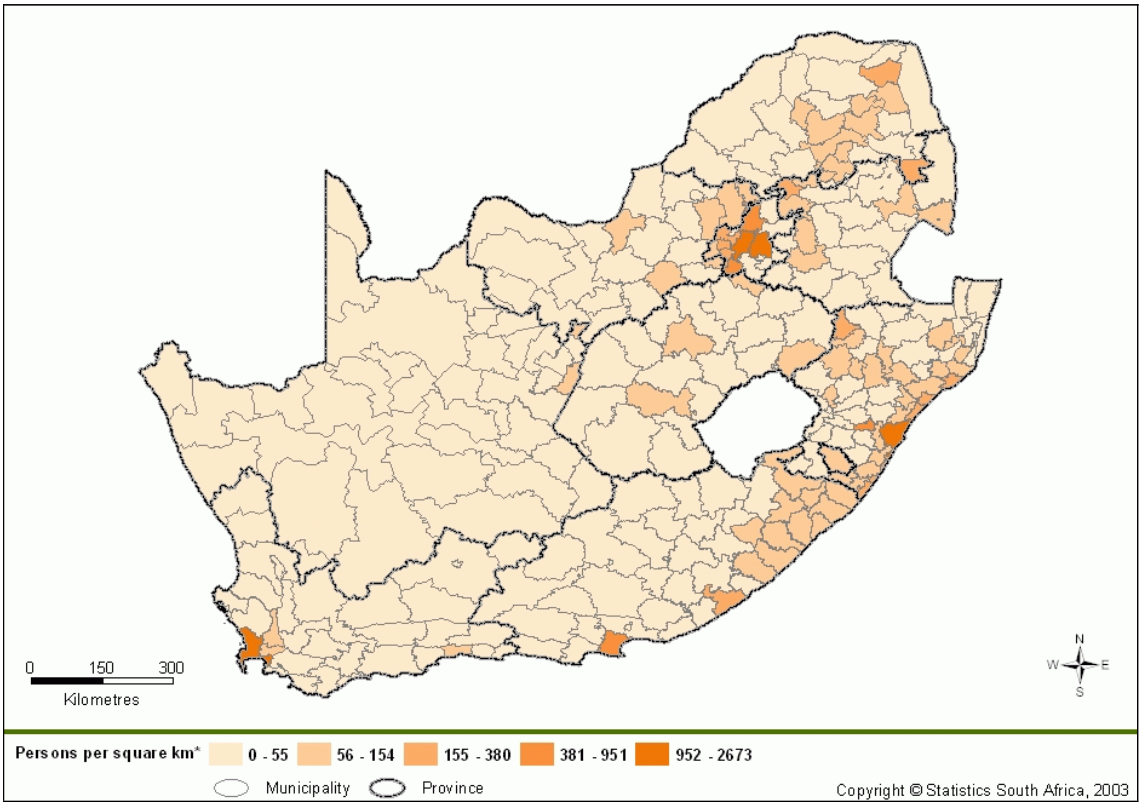

Figure 2.6 Population density in South Africa

Source: www.statssa.gov.za

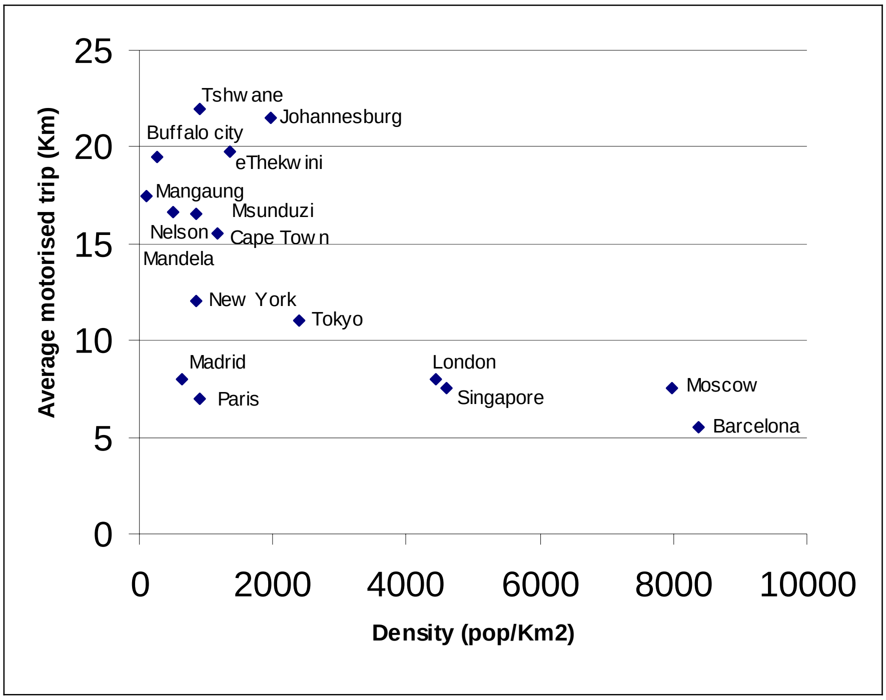

Figure 2.7 Average motorised trip length versus city densities

Sources: Kenworthy and Laube, 1999; SA cities network, 2004 and estimates by the author based on the NHTS[3], 2003

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[3] NHTS = National Household Travel Survey

2.1.3 South Africa's economic development

"Over the past decade we have laid the macroeconomic and fiscal foundations on which increased investment and a stable business environment rest. In the years ahead we must see more rapid expansion in the productive capacity of our businesses, creating jobs for work seekers, while also growing the revenue base that makes possible an expanded envelope of public services to citizens". These were the words in the 2005 National budget speech (Manuel, 2005).

It is clear that the aim of South Africa's government is to increase economic growth. In detail Manual (2005) indicates: "Growth of the South African economy has averaged 3.2% a year over the past four years. We expect a continued expansion of between four and 4.5% over the next three years, signalling a significant step-change in the pace of economic growth.

In October 2000, there were an estimated 26.9 million people, aged between 15 and 65 years, living in South Africa. This is considered to be the population of working age. Of these people, when using the official definition of unemployment, an estimated 11.1 million people were classified as being not economically active, while 4.1 million were unemployed (see figure 2.8) and had looked for work in the four weeks prior to the interview, and 11.9 million were employed (Statistics South Africa, 2002).

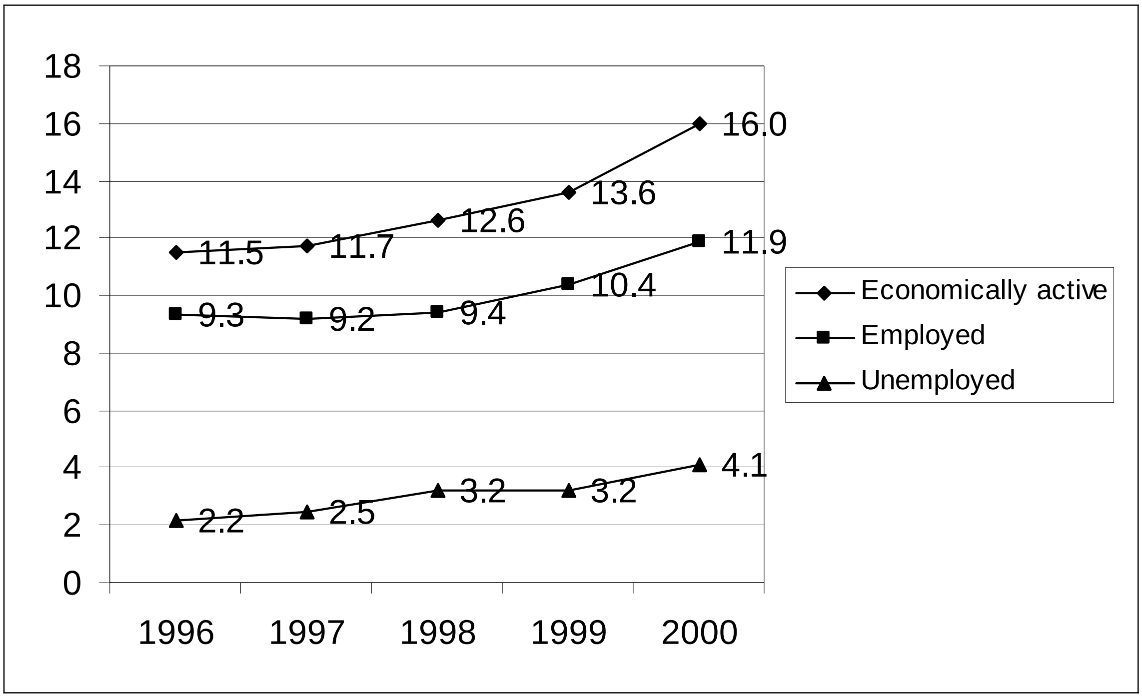

Figure 2.8 Labour market status among those aged 15-65 years (in millions)

Source: www.statessa.co.za, based on the October Household Surveys (OHS)

To put the current economic development in perspective, a comparison with the developed and developing world was carried out (figure 2.9).

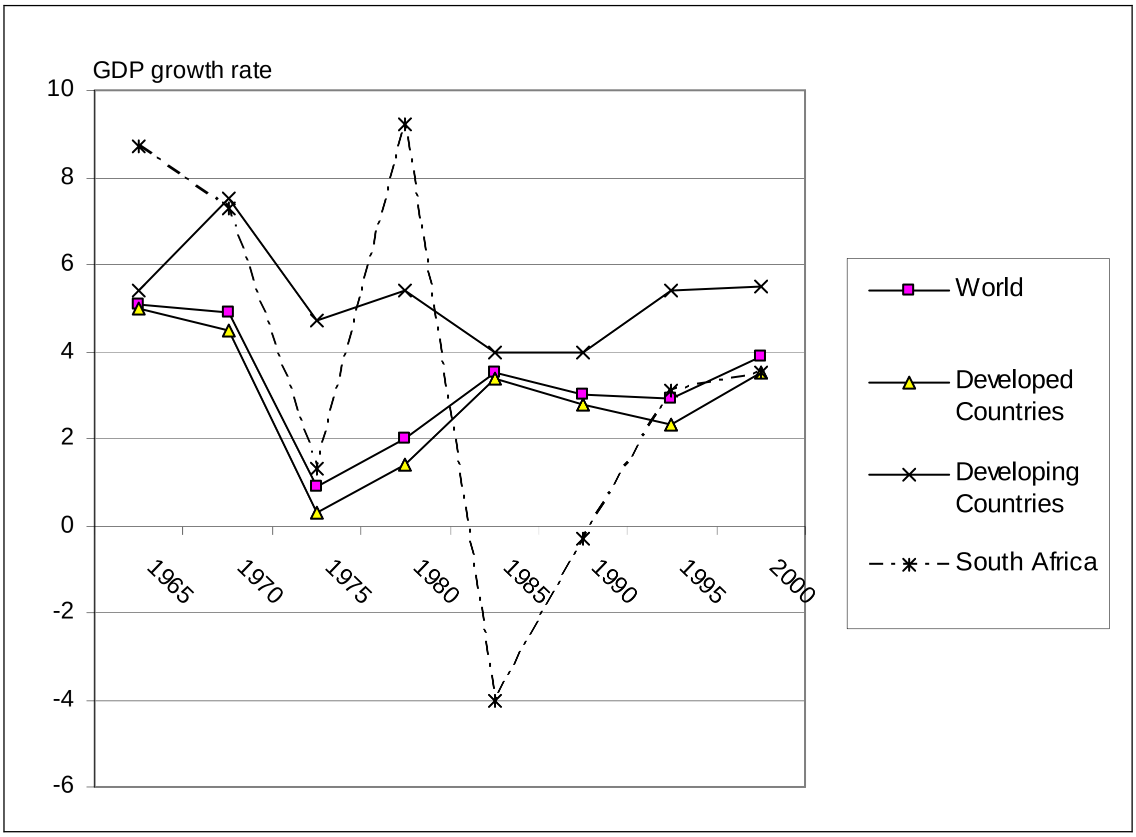

Figure 2.9 Economic development of South Africa compared to world trends
Source: World Resources Institute (WRI), 2005

Figure 2.9 clearly indicates that economic growth rates in South Africa have been turbulent. In the mid-60s and late 70s, economic growth in South Africa was more then eight percent. In the early 80s, growth rates dropped to minus four percent. As mentioned previously, growth rates during the last couple of years have been at least as large as those of developed countries and these growth rates are expected to continue. This will obviously have an impact on the transportation system, in particular transport demand. Unfortunately, information with regards to world growth rates was not available after 2000.

Despite economic growth, unemployment rates in South Africa are still high. Some parts of the country have unemployment rates as high as 40%. In urban areas the rates are generally lower. Cape Town, for example, has an unemployment rate of 18%. Figure 2.10 provides an overview of the employment percentages of different regions in South Africa.

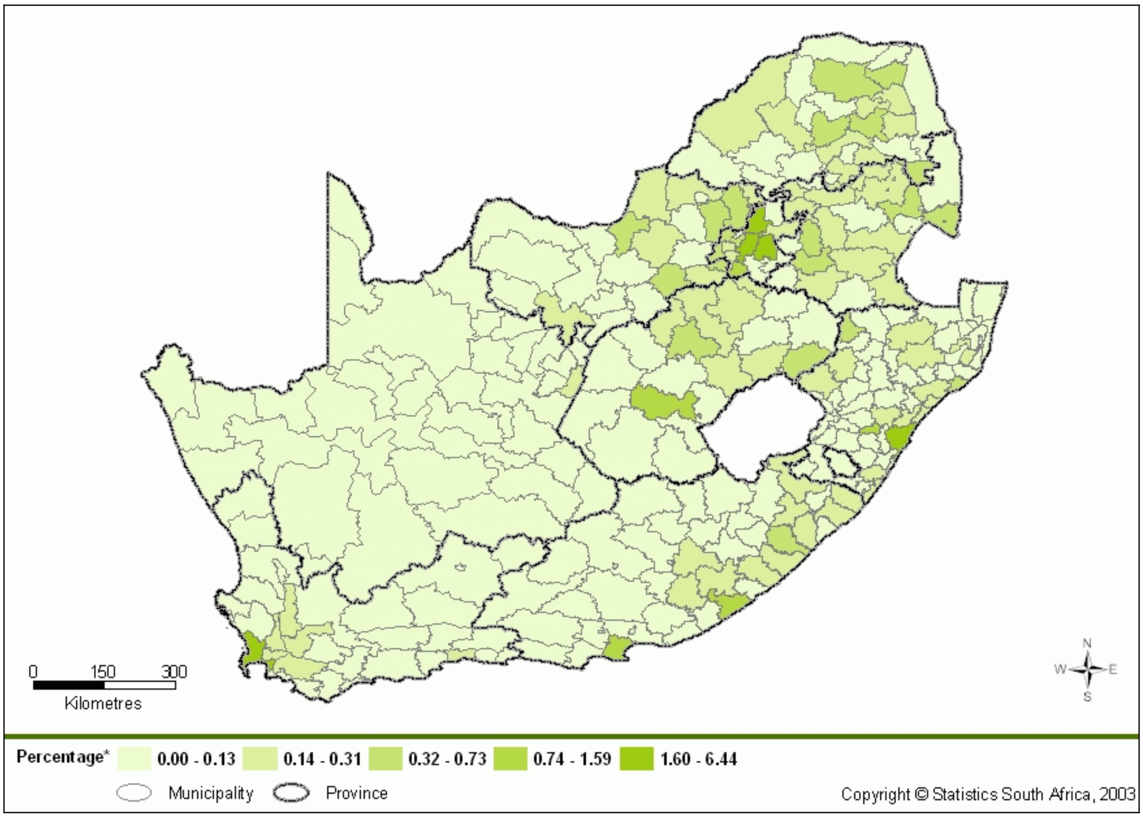

Figure 2.10 Employment percentages in South Africa

Source: www.statssa.co.za

In both 1995 and 2000, household income and expenditure in South Africa were unevenly distributed by population group and sex, urban and non-urban area of residence, and by province (Statistics South Africa, 2002).

- In both years, African-headed households had the lowest average annual income and expenditure in the country, followed by Coloured-, Indian- and then White-headed households.
- In both years, average annual household income and expenditure varied by type of dwelling in which the household lived and the household size.
- During both 1995 and 2000, African, female-headed households were generally earning and spending less than African, male-headed ones, followed by Coloured, female-headed, and then Coloured, male-headed households.
- White, male-headed households were the most affluent in the country in both 1995 and 2000.
- Over this time period, South African households in non-urban areas were likely to be earning and spending less than South African households in urban areas. Income and expenditure were unequally distributed by province. In 1995, the Eastern Cape and Free State were, on average, the poorest provinces. In 2000, however, proportionally more of those living in the Eastern Cape and Limpopo were in the bottom income category.
- There were relatively few households in the bottom income and expenditure categories in the Western Cape or in Gauteng in 1995. In 2000, however, the average income and expenditure per household decreased significantly in

Gauteng, probably explained, at least in part, by the increase in migration of young people from rural areas into the province in search of work.

In October 1995, the average annual household income for the country as a whole was R37 000[4]. This includes regular income, such as salaries and wages, as well as any other income. When the figures are raised to market values in 2000, taking inflation into account, the average annual household income becomes R51 000. In the actual Income Expenditure Survey of 2000, the average household income for that year was R45 000. This is lower than the inflation-adjusted figure for 1995 of R51 000 (Statistics South Africa, 2002).

Household incomes and expenditure in South Africa, in both 1995 and 2000, when taking inflation into account, have on average decreased over time. Individual incomes and expenditure have also decreased on average. In other words, when looking at poverty in relation to earning and spending, South Africans, on average, became poorer between 1995 and 2000 (Statistics South Africa, 2002).

Unfortunately, no data was available for the period after 2000. Nevertheless, the personal impression of the author is that this trend has been reversed. Slowly but surely South Africans are becoming wealthier. Moreover, initiatives like Black Economic Empowerment have increased the total number of people leading ‘wealthy’ lifestyles. With regards to transport, this translates into the purchasing of private vehicles.

2.2 South Africa’s transport demand

Choking congestion and pollution is a daily reality in most South African cities. Traffic volumes are growing at seven percent a year. There has been a massive increase in the use of cars to get to work. Between 1997 and 2004, the national percentage of people who used cars rose from 30% to 45%. In Gauteng, the figure is 55% (NHTS, 2003).

Mobility patterns of South African inhabitants are dependent on the level of income. While most of the urban rich are car owners, the urban poor depend on public transport. Moreover, a fair share of the population cannot afford any type of transport. Nevertheless, the urban poor aim to own private vehicles as soon as possible. Apparently many households, with an income of only R4 000 per month (€450), purchase a vehicle.

Table 2.2 shows the number and proportion of different urban passenger segments in 1996 and the expected growth by 2020. An important point to note is that the number of people who ‘use car only’ is expected to increase largely by 2020.

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[4] €1 = R9, July 2006

Table 2.2 Number and proportion of different urban passenger segments 1996

Segment	Total (Mln)	Proportion of urban population	Expected growth by 2020 (%)
Strider (prefers to walk or cycle)	5.4	23	28
	2.8	12	28
	4.1	17	24
Stranded (no affordable public transport available)	2.1	9	25
Survival (captive to cheapest public transport option)	4.1	19	39
Stubborn (uses car only)	3.0	19	88
All	21.5	100[5]	38

Source: Department of Transport, 1999a

For the past 18 months, South Africa has had record car sales. Every month the amount of new vehicles sold is higher than the month before. The high fuel price does not seem to have an effect. According to the television programme *Carte Blanche* (16 October 2005), car ownership is currently growing by 10% a year. These developments will lead to major problems, as the current infrastructure already struggles to meet demand during the peak period.

The difference with regards to transport options, between the Previously Disadvantaged Individuals (PDI) and Whites, is still very large. To give an impression of the use of cars versus public transport for different population groups, the Cape Town area is used as an example. Although there is no hard evidence, Cape Town is representative for the whole of South Africa. It is the author's impression that the differences between Cape Town and other urban areas in South Africa are minimal.

In his PhD, Behrens (2002) distinguishes the following income groups:

- Low income: less than R1 800 per month,
- Middle income: between R1 800 and R5 500 per month, and
- High income: more than R5 500 per month.

The relationship between income group and race is obvious: almost all African Blacks earn low incomes, Coloured people earn middle incomes and Whites are generally part of the high-income bracket (see figure 2.11).

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[5] Figures should add up vertically but may not, owing to rounding.

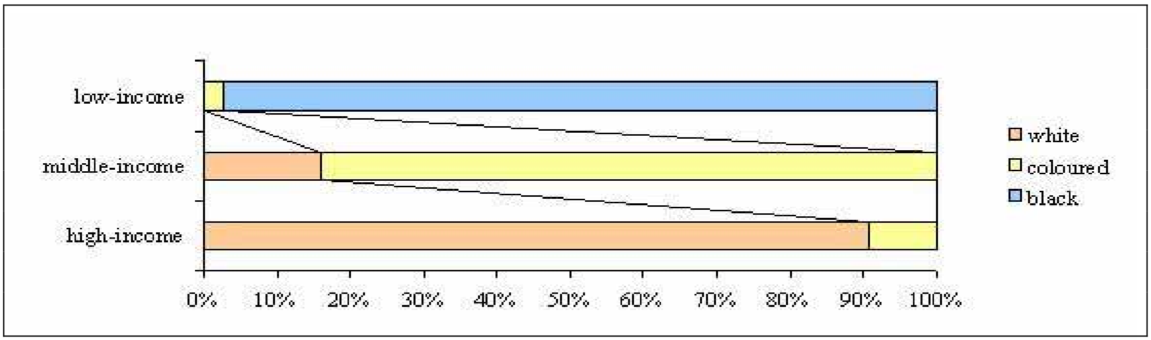

Figure 2.11 Resemblance between income groups and race
Source: Behrens, 2002

Caused by these severe differences, income determines the mobility pattern of inhabitants much more than in developed countries. Among the high-income households surveyed, 94% have access to the use of one or more cars, while among middle-income households 50% have access to at least one car. In low-income households only three percent have access to at least one car (see figure 2.12).

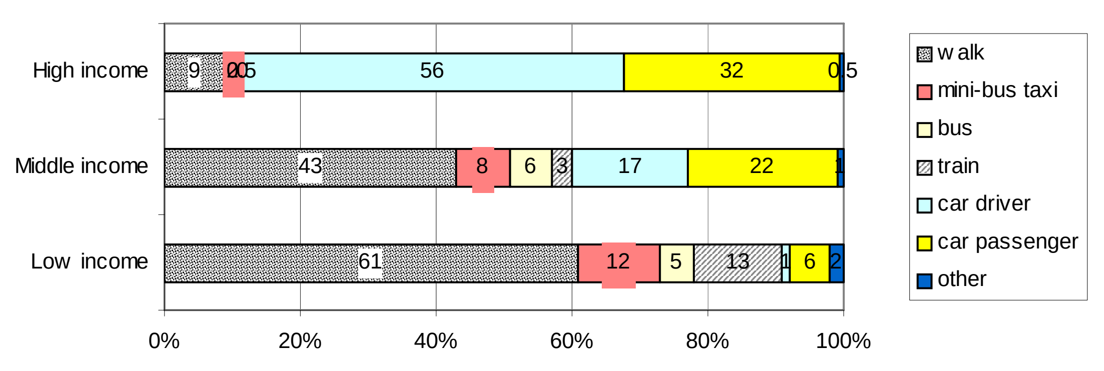

Figure 2.12 Resemblance between income groups and travel mode
Source: Behrens, 2002

It can be concluded that although the apartheid era is over, many disadvantages still exist for the majority of the population. Generally speaking, the people who have access to at least one car are White males with a high income (Behrens, 2002). People in lower-income brackets, on the other hand, are lucky to have a poor public transport system at their disposal.

2.3 Road safety in South Africa

"*Don't fool yourself, speed kills*" is one of the slogans used during the Arrive Alive campaign. Based on statistics it can be concluded that South Africa has a problem with traffic safety. A comparison with other countries shows that South African cities are among the unsafest in the world, together with Seoul, Kuala Lumpur and Houston (Vanderschuren and Irvine, 2002).

South Africa has high fatality rates on roads. Although the current amount of cars and kilometres driven per year are virtually the same as the Netherlands, the number of fatalities is about 10 times higher in South Africa. A more detailed international comparison shows that South African cities have exceptionally high percentages of people killed on roads (figure 2.13).

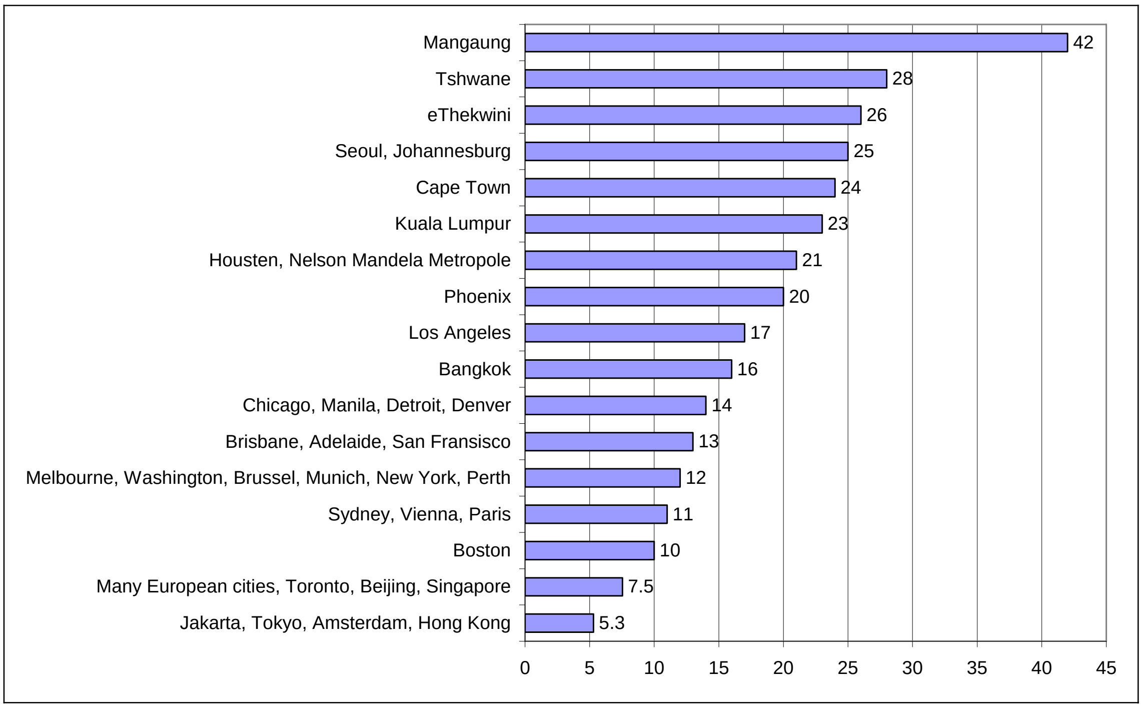

Figure 2.13 Road accident fatalities in various international cities (/100 000 inh)[6]

Sources: Newman and Kenworthy, 1999; CMC, 2000; Pladsen, 2002

The road accident costs for South African society are substantial. On average, the estimated total amount is some R14.5-billion. A breakdown of road accident costs is provided in table 2.3.

Table 2.3 Road accident costs in 2000 and 2001 (million)

	2000	**2001**
Fatal	2 404.7	2 546.6
Major	2 491.4	1 951.4
Minor	1 737.8	1 951.4
Damage only	7 970.5	8 081.3
Total	14 604.4	14 530.7

Source: NDoT, 2002

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[6] The cities with less than 10 fatalities per 100 000 inhabitants are combined. The fatality rate of 6.94 is the average. The European cities with less than 10 fatalities per 100 000 inhabitants are: Amsterdam, Stockholm, Copenhagen, Zürich, Frankfurt, Hamburg and London.

There were 9 918 fatal road accident[7] in South Africa during 2002. The main contributory factors to fatal accidents in December 2002 were categorised as follows: human factors 78%, road factors 12% and vehicle factors 10% (UNIARC, 2003).

Figure 2.14 Jaywalking on a major highway in Cape Town with informal settlement in the background
Source: Behrens, 2002

A recently conducted investigation with regards to road safety in South Africa has found that jaywalking (see figure 2.14) due to informal settlements along the highway, speeding, alcohol abuse and unroadworthy vehicles are the main causes of fatal accidents (Ojungu-Omara, 2006).

2.4 South Africa’s transport supply

2.4.1 The road network

Although the building of the road network started centuries ago, South Africa still has many unpaved roads. The demand in many rural villages is so low, that paved roads are not cost efficient. Figure 2.15 provides an overview of the paved and unpaved road network per province and for the South African Road Agency Pty Ltd (SANRAL).

Figure 2.15 clearly indicates that the majority of the South African road network is still based on gravel roads. Nevertheless, the major cities and routes are connected with paved road. Gravel roads exist to connect rural villages. Paving and maintaining these

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[7] http://www.arrivealive.co.za/pages.asp

roads, the use of which is very limited, is not affordable for the South African government (national, provincial and municipal).

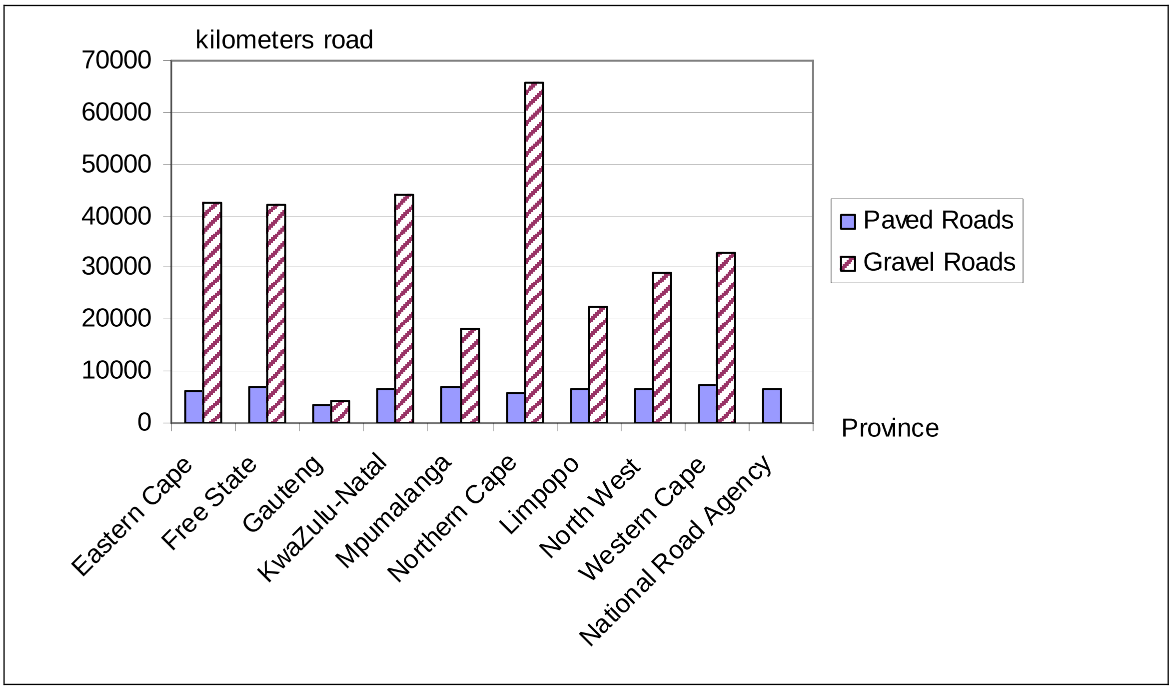

Figure 2.15 Length of the South African road network
Source: NDoT, 2002

SANRAL is responsible for the national roads. The total of 6 713 kilometres of road under the responsibility of SANRAL is broken down into 239 kilometres of six-lane highways, 1 154 kilometres of four-lane highways, 433 kilometres of four-lane roads and 4 863 kilometres of two-lane roads. Moreover, SANRAL is responsible for a 24 kilometre stretch of gravel road.

In addition to the mentioned provincial and national roads, the cities are responsible for urban roads. In total 170 000 kilometres of, mainly paved, urban roads exist in South Africa.

Currently, the expenditure on infrastructure in South Africa focuses on the improvement and maintenance of roads, as most connections between cities, as well as the accessibility of urban areas, have been built in the past. Only where villages and cities grow, new roads are required. These roads are generally small and are often financed by urban developers.

The maintenance of roads is a major problem in South Africa. In the early days, road building and maintenance was financed out of toll collection. In 1984, the South African government re-introduced toll on the national roads. The total length of toll roads grew from 27 kilometres in 1984 to 1 709 kilometres in 2001 (NDoT, 2002).

Finally, it needs to be mentioned that South Africa has adopted the American approach with regard to road design, resulting in car dependency similar to that in the US. Many places in South Africa are only accessible by motor vehicles.

2.4.2 Public transport supply

The majority of South Africans are dependent on Public Transport. South Africa offers rail- and road-based public transport.

The South African Rail Commuter Corporation (SARCC) was established as an agency of the NDoT to take responsibility for commuter rail services throughout the country. The agglomerations where the SARCC operates are: Buffalo City, Cape Town, eThekwini, Nelson Mandela Metropole, Tshwane and Witwatersrand.

At the inception (1990) of the SARCC, rail assets to the value of approximately R5.3-billion were transferred to the corporation (see table 2.4 for details).

Table 2.4 SARCC assets (1990)

Assets	**Number**
Stations and stops	308
Motor coaches	1 308
Carriages	3 340
Single track km	2 400
No. of suburban trains per day	2 613

Source: SARCC, 2005

The maintenance of rail infrastructure and services is costly. Due to limited funding being available, services have decreased. Moreover, the city of Cape Town estimates that the provision of services will vanish within the next 15 years, due to safety problems, if the expenditure on maintenance does not increase.

Different to many other developing countries, South Africa offers regular scheduled bus services. Most services are offered by various bus operators in the urban agglomerations. Nevertheless, there are some long-distance services on offer as well. In December 2002, 26 526 busses, bus-trains and midi-busses were providing the scheduled services in South Africa (NDoT, 2002).

In December 2002, 240 427 minibus taxis were operating on South African roads (NDoT, 2002). The minibus taxi industry provides unscheduled services. Services are provided in urban areas as well as over longer distances. Although the government currently provides licences for routes, it can be concluded that the services are not organised and are often ad hoc. The South African government is trying to include minibus taxi services in the regulated part of public transport (see section 2.6).

The president of the South African Commuter Organisation (SACO), Stephen Sangweni, says that the public transport system lacks coherence. It does not cover enough routes to serve commuters properly, and services do not run frequently enough. It will take up to five years before the public transport system in SA becomes efficient, he believes[8].

2.5 Transport policy development

Three important legislative documents in the field of transport have emerged since the current government came into power (in 1994). The first was the White Paper (1996), followed by Moving Ahead (1999) and the National Land Transport Transition Act (NLTTA; NDoT, 2000).

The aim of these documents is two fold. Firstly, it provides a framework of procedures indicating which documents, permits etc. are required by national government (NDoT, 2000). Municipalities and operators also have to comply and provide the required documents timeously.

The second, more important, aim is to provide a policy focus. This focus can be summarised as the aim to provide mobility for all. The vision statement is as follows (NDoT, 1996):

> *"Provide safe, reliable, effective, efficient, and fully integrated transport operations and infrastructure which will best meet the needs of freight and passenger customers at improving levels of service and cost in a fashion which supports government strategies for economic and social development whilst being environmentally and economically sustainable".*

The strategies for implementation are the promotion of integration and inter-modalism. In other words, promotion of public transport is key.

The administration analysed the current market and identified challenges. With regards to urban passenger customers, the main focus of this dissertation, different segments with specific needs were identified, and specific issues were generated in respect of each segment. A large number of "Stranded" passengers were identified, and predicted to grow well to over three million by 2020. The core challenges that emerged were (NDoT, 1999a):

- The lack of affordable basic access;
- The ineffectiveness of the public system for commuters and other users;
- The increasing dependency on cars within the system; and
- The impact of past land-use patterns and existing planning and regulation of public transport.

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[8] www. businessday.co.za

Based on the customer analysis, three key thrusts have been adopted for urban areas (NDoT, 1999a):

1. *High-volume corridors*: Densification in corridors and nodes to achieve economies of scope, effectively turning around the current trend towards dispersal;
2. *Sustainable operations*: Optimise modal economics and service mix through infrastructure investment to support the corridors, and by selecting the optimal mode based on the cost/service trade-off. This involves also facilitating differentiated service and choice, wherever possible, but with subsidisation only for the optimal mode, if at all. Tough road-space management is necessary to prioritise public transport and subsidies should be targeted at affordable access to the optimal mode, and
3. *Improved efficiency*: Improve firm-level performance through competitive tendering to the private sector with incentives for productivity innovations, effectively regulating all modes, especially taxis, and improving sustainability through capital investment.

2.6 The promotion of public transport in practice

Following the three legislative documents, several initiatives were started to promote public transport. This section includes a summary of these initiatives, as it provides a good demonstration of the translation of legislation into practice.

Taxi re-capitalisation

Although the minibus taxi industry offers an informal form of public transport, the service is important to South African society. Unfortunately, reliability and road safety are often jeopardised by the minibus taxi providers.

In the summer of 1999, the Departments of Transport, Trade and Industry, Minerals and Energy, and Finance were involved in preparing a re-capitalisation strategy for the minibus taxi industry. An international tender for a purpose-built vehicle was advertised at the end of July of that year, which would enable local and international motor manufacturers to bid (NDoT, 1999b). Besides safe and comfortable vehicles, government also required driver training and operating permits.

As of today, November 2005, government still talks about the taxi re-capitalisation, but the situation on the ground is still the same. Thousands of travellers still risk their lives on a daily basis as services have not improved.

The Gautrain

The Gautrain project, one of the largest and most ambitious transportation projects in South Africa and indeed Africa, is expected to play an important role in stimulating economic growth and job creation in Gauteng. It will also relieve traffic congestion, promote public transport, tourism and public-private partnerships, and change the culture of public transport usage in South Africa[9].

The Gautrain is a project of Blue IQ, the Gauteng Provincial Government's multi-billion Rand initiative to invest in strategic economic infrastructure. The Gautrain Rapid Rail Link 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.

Currently (November 2005), the estimated cost for the Gautrain project is twice the original amount. The new budget is four times higher than the annual cost for public transport in the country. Opposition against the Gautrain is, therefore, growing and the government has decided to re-evaluate the project.

Klipfontein corridor

The Western Cape Province and the City of Cape Town have entered into a formal partnership to ensure effective delivery of public transport plans within the Metropole. The planning of the first phase, known as the Klipfontein corridor, which stretches from Khayelitsha to the Cape Town Central Business District (CBD), is well on its way. The infrastructure needed for this project alone will create an estimated 2 400 new construction jobs for 12 months.

This, together with the improved mobility resulting from an effective public transport system, will materially impact on the alleviation of poverty. Poverty, not only in the narrow economic sense, but also in the social and cultural sense, as poor people will have access to sport, recreational and cultural facilities and generally have freedom of movement. The added benefits would be the catalytic impact for development and economic growth in the South East corridor, redirecting and unlocking private sector investment into the Cape Flats. Klipfontein Road, from Mowbray to Khayelitsha, has huge stretches of barren land alongside it. Almost overnight, it will become prime land for development. The plan is to change the 20 kilometre long Klipfontein Road corridor from a mostly desolate stretch into a road of economic transformation - in Athlone, Gatesville, Gugulethu, Nyanga and Khayelitsha. Existing buildings along the route are expected to draw investment for refurbishment.

The first phase of the Klipfontein corridor project ended more than a year ago. The Western Cape Province and the City of Cape Town still indicate that the Klipfontein corridor project will be realised. Nevertheless, it has been awfully quiet for the past 14 months.

One of the reasons for the lack of planning and project realisation is the split of responsibility for transport matters among the three spheres of Government. Most

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[9] www.gpg.gov.za

metropolitan areas are planning to establish a Transport Authority (TA) to overcome this problem. The founding of a TA has, so far, only materialised in eThekwini.

In November 2002, the eThekwini Council passed a resolution agreeing to the establishment of a TA subject to the finalisation of a few outstanding issues. One of the most important outstanding issues was the finalisation of a Founding Agreement[10], which is required by the NLTTA (NDoT, 2000). Although Durban has not implemented major changes in the transport system, they have been able to implement their redesigned public transport plan.

2.7 Infrastructure and ITS policy and practice

Although the main government focus is public transport, it needs to be mentioned that most (public) transport in South Africa is road based. Moreover, the current indications point to a further growth of road-based public transport. It is, therefore, important to invest in infrastructure and systems that can make use of the available infrastructure in the most efficient way. The NDoT is well aware that ITS systems are one of the ways to improve safety and efficiency of a road system. Plans to investigate possibilities have been verbalised.

With regards to the National Highway System, the responsibility to build, maintain and optimise the efficiency of the systems lies with SANRAL.

SANRAL has concluded that ITS needs to be part of their plans. In their last Annual Report (2005), the following was mentioned with regards to ITS.

Severe traffic congestion is experienced on South African urban highways, which has a negative effect on productivity, the running costs of vehicles, the amount of time people spend with their families, and the environment. It is often too costly to provide additional road capacity within the restricted space and alternative solutions must be explored in order to optimise congestion management (SANRAL, 2005).

Another important aspect of traffic management is the handling of incidents, such as crashes or breakdowns. The speed of response to an accident has a direct influence on the safety of any persons involved in the emergency, as well as the extent of congestion caused directly or indirectly by the stationary vehicles (SANRAL, 2005).

During the year under review, SANRAL investigated the feasibility of implementing Intelligent Transport Systems (ITS) along the N1 Ben Schoeman Freeway in Gauteng. This is a pilot project which, apart from the deployment along the Ben Schoeman, will

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[10] www.durban.gov.za

also monitor other freeways in Gauteng, although initially not as detailed as the aforementioned project (SANRAL, 2005).

With the implementation of the pilot ITS project, in co-operation with the Gauteng Department of Transport, Roads and Works and the Tshwane, Johannesburg and Ekurhuleni Local Governments, SANRAL aims to achieve improved incident management, reduced congestion, increased road safety and the evaluation of the effectiveness of ITS technologies with a view to possible further deployment (SANRAL, 2005).

This will be achieved through the deployment of several forms of ITS technology, including a centralised network management centre in Midrand (NMC), closed circuit television cameras (CCTV), variable message signs (VMS), loops and other traffic detection and information devices, as well as continuous monitoring of the systems and their impact on improved road network operations. Further experimentation and research will take place during the course of the five-year operational phase of the pilot project to determine tailor-made solutions for local conditions and road users (SANRAL, 2005).

A key component of the project is the interaction and enhancement of existing Incident Management Systems (IMS) in order to facilitate faster emergency and incident response. This will be achieved by improving the lines of communication, and the speed and efficiency of notification, between the incident location and the IMS (SANRAL, 2005). The first part of the system will be operational from April 2006.

Section 2.2 provides an overview of the South African demand for transport. It is expected that private cars will play an even greater role in the future. As mentioned, for the last 18 months South Africa has had record car sales. Every month the amount of new vehicles sold is higher than the month before. The high fuel prices, which are also occurring in South Africa, do not seem to have an effect on car sales. This trend does re-emphasise the need for safe and efficient road systems.

South Africa has won the bid for the Soccer World Cup in 2010. Like in many other countries, the hosting of major events provides an opportunity for transport infrastructure investment. Additional investment budgets communicated are around R3-billion (€333-million) for South Africa (NDoT) and about R250-million (€27.8-million) for Cape Town. These budgets will hopefully provide an opportunity for some of the projects, which have been planned for years, to be implemented.

2.8 South African culture

With 11 official languages and an array of cultures, South Africa is referred to as the Rainbow nation. It is likely that the different cultures and behaviours within these cultures also manifest in driving behaviour. The question is, is there a significant difference between EU/US traffic flows and South African traffic flows due to the differences in driving behaviour?

Unfortunately, there is a lack of research with regards to driving behaviour in South Africa. It is, therefore, necessary to explore other research areas that might provide usable information for traffic flow theory and driving behaviour research.

Analysing cultural differences is not straightforward, mainly because of a lack of data. Not many authors have managed to collect data for a vast amount of countries. One of the authors who did manage is Geert Hofstede (1991). His data contains more then 116 000 records of people, working at IBM branches in 72 different countries, covering 38 different functions within the company. Table 2.5 provides an overview of the abbreviations used for the different countries.

Analysing his data, Hofstede (1991) comes to the conclusion that different cultures/countries score differently on the following four criteria:

1. **Power distance** is a measure of the acceptance of unequally distributed control.
2. **Individualism** measures the strength of family or group ties. More individual societies inspire more freedom, challenges and the utilisation of talent and skills.
3. **Masculine/feminine attitude** is a measure of assertiveness.
4. **Uncertainty avoidance** measures how threatened a person of a cultural group feels with regards to uncertainty of unknown situations. More formality and rules form part of these cultures/societies.

Societies with a large power distance are based on respect. Children and pupils obey their parents and teachers (teachers are seen as ‘heroes’). Organisations in a society with large power distance are generally centralised. Employees expect to be told exactly what to do and the remuneration differences between management and workers are significant. Power distance in certain countries is the answer to fundamental problems with regards to social differences (Hofstede, 1991). Certainly, in the apartheid era of South Africa, power distance was high. Nevertheless, in the literature no indication was found that power distance influences driving behaviour.

Hofstede (1991) obviously concludes that individualism leads to different behaviour. Societies can either be ‘we’ or ‘I’ orientated. In a more collective orientated society, management focuses on groups versus the orientation on individuals. In a collective orientated society, personal relationships are more important than the task. In a more individual orientated society, the carrying out of the task is essential. Hofstede (1991) does not answer the question of whether driving behaviour is influenced by more collective versus more individual ways of thinking. Nevertheless, it could be assumed that more group orientated drivers display more social behaviour on the road.

Table 2.5 Abbreviations for country and group of country names

ARA	Arabic countries (Egypt, Kuwait, Lebanon, Liberia, Saudi-Arabia, United Arabic Emirates)	ITA	Italy
		JAM	Jamaica
		JPN	Japan
		KOR	South Korea
ARG	Argentina	MAL	Malaysia
AUL	Australia	MEX	Mexico
AUT	Austria	NET	The Netherlands
BEL	Belgium	NOR	Norway
BRA	Brazil	NZL	New Zealand
CAN	Canada	PAK	Pakistan
CHL	Chile	PAN	Panama
COL	Colombia	PER	Peru
COS	Costa Rica	PHI	Philippines
DEN	Denmark	POR	Portugal
EAF	East Africa (Ethiopia, Kenya, Tanzania, Zambia)	**SAF**	**South Africa**
		SAL	Salvador
EQA	Ecuador	SIN	Singapore
FIN	Finland	SPA	Spain
FRA	France	SWE	Sweden
GBR	Great Britain	SWI	Switzerland
GER	Germany	TAI	Taiwan
GRE	Greece	THA	Thailand
GUA	Guatemala	TUR	Turkey
HOK	Hong Kong	URU	Uruguay
IDO	Indonesia	USA	United States of America
IND	India	VEN	Venezuela
IRA	Iran	WAF	West Africa (Ghana, Nigeria, Sierra Leone)
IRE	Ireland		
ISR	Israel	YUG	Yugoslavia

Source: Hofstede 1991

So called ‘Macho’ behaviour is more present in masculine societies. Masculine societies focus on material success and improvement of their situation. More feminine societies focus on people. They care for each other and everybody (both male and female) is allowed to show their ‘soft’ side. Masculine cultures are less tolerant than feminine ones (Hofstede, 1991). Although Hofstede does not translate these differences to driving behaviour, the author assumes that masculinity provides an explanation of more aggressive driving behaviour.

Uncertainty avoidance does not lead to a reduction of risk but to a limitation of the unknown (Hofstede, 1991). There appears to be a statistical relationship between the level of uncertainty avoidance in (developed) countries and the maximum speed on highways. The correlation is positive: higher uncertainty avoidance means a higher maximum speed (Hofstede, 1991). Obviously, a higher speed leads to a higher risk. Nevertheless, this is a known risk which does not bother individuals much.

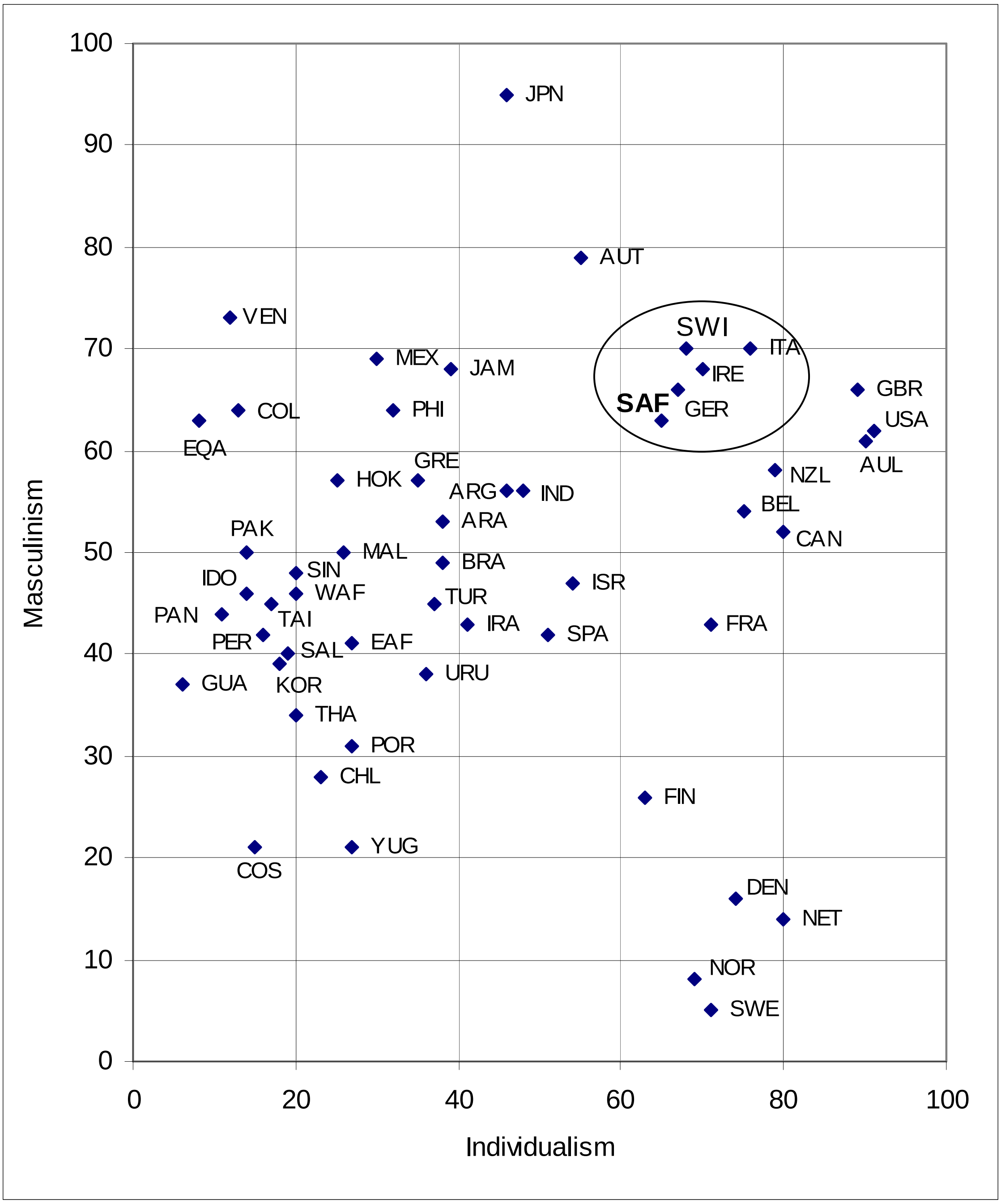

Figure 2.16 Individualism vs. Masculinism (every dot is a different country)
Source: Hofstede, 1991

The high stress in uncertainty avoidance countries presents itself in agitated behaviour, which leads to an urge to drive faster. An unrealistic impression is created that equates a reduction of time with a reduction of risk and, therefore, a reduction in lives lost on the road (Hofstede, 1991). Figures 2.16 and 2.17 provide an overview of South Africa's score compared to other countries included in Hofstede's research.

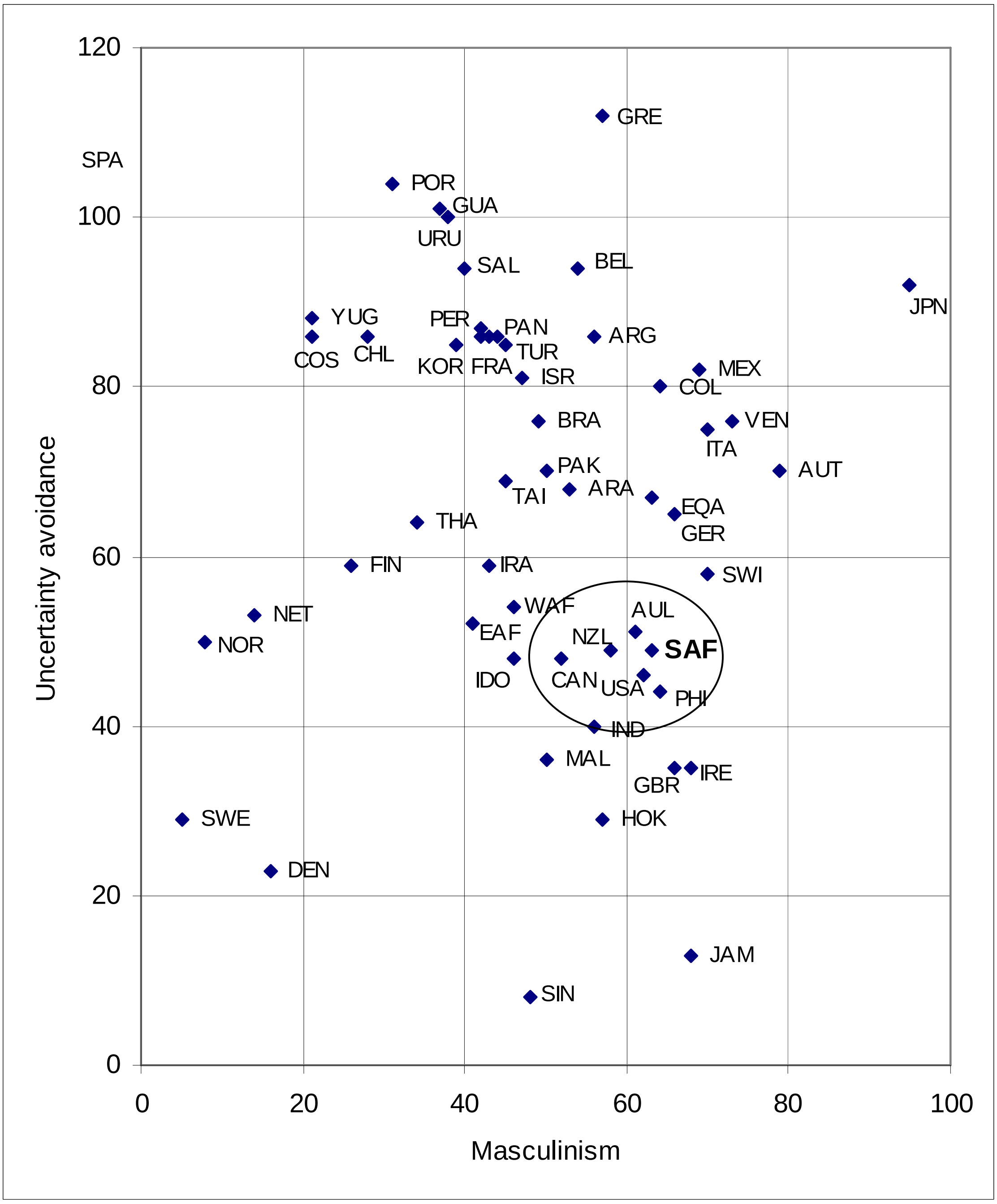

Figure 2.17 Mascilinism vs. Uncertainty avoidance

Source: Hofstede, 1991

This international comparison shows that South Africa (SAF), on average, scores high for masculinism and individualism. With regards to uncertainty avoidance, the average score for South Africa is just below average (49). A translation of Hofstede's scores for South Africa provides a first indication that South Africans are aggressive drivers. Nevertheless, the analysis of behaviour in different countries does not indicate that South Africa scores significantly differently to Europe or the US.

After his analysis of South Africa, Trompenaars (Trompenaars and Hampden-Turner, 1998) indicates that the country has a triple heritage, from African society, Europe and

Asia. It is, therefore, ‘tricky’ to compare the South African average score with other countries.

Although Trompenaars’ analysis is partly based on Hofstede’s theory, he uses different indicators. Trompenaars (Trompenaars and Hampden-Turner, 1998) uses six indicators:

1. **Universalism versus particularism**: The universalist approach is roughly: “What is good and right can be defined and always applied’. In particularist cultures, far greater attention is given to the obligations of relationships and unique circumstances. For example, instead of assuming that the one good way must be followed, the particularist reasoning is that friendship has special obligations and hence may come first. Less attention is given to abstract societal codes.
2. **Individualism versus communitarianism**: This indicator explores if people regard themselves primarily as individuals or primarily as part of a group. Is it more important to focus on individuals so that they can contribute to the community if they wish, or is it more important to consider the community first, since many individuals share in this?
3. **Neutral versus emotional**: This indicator explores if the nature of our interaction should be objective and detached, or is expressing emotion acceptable. In North America and north-west Europe business relationships are typically instrumental and all about achieving objectives. The brain checks emotions because these are believed to confuse the issues. The assumption is that we should resemble our machines in order to operate them more efficiently. But further south and in many other cultures, business is a human affair and a whole gamut of emotions is deemed appropriate. Loud laughter, banging your fist on the table or leaving a conference room in anger during negotiations is all a part of business[11].
4. **Specific versus diffuse**: When the whole person is involved in a business relationship there is a real personal contact (diffuse), instead of the specific relationship prescribed by a contact. In many countries, a diffused relationship is not preferred, but is necessary before business can proceed. In Trompenaars’ research, the case of one American company, trying to win a contract with a South American customer, shows how disregard for the importance of the relationship led to the deal being lost.
5. **Achievement versus ascription (status)**: Achievement means that you are judged on what you have recently accomplished and on your record. Ascription means that status is attributed to you, by birth, kinship, gender or age, but also by your connections (who you know) and your educational record.
6. **Inner-outer directedness (control)**: This indicator explores the way societies look at time, the environment etc. In some societies, what someone has achieved in the past is not that important, and it is more important what plan they have developed for the future. In certain cultures, like American, Swedish and Dutch, time is perceived as passing in a straight line, a sequence of disparate events.

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[11] In the author’s view, this indicator is related to Hofstede’s masculinism versus feminism

Other cultures think of time as moving more in circles; the past and present together with future possibilities.
Some cultures see, with regards to environment, the major focus affecting their lives and the origins of vice and virtue as residing within the person. Here, motivations and values are derived from within. Other cultures see the world as more powerful than the individual. They see nature as something to be feared or emulated.

Africa is culturally diverse, not simply between Blacks and Whites, but also among the various language groups within the Black community, as well as between the rural and urban Black communities (Trompenaars and Hampden-Turner, 1998).

Trompenaars researched eight cultural groups within South Africa. Based on economical achievement, he made sure the respondents came from an urban background. Table 2.6 provides an overview of the average score per identified indicator for these different cultural groups. A high Standard Deviation (SD) indicates large differences between cultural groups.

Table 2.6 Scores for eight different cultural groups in South Africa

	South Africa							
	English	Afrikaans	Zulu	South Sotho	North Sotho	Xhosa	Tsonga	Tswana
Universalism (SD 20.07)	92	89	78	70	71	38	71	40
Individualism (SD 17.21)	72	58	51	42	68	73	22	52
Neutral (SD 10.89)	57	70	65	54	53	36	45	61
Specific (SD 10.65)	72	70	75	70	51	84	58	78
Status (SD 7.35)	65	61	58	58	41	58	55	63
Control (SD 8.31)	67	72	60	48	60	61	49	65

Source: Trompenaars and Hampden-Turner, 1998

Generally, it can be concluded that South African societies score high on all the indicators Trompenaars uses. Analysing the scores in more detail, it can be concluded that there are large differences between the different cultural groups in South Africa. The standard deviation, especially for universalism and individualism, is very high. Hofstede (1991) concludes that masculinism and uncertainty avoidance are the main indicators for ‘aggressive’ driving behaviour. The large standard deviations found by Trompenaars (Trompenaars and Hampden-Turner, 1998) for different South African cultures indicates that the differences in driving behaviour within South Africa are most probably larger than in Europe and the USA.

2.9 Are South Africans ready for technological developments?

ITS have proven to be of benefit in other countries (see chapter three). Nevertheless, an important aspect of the introduction of ITS systems is user acceptance. The question is: "Would South Africans accept technologies that aim to improve the transportation system?"

There is no problem with introducing technologies into the South African market. Automatic Teller Machines (ATMs), to draw money, are used by a large part of the population. The first ATMs were placed in March 1984, several years before Europe started to use ATMs. The use of mobile phones is also common; almost 42% of the population owns a mobile (cell) phone. Use of ATMs and cell phones is described to provide a better overview of the possibilities when it comes to the introduction of ITS in South Africa.

South Africa has an extremely sophisticated banking system with very high levels of infrastructure. SA banks are world leaders in technology, including full-service Internet banking. In 1996, South African banks ranked sixth out of 46 countries in the World Competitiveness Report[12].

South Africa uses the Universal Electronic Payment System (UEPS) that makes use of our patented Funds Transfer System (FTS) methodology. This provides a fully integrated payment, switching and settlement system suitable for multiple applications and services, meeting the requirements of both the un-banked and under-banked populations.

ATMs are widely used and largely replace the need to enter banking halls. The network of ATMs is extensive, located adjacent to banks, in shopping malls and petrol service stations. In secure environments, such as the latter, they are open 24 hours a day, although in some city centre locations they have limited times of operation.

ATMs were the first electronic banking service to be introduced to consumers. Other forms of electronic banking are telephone, cellular phone and Internet banking. Compared to European ATMs, there is a wider range of transactions that you can undertake at South African ATMs, including[13]:

- drawing cash from your account,
- transferring money between your accounts, for instance, between your current and your credit card account, in order to pay your credit card account,
- paying any of your normal monthly bills, such as municipal, telephone or clothing accounts,

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[12] http://www.capeinfo.com/capeguide/banking.asp

[13] http://www.persfin.co.za/

- making other payments, such as your children's pocket money or your domestic worker's salary, provided the recipients have bank accounts,
- printing balances or statements on your accounts, and
- depositing cash or cheques into any of your accounts.

Another technology that has been introduced in South Africa over the last decade is the cell phone. As at June 2005, 18.7 million people were using cell phone technology, of which 80% were actively[14] using this technology.

Since 2001, South Africa has introduced a third provider to the cellular market. Since 2001, the third operator has been able to gain 17% of the market, while the other two providers have 54% and 29% respectively. More than 90% of all customers are users of pre-paid contracts[14]. In a country with 40% unemployment and severe poverty issues, that is obviously not surprising.

South African banks are now even using cell phones to offer their services. For the first time in South Africa, anyone can bank anytime, anywhere on their cell phone without paying banking fees for six months. The offer (by one of South Africa's major banks), will be valid until 31 March 2006. Even SMS charges for transacting will be waived by operators for the first three months. The bank indicates: "We hear stories of people in rural areas travelling miles to the nearest ATM or branch just to get an account balance or to check if a payment has been made. With cell phone banking you don't even have to get out of bed[15]".

Because of the demographic profile of cell phone users, the offer cuts across economic and social groupings, and is a channel that can deliver banking services to the previously un-banked portion of society. "Everyone from the baker to the CEO has a cell phone. You don't need access to a landline, Internet, ATM or branch to make payments or check your financial details. Our free offer is our way of encouraging people to use their cell phones as a bank," explains the Managing Executive (ME)[15].

The bank has currently over 70 000 cell phone banking customers making it a leader in the market. Cell phone banking has experienced customer growth of more than 65% in recent months. "We expect this growth to continue as customers start realising the value of cell phone banking", says the ME[15].

Within the transportation field, Tracker Systems (TS) and Fleet Management Systems (FMS) have been introduced. TS are security systems that track a stolen vehicle. The two companies providing this service have equipped just under 700 000 vehicles with their systems. Over the last eight years or so, they have recovered about 50 000 vehicles from all over South Africa and in neighbouring countries. One of the companies indicates that the recovery time is 48 minutes (on average). Moreover, these companies

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[14] www.cellular.co.za

[15] ABSA media services, 6 October 2005

have assisted the South African Police Services to make arrests, and identify syndicates and "chop shops" (where vehicles are taken apart so the parts can be used or sold)[16].

FMS make it possible for companies to identify the position of a vehicle at any time. More advanced systems record speed violations. Driver ID systems, integrated in the fleet monitoring systems, provide an opportunity to analyse the behaviour of drivers.

Providers of FMS have indicated that implementation processes have been difficult in the past. Drivers and Unions are not keen to co-operate. The introduction of a FMS to 7 500 vehicles of a large, national civil service company took approximately five years. Drivers did not want "Big Brother" to watch them and many systems were vandalised after implementation.

For the company, the benefits after the implementation of the system were huge. Awareness of driving behaviour (resulting in lower speeds), better route choices and a reduction of private use of the vehicle resulted in fuel savings of between 15%-25%. There was a significant reduction in the number of accidents, decreasing repair costs by a phenomenal 70%. Other benefits experienced were less wear and tear to tyres, gear boxes etc. There was even a reduction in telephone costs as the company did not have to call the drivers to verify their positions. Moreover, FMS can be used as tracking devices in case of vehicle theft. Insurance premiums for companies using FMS are, therefore, reduced.

It has become clear over the years that the implementation of FMS requires careful planning. All stakeholders, including the drivers and Unions, need to be part of the process from the beginning. Newsletter distribution and "public" hearings need to take place to foster acceptance. It needs to be very clear to the drivers that management is not implementing the system to have a "big stick", but rather to optimise performance. Moreover, driver benefits like quicker response in case of an accident or security problems should be highlighted. Some companies even started a competition for the most economical driver, providing a prize or bonus (mostly a financial incentive).

A more recent implementation process at a company in Cape Town with 60 vehicles showed that an open communication process prevents vandalism of the system. Only four drivers tampered with the system as they were not willing to accept the monitoring of their driving. In the end the company forced them to pay for the repairs. Other companies apply an instant dismissal process for tampering with the equipment. These measures have virtually eliminated vandalism.

All in all it can be concluded that South Africans are willing to accept new technologies, especially if they can identify the benefit to themselves.

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[16] www.tracker.co.za and www.netstar.co.za

2.10 Résumé

The new South African government has inherited low density urban agglomerations that encourage motorised transport. The majority of South Africans use public transport. Nevertheless, private car ownership and use is growing and transport related problems like congestion and pollution are expected to increase.

Since they came into power, the South African national government has developed policies and strategies to improve current systems. Nevertheless, the lack of knowledge, skill and capacity in the municipalities, together with the split of responsibilities for transport matters among the three spheres of government, has resulted in a 'paralysis' in practice. Required ITPs are virtually non-existent. Only pilot projects are planned and the realisation has, so far, not materialised.

It can be concluded that the current road network has developed according to world standards, but limited maintenance of the current network and the policy problems described before, might lead to a deterioration of the system.

The South African transport demand exists for two groups. The urban wealthy that use their private vehicle and whose behaviour is very similar to the developed world, and the urban poor who have to walk or use unsafe and unreliable public transport.

The two demand groups create additional conflict, especially between pedestrians and private vehicles. The death toll on the roads is, therefore, much higher than in developed countries. Moreover, the urge to own a private vehicle by the urban poor results in the purchasing of old cars. Unfortunately, these households do not have the funds to maintain their vehicles. Unnecessary fuel consumption, pollution and accidents are the result.

With regards to the acceptance of new technologies, it was concluded that South Africans are generally open minded. Technologies in other fields, like ATMs and cell phones, as well as transport related systems like tracking devices and fleet monitoring systems, are used by a number of people.

During the planning and realisation of transport projects, it needs to be borne in mind that South Africa is a nation of many backgrounds and cultures. International research has shown that people of different backgrounds show different behaviours and attitudes. There is even an indication that these differences are also visible in driving behaviour.

Chapter 3

Intelligent Transport Systems

3.1 Background

As transport networks become more congested, and new highway construction recedes as a sustainable long-term solution, there is a growing need to adopt policies that manage demand and make full use of existing assets.

Advances in information technology are now such that ITS offer real possibilities for authorities to meet this challenge: by monitoring what is going on, predicting what might happen in the future and providing the means to manage transport proactively and on an area-wide basis.

This chapter focuses on ITS measures. First, a description of ITS objectives (benefits) is provided, followed by a general description of ITS measures. Thereafter, an explanation is given as to why this thesis focuses on infrastructure related systems, in particular highways. The benefits of highway ITS systems, based on estimates via modelling studies, as well as measurements of before and after studies, is described.

The information presented in this chapter aims to answer the following questions:

- Which benefits of ITS have been established in the developed world?
- Which ITS systems are potentially beneficial for South Africa?

3.2 Objectives of ITS measures

Importantly, ITS can facilitate the delivery of a wide range of policy objectives, beyond those directly associated with transport, bringing significant benefits to transport users and those who live and work within the area. There are six main objectives/benefits that have been identified in the international literature (Mitretek Systems, 2001).

Safety: An explicit objective of the transportation system is to provide a safe environment for travel while continuing to strive to improve the performance of the system. Although undesirable, crashes and fatalities are inevitable occurrences. Several ITS services aim to minimise the risk of crash occurrence. This objective focuses on reducing the number of crashes and lessening the probability of a fatality should a crash occur. Typical measures of effectiveness used to quantify safety performance include the overall crash rate, fatality crash rate and injury crash rate. ITS services should also strive to reduce the crash rate of a facility or system. Crash rates are typically calculated in terms of crashes per year, crashes per million vehicle kilometres travelled or crashes per 10 000 inhabitants.

Mobility: Improving mobility (and reliability) by reducing delay and travel time is a major objectives of many ITS components. Delay can be measured in many different ways, depending on the type of transportation system being analysed. Delay of a system is typically measured in seconds or minutes of delay per vehicle. Also, delay for users of the system may be measured in person-hours. Delay for freight shipments could be measured in time past scheduled arrival time of the shipment. Delay can also be measured by observing the number of stops experienced by drivers before and after a project is deployed or implemented.

Travel time variability indicates the variability in overall travel time from an origin to a destination in the system, including any modal transfers or en-route stops. This measure of effectiveness can readily be applied to inter-modal freight (goods) movement as well as personal travel. Reducing the variability of travel time improves the reliability of arrival time estimates that travellers or companies use to make planning and scheduling decisions. By improving operations and incident response, and providing information on delays, ITS services can reduce the variability of travel time in transportation networks. For example, traveller information products can be used in trip planning to help re-route commercial drivers around congested areas resulting in less variability in travel time.

Efficiency: Many ITS components seek to optimise the efficiency of existing facilities and use of rights-of-way so that mobility and commerce needs can be met while reducing the need to construct or expand facilities. This is accomplished by increasing the effective capacity of the transportation system. Effective capacity is the "maximum potential rate at which persons or vehicles may traverse a link, node or network under a representative composite of roadway conditions," including "weather, incidents and variation in traffic demand patterns" (McGurrin and Wunderlich, 1999). Capacity, as defined by the *Highway Capacity Manual,* is the "maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a given point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic and control conditions" (TRB, 2000). The major difference between effective capacity and capacity is that capacity is generally measured under typical conditions for the facility, such as good weather and pavement conditions, with no incidents affecting the system, while effective capacity can vary depending upon these conditions and the use of management and operational strategies.

Throughput is defined as the number of persons, goods or vehicles traversing a roadway section or network per unit time. Increases in throughput are sometimes realisations of increases in effective capacity. Under certain conditions, it may reflect the maximum number of travellers that can be accommodated by a transportation system. Throughput is more easily measured than effective capacity and, therefore, can be used as a surrogate measure when analysing the performance of an ITS project. The reader needs to bear in mind that local circumstances influence local capacities, as well as measured throughputs.

Productivity: ITS implementation frequently reduces operating costs and allows productivity improvements. In addition, ITS alternatives may have lower acquisition and life cycle costs compared to traditional transportation improvement techniques. The measure of effectiveness for this objective is cost savings as a result of implementing ITS. Another way to view the cost savings is to quantify the cost savings between traditional and ITS solutions to addressing problems.

Energy and environment: The air quality and energy impacts of ITS services are very important considerations, particularly for non-attainment areas. In most cases, environmental benefits can only be estimated by the use of analysis and simulation. The problems related to regional measurement include the small impact of individual projects and large numbers of exogenous variables including weather, contributions from non-mobile sources or other regions, and the time-evolving nature of ozone pollution. Small-scale studies generally show positive impacts on the environment, and these impacts result from smoother and more efficient flows in the transportation system. However, environmental impacts of travellers reacting to large-scale deployment in the long term are not well understood. Decreases in emission levels and energy consumption have been identified as measures of effectiveness for this objective.

Customer satisfaction: Given that many ITS projects and programmes were specifically developed to serve the public, it is important to ensure that user (i.e., customer) expectations are being met or surpassed. Customer satisfaction measures and characterises the distance between users' expectations and experiences in relation to a service or product. The central question in a customer satisfaction evaluation is, "Does the product deliver sufficient value (or benefits) in exchange for the customer's investment, whether the investment is measured in money or time?" Typical results reported in evaluating the impact of customer satisfaction with a product or service include product awareness, expectations of product benefit(s), product use, response (decision-making or behaviour change), realisation of benefits and assessment of value. Although satisfaction is difficult to measure directly, measures related to satisfaction can be observed including the amount of travel in various modes, and the quality of service, as well as the volume of complaints and/or compliments received by the service provider.

In addition to user or customer satisfaction, it is necessary to evaluate the satisfaction of the transportation system provider or manager. For example, many ITS projects are implemented to improve co-ordination between various stakeholders in the transportation arena. In such projects, it is important to measure the satisfaction of the transportation provider to ensure the best use of limited funding. One way to measure the performance of such a project is to survey transportation providers before and after a project was implemented to see if co-ordination was improved. It may also be possible to bring together providers from each of the stakeholder groups to evaluate their satisfaction with the system before and after the implementation of an ITS project.

3.3 Description of ITS measures

ITS is a very broad field. It varies from traffic light control to incident management, from enforcement to passenger information and from driver assistance to intelligent speed limit enforcement. Structuring a broad field like ITS measures is difficult as each structure can be challenged.

ERTICO[1], the European equivalent of ITS America[2], splits ITS measures into three groups:

1. **Intelligent Traffic Management Systems** measure and analyse traffic flow information and take ITS measures to reduce problems. They are consisting of computerised traffic signal control, highway and traffic flow management systems, electronic licensing, incident management systems, electronic toll and pricing, traffic enforcement systems and intelligent speed adaptation.
2. **Intelligent Passenger Information Systems** improve the knowledge base of Customer and consist of passenger information systems, in-vehicle route guidance systems, parking availability guidance systems, digital map database and variable messaging systems.
3. **Intelligent Public Transport Systems** include ITS measures that aim to improve public transport performance. They are consisting of intelligent vehicles, Intelligent Speed Adaptation, transit fleet management systems, transit passenger information systems, electronic payment systems, electronic licensing, transportation demand management systems and public transport priority.

As mentioned in section 3.2, safety, mobility, efficiency, productivity, energy and environment, and customer satisfaction are the benefits internationally identified for ITS measures. The focus of this dissertation is on transportation benefits. It was, therefore, decided to exclude productivity, as it aims to produce economic benefits.

Energy and environmental benefits generally focus on benefits with regards to natural resources and are secondary effects. This study focuses primarily on the impacts of measures. The characterisation of benefits in this dissertation is as follows:

- *Safety*: Safety related ITS measures aim to reduce accidents and dangerous situations,

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[1] www.ertico.com

[2] www.itsa.org

- *Mobility and efficiency*: These measures aim to optimise the use of road capacity, and reduce unnecessary and inefficient driving, and
- *Customer satisfaction*: the provision of information, security etc.

Table 3.1 provides an overview of the ITS identified measures.

Table 3.1 Overview of ITS measures per objective

	Intelligent Traffic Management Systems	**Intelligent Passenger Information Systems**	**Intelligent Public Transport Systems**
Safety	• Variable speed limits • Lane management • Incident management • Warning systems • CCTV cameras • Automatic vehicle identification • Intelligent Speed Adaptation • Weight in motion	• Navigation systems • Parking guidance • Cruise control • Warning systems • Intelligent Speed Adaptation • Black-box systems • Automated vehicle identification • Docking systems • Distance warning	• Fleet management • Navigation systems • Electronic ticketing • CCTV cameras • High-speed ground transportation • Automatic vehicle identification • Intelligent Speed Adaptation • Distance warning
Mobility and Efficiency	• Variable speed limits • Lane management • Incident management • Warning systems • CCTV cameras • Ramp metering • Traffic control • Electronic toll collection • Real-time information • Parking guidance	• Navigation systems • Parking guidance • Cruise control • Warning systems	• Public transport priority • Fleet management • Navigation systems • Electronic ticketing • System integration • High-speed ground transportation • Real-time Information
Customer satisfaction	• CCTV cameras • Lane management • Warning systems • Electronic toll collection • Real-time information • Parking guidance	• Navigation systems • Parking guidance • Real-time information • Electronic toll collection • Docking systems • Warning systems	• Real-time information • System integration • Electronic ticketing • CCTV cameras

3.3.1 Intelligent Traffic Management Systems

Government and road agencies are responsible for the provision of infrastructure and infrastructure related (ITS) systems enhancing road safety, mobility etc. Systems for highways and secondary roads are generally different. Examples of infrastructure related ITS systems are:

- *Variable Speed Limits (VSL)*: Variable Message Signs (VMS) are mostly used to apply VSL on a road. The aim is to reduce the speed before congestion appears, which will result in a more homogenised traffic flow (efficiency),
- *Lane management*: dedicated lanes for trucks, busses and High-Occupancy Vehicles (HOV) are commonly used in the developed world to improve the road system,

- *Incident management*: Incidents have a negative impact on the traffic flow handling of a road. Better incident handling procedures can limit the time factor of an incident. Moreover, predicting the risk of an incident will also help to clear the incident quicker,
- *Warning systems*: These systems are able to provide several types of information (like fog, congestion, incidents etc.). There are several communication systems (i.e. beacon-vehicle or GPS based systems) that can be used for the development of warning systems,
- *CCTV cameras*: Closed Circuit TeleVision (CCTV) cameras take video or photo shots of previously identified situations. The general aim is to 'smoothen' traffic flows. Virtual loops are often used to analyse video material automatically,
- *Automated Vehicle Identification* (AVI): The general trend is that automated vehicle identification is done using tags, which can help law enforcement,
- *Intelligent Speed Adaptation (ISA)*: ISA is a collective name for systems in which the speed of a vehicle is permanently monitored within a certain area. When the vehicle exceeds the speed limit, the speed is automatically adjusted or a warning is provided to the driver,
- *Weight In Motion (WIM)*: These systems are currently used in South Africa, whereby technology assists to check trucks with regards to overloading,
- *Ramp metering:* Ramp metering is a method to limit/regulate the entering of vehicles onto an arterial or highway. Loops in the road are used to measure the flows, and traffic lights let single vehicles through,
- *Traffic control:* Traffic controllers are used to regulate traffic flows at intersections (see also public transport priority),
- *Electronic Toll Collection (ETC)*: From an infrastructure point of view, the aim is to collect fees in an undisruptive way. Pay lanes and road pricing should ideally be realised using ETC,
- *Real-time information systems:* Real-time information systems use data collected by traffic management centres to inform road users of incidents, delays etc., and
- *Parking guidance:* Parking guidance systems, based on navigation systems, provide drivers with information regarding the availability of parking bays.

3.3.2 Intelligent Passenger Information Systems

The international car industry has been adding several ITS systems to private vehicles. These systems focus on safety, enforcement and control, mobility and efficiency, pre- and on-trip information, as well as assist in the realisation of ticketing and pricing systems. It is not attempted to have a complete list of systems, as new systems are developed and added to the market all the time. Nevertheless, table 3.1 provides a broad range of systems on the market. Systems included in private and freight vehicles are:

- *Navigation systems*: Electronic systems that provide road information to the (co)driver,
- *Cruise Control (CC):* Manual systems make sure that the speed limit is not exceeded. Moreover, more intelligent systems are Adaptive Cruise Control (ACC),
- *Warning systems:* Warning systems related to the vehicle include anti-collision systems (using sensors), weather systems (via radio, navigation systems etc.), congestion warning, fuel efficiency (the so called econometer), speed trap

warning (via LCD display or sound), etc. Some of these devices, like congestion and weather warning systems, need real-time information,

- *Black-box systems*: These systems have been used in aviation for many years, but in the road environment the idea is new. The aim is to analyse the vehicle status and warn the driver if problems might occur. A possible application is analysing the status of the truck to be able to warn drivers if the system analysis behaviour indicates that the driver is falling asleep,
- *Automated Vehicle Identification* (AVI): The general trend is that automated vehicle identification is done using tags. The identification feature of a tag can help law enforcement,
- *Docking systems:* Sensors are used to measure the distance of a vehicle to other vehicles or objects. Using docking systems, users are able to park their vehicles more accurately. Moreover, generally, it is possible to park in smaller spaces (parking bay), and
- *Distance warning:* Similar to docking systems, sensors are used to warn drivers of vehicles that they are getting too close to other vehicles. This happens in a longitudinal as well as lateral manner. Warning systems take the distance and vehicle speed into account.

Other Intelligent Passenger Information Systems are: Parking guidance systems, ISA, real-time information systems, ETC (including road pricing).

3.3.3 Intelligent Public Transport Systems

Several systems have been developed and/or are under (further) development to enhance public transport. These systems include:

- *Fleet management*: These systems are based on navigation technology, and feedback link with operators is added. The operator will be able to follow the vehicle, analyse driver behaviour and take steps if behaviour is unsatisfactory,
- *Electronic ticketing*: Electronic ticketing will improve the efficiency of a public transport system (payments are made quicker) and will provide a safer environment (the user ID is available and it will be more difficult for criminals to stay anonymous). Moreover, from a traffic engineering point of view, electronic ticketing provides opportunities to improve the collection of travel demand data,
- *High-speed ground transportation:* These are guided systems that are capable of sustaining operating speeds in excess of 200 km/h. High-speed trains were first used in Japan about 30 years ago. Due to their success in Japan, many European countries started investigating high-speed trains as a viable option (Eastham, 1995),
- *Public Transport Priority (PTP)*: These systems minimise the negative impact of traffic lights for public transport. Many traffic control systems, like the Split, Cycle and Offset Optimiser Technique (SCOOT) system, are able to give public transport priority at intersections. It is, however, necessary that public transport vehicles can be identified (for example via tags),
- *Real-time information*: With regards to public transport, real-time information can be used as a Travel Demand Management (TDM) tool. TDM is finding ways

to influence human behaviour and encourage a shift from private to public transport. ITS systems assist to generate this shift, and

- *System integration*: To enhance the attractiveness of public transport versus the private car (i.e. travel time, waiting time at stops etc.) has to be improved. Car drivers get information about public transport via Variable Message Signs (VMS). PTP will help to improve the travel time. System integration will reduce the waiting times and possibly the number of transfers providing dynamic stop information (using VMS).

Other Intelligent Public Transport Systems include: navigation systems, CCTV cameras in vehicles and transit points, AVI, ISA, distance warning and real-time information.

3.4 How beneficial are ITS systems?

3.4.1 Definition of the research framework

Obviously it is not possible to investigate all ITS systems within this dissertation. Research with regards to Intelligent Passenger Information Systems is ‘controlled’ by the car manufacturing industry. Several systems, such as navigation systems, vehicle tracking systems (automated vehicle identification) and warning systems (including econometers), are commercially available in South Africa. If systems are financially viable, the South African car industry will implement them. It was, therefore, decided to exclude Intelligent Passenger Information Systems from this dissertation.

As described before (section 2.3), the majority of South Africans are dependent on the public transport system, but the quality of this system is mostly poor. It would, therefore, be worthwhile to investigate the benefits of Intelligent Public Transport Systems. Originally, the aim was to conduct a case study in this respect. A system design was established and the Physical Planning Unit at the University of Cape Town agreed to use the so called Jammie Shuttles (campus shuttle service) to conduct an ITS case study. The size and closed access (only University staff and students) of the Jammie Shuttles would have made this system an ideal test case. The aim was to investigate the benefits of a vehicle tracking system as well as a smart card system. During the course of the research it became impossible to find the funds to purchase the required equipment and the idea of a public transport case study had to be abandoned. It was, therefore, decided to focus on Intelligent Traffic Management Systems.

3.4.2 Estimated international ITS benefits

The main focus of this section is to provide an overview of the benefits of ITS based on ex-ante modelling exercises. Studies are mainly European based, although some are from the US.

To provide an impression of the efficiency of ITS measures, data from different studies has been collected and compared. Figure 3.1 summarises the comparison. The actual information is included in appendix A.

Readers must keep in mind that the results of these studies have been obtained using different dynamic models. Moreover, some studies include an increased demand in the future, while others do not. Additionally, the research period of the different studies varies, which influences the findings. Despite these differences, a general impression of the impact of ITS measures can be achieved.

In some cases, vehicle related ITS measures have been included in this overview. The criterion for inclusion was that there must be infrastructure related benefits (i.e. throughput).

In a study carried out by Ludmann (Ludmann et al, 1999), 100% of vehicles were equipped with **Adaptive Cruise Control**. Estimates, using the PELOPS model, were done for highways as well as urban traffic. Two different systems were tested (the second one reacted slightly smoother). The changes in speed and throughput were calculated. The average speed in the first scenario decreased by 13%, while the speed increased by six percent in the second scenario. Both scenarios showed an increase in throughput (12%-14%).

The effect of **Autonomous Adaptive Cruise Control**[3] on speed, travel time and throughput (traffic flow) is minor, in a study by Vanderschuren (Vanderschuren et al, 2000). The estimates were obtained for a highway link, using the microscopic simulation model MIXIC. Despite the minor effects on speed, travel time and throughput, a phenomenal reduction in shock waves was estimated, which is an indication of an improvement of the road safety situation. Another study conducted by VanderWerf (VanderWerf et al, 2002), estimating the effects for a highway with on and off ramps, indicates that more advanced Adaptive Cruise Control (Co-operative Adaptive Cruise Control) will have a major impact on throughput. Twice as many vehicles will be able to use the road if 100% of the vehicles have Co-operative ACC. The study of Marsden (Marsden et al, 2000) indicates that there is an optimal percentage of penetration with ACC. In his modelling exercise for highways, he concludes that optimal penetration is between 10% and 20%. If 40% or more of the vehicles have ACC, the average speed decreases.

Dynamic Road Profiles are applicable to highways. Tampère (1999) found a substantial increase in the capacity of the road (indicated by the throughput). In this study, three traditional highway lanes were replaced by four smaller lanes with lower maximum speed during peak hour. An estimated capacity increase of 30% is very promising. The study done by Stemerding (Stemerding et al, 1999) indicated that the overall throughput increases by about five percent. In this study, the maximum speed decreased from 100 km/h to 70 km/h. The decrease (four percent) in the number of stops is an indication that the road safety situation has improved. Goudappel Coffeng (1997a) investigated different types of Dynamic Road Profiles. In general, a decrease in

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[3] Autonomous Adaptive Cruise Control is the second generation ACC.

travel time was measured (up to 41%). In one case[4], an increase in travel time of 16% was measured.

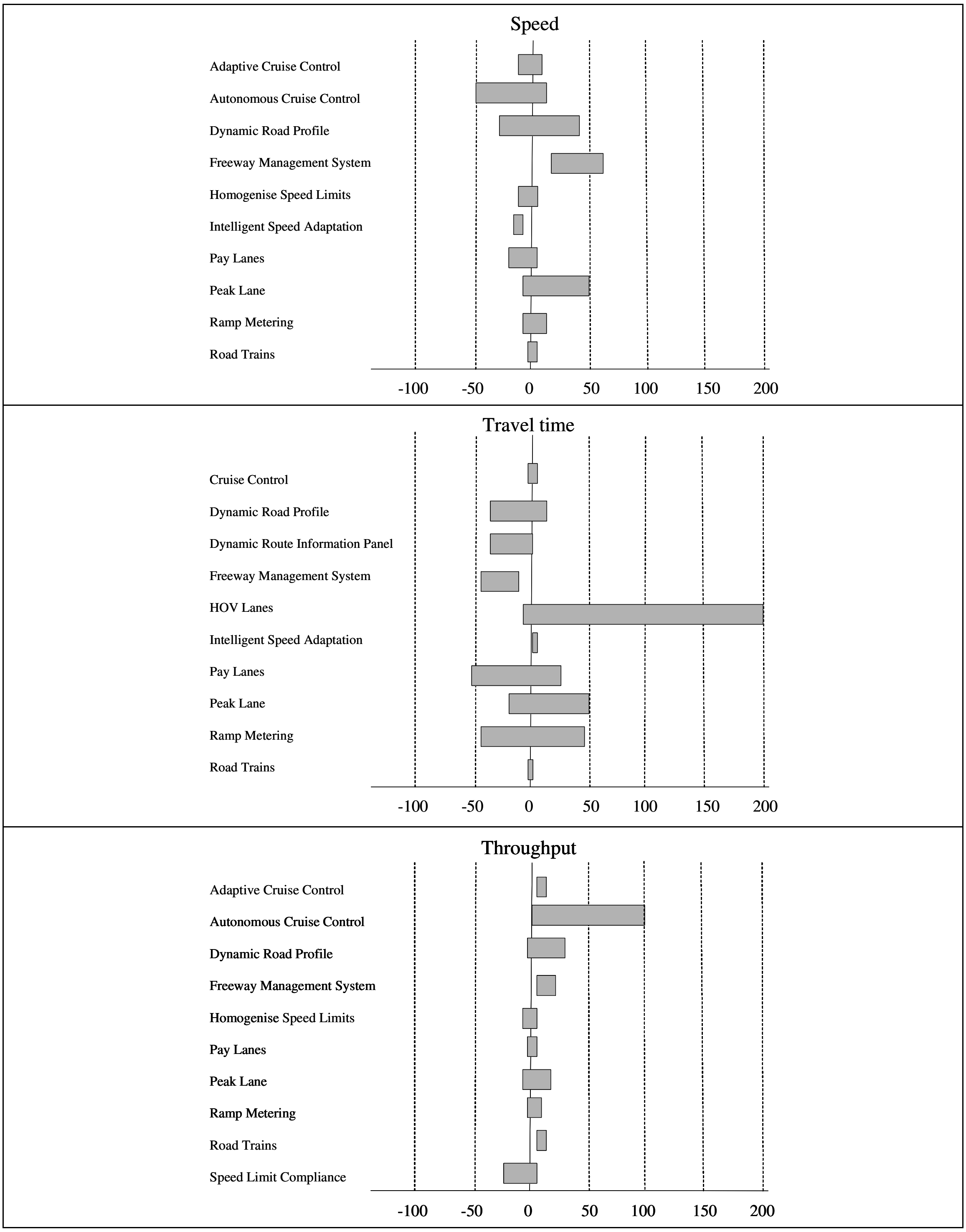

Figure 3.1 Estimated international ITS benefits (%)

Source: Based on 20 international studies[5]

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[4] Six different road sections were investigated.

[5] See also appendix A

Dynamic Route Information Panels are Variable Message Signs (VMS), which inform the driver about congestion ahead, mostly on the highway and/or expected travel times. The study by Van Straaten (2001) shows that these types of VMS reduce the severity of congestion. Average travel times decrease by up to 42%. This result is significant. Although it is unknown how many drivers follow the suggested, less congested route, this study indicates that the percentage is high enough to make a difference.

The effects of a **Freeway Management System** are very promising. Estimated decreases in travel times up to 48% are remarkable. An estimated increase in the capacity of the highway (throughput) of up to 25% is a striking indicator as well (Thomas, 2001). The results partly appear so positive because a Freeway Management System is a combination of measures:

- Variable Message Signs (VMS);
- Advanced mobile information systems, such as in-vehicle monitoring;
- Automatic toll collection or electronic fare payment;
- CCTV security surveillance (incident management) and vehicle identification, and
- Radio reports, aerial patrols and such.

It would have been interesting if the author had split the effects of the mentioned sub-measures. Comparing this package of measures with the Dynamic Route Information Panel, the difference is minimal. The question is whether the extra effort and costs to provide this package of measures is, therefore, justified.

The estimated effect of **High Occupancy Vehicle (HOV) lanes** created on the highway, concentrate on a change in travel time. A travel time reduction of up to eight percent is estimated (Dahlgren, 1998 and Johnston, 1996). Nevertheless, in many instances the travel time, especially for non-HOV vehicles, increases. In the study conducted by Johnston (1996) this increase is up to 200%.

Homogenising via Speed Limits does not always result in more homogenised traffic on a highway system, at least not with the modelled maximum speed limit of 90 km/h (Stemerding et al, 1999). The total throughput in this study decreases by two percent; more traffic is using the secondary road network. Moreover, the number of stops increases, which is negative from a road safety aspect. Analysing the details, the authors are of the opinion that the limits of the software used might also have influenced the results.

The main aim of **Intelligent Speed Adaptation** (ISA) is an improvement in road safety. As it is not possible for drivers to exceed the speed limit in the mandatory system modelled, the average speed of vehicles decreases (34% of the vehicles exceeded the speed limit before the introduction of ISA). The modelling was carried out for a network of highways and a limited number of secondary roads. The changes in total travel time are minor. Although this study (Lui and Tate, 2000) does not provide shockwave information, it is expected that ISA will reduce shockwaves and, therefore, improve the safety situation on the roads.

Pay lanes are dedicated lanes on highways where a toll is collected. The collection process mostly happens electronically. The estimated effects of pay lanes are generally positive. Schoemakers (Schoemakers et al, 2000) find an overall decrease in travel time of 33%. Stemmerding (Stemmerding et al, 1999) find that the decrease is generally for the paying drivers. The non-paying drivers experience an increase in travel time. The effect on the throughput in the study of VanderWerf varies. Both studies focus on highways.

Peak lanes are lanes on the medium of a highway that are only open for traffic during peak hours (could be tidal flow lanes). They are often used in different directions during the morning and evening peak. Peak lanes manage to decrease the congestion risk and keep the flow more homogenised. The total throughput increases by about five percent during peak hour (vehicles currently travelling at other times; Stemerding et al, 1999). The road safety situation improves slightly. Westra and Bosch (2002a) also investigated the effects of peak lanes. They found an overall decrease in travel time on the whole network of about 21%. Nevertheless, on parts of the network an increase (+40%) in travel time was found. Bosch et al (2003) found a throughput that varies from –5% to +6%. This study identifies a high risk of increased travel times (between –9% to +50%).

Ramp metering is the application of traffic controllers on on-ramps to reduce disturbance and shockwaves on a highway. First implemented in Chicago, Detroit and Los Angeles, they have been deployed in at least twenty areas in the United Stated (Pearson et al, 2001). Efficient use of ramp metering can reduce total system travel time, accidents, fuel consumption and vehicular emissions (Chaudhary and Messer, 2000). Many studies determined that proper ramp metering results in a better overall traffic flow during periods of traffic congestion (Chen and Variaya, 2001, Levinson and Zhang, 2006 and Wu, 2001). In a European study by Stemerding (Stemerding et al, 1999) the general outcome of ramp metering is that the throughput does not change (neither on the highway nor on the secondary roads) and the speed increases slightly (eight percent overall). The findings of the Ramp Metering study done by Westra (Westra et al, 2000b) indicate that Ramp Metering can have a positive and negative impact on the travel time. Overall the travel time increases by two percent in the morning peak. In this study, the total travelled distance was also analysed. The distance hardly changes; neither in the morning peak nor in the evening peak. The study from Goudappel Coffeng (1997b) found a six percent decrease in travel time after introducing Ramp Metering. At certain spots congestion can be avoided. Nevertheless, it appears that the amount of traffic in this study is so high that a good level of service on the road cannot be achieved everywhere. A decrease in travel time of up to 48% was calculated in the study of Goudappel Coffeng in 1998. They also found an increase in the throughput by eight percent. All in all the estimated effects of Ramp Metering are very promising.

Road trains are vehicles longer than currently allowed in Europe. The modelling exercises, both for highways, clearly show that freight can be transported using road trains without any negative effects to the speed, travel time or safety of other road users (Hoogvelt et al, 1996). Ludmann (Ludmann et al, 1999) estimates an increase in throughput of between 10% and 14% on a two-way highway. In this study, a fuel consumption reduction of 34% was calculated as well. South Africa currently has major problems with road deterioration due to heavier vehicles and overloading. The introduction of road trains is, therefore, not recommended in this country.

Bonsall (Bonsall et al, 2005) investigated **speed limit compliance on highways**. It was estimated that the throughput generally increases with between 2.9% and 5.7%. Nevertheless, the throughput during off peak, if the speed limit is reduced by 10 km/h, will drop by 24.2%.

The first observation that needs to be made is that modelling studies have focussed on the effects of ITS measures on highways. The selected sections were identified because there were congestion problems.

According to the author, there are two reasons why the focus in on highway systems. Firstly, urban ITS systems, mainly traffic management systems like SCOOT, are optimised in practise. Modelling studies with regards to these systems were carried out during the development phase, over 20 years ago. Moreover, municipalities hardly publish their experiences with urban traffic management systems. Secondly, the focus of studies on highways is due to the complexity of microscopic simulation models, which are needed to simulate ITS measures appropriately (see also chapter four). By reducing the research area, calibration problems etc. can be limited.

Overall it was found that the margin in speed, and more importantly travel time and throughput, is large. **Speed** generally drops, which indicates a safety improvement. In two cases, additional capacity is created by dedicated lanes: for dynamic road profiles and peak lanes the speed increases by almost 45% and more than 15%. The extra lane appears to create additional capacity resulting in higher throughputs and higher speeds with a lower travel time. Obviously, the travel time gains will lead to acceptance by users. In both cases, the higher speeds do not create an unsafe environment. Shockwaves decrease by four percent, which improves the safety situation.

The other exception is the Freeway Management Systems. This ITS measure shows results similar to the dedicated lane cases. Speed and throughput increase, while travel time decreases. The main aspects of the modelled freeway management system are the provision of information and improvement of safety and security. Although no shockwave information is available, better information and special attention to safety will most probably lead to a safer environment.

Travel time is generally reduced (which means a better Level Of Service (LOS) for road users). HOV lanes show a wide range of results. It needs to be kept in mind that the LOS for HOV and Single Occupancy Vehicles (SOV) varies. Generally, the LOS for HOV increases while the LOS for SOV decreases. In many cases this is a policy decision that needs to be made. Unfortunately, it needs to be mentioned that the decrease in LOS for SOV will have a negative effect on user acceptance (and fuel consumption).

Throughput generally shows an increase of about 20%. A conspicuous exception is CACC with a throughput increase of 100%. A negative exception is the speed compliance system that shows a drop of up to 24% (in off peak with a reduced speed limit).

Overall it can be concluded that the modelled ITS measure clearly improves the management of traffic flows on highways and generally leads to a safer road environment.

3.4.3 International measured ITS benefits

The previous section summarised the findings in ex ante studies. This section focuses on the measured benefits of ITS. Data from the US, as well as Europe, appeared to be available.

The US Federal HighWay Administration (FHWA) provides web-based information with regards to the benefits and costs of ITS measures[6]. Unfortunately, the relationship between the reported benefits and costs is unclear. The benefits of a large group of projects are made available in an accessible way. These benefits are summarised in table 3.2.

With regards to the costs, this is not the case. The cost of different realised projects, or parts thereof, are available. Accessibility of this information is less user-friendly and the link between the benefits and costs is lacking. It could be assumed that realised projects must be cost efficient. Other than implementing a pilot study to investigate effects, it would not be in a government's interest to implement non-cost efficient projects.

With regards to **Arterial Management Systems** (AMS) only positive effects were measured. Red-light violations dropped (20%-70%), peak travel time (5%-11%) and fuel consumption (2%-13%) were reduced and the same Level of Service (LOS) was provided with less rolling stock. Moreover, drivers generally felt that they were 'better off'.

Highway Management Systems (HMS) show very positive effects. The number of accidents is reduced by 15% to 50%, injury accidents by 20% to 29% and delays are 46% less. Generally, the public support the measures although throughput decreases by 14%.

The **Transit Management Systems** (TMS) prove to be beneficial. The vehicle on-time performance (9%-23%) and ridership (45%) increases, while the number of complaints has dropped (26%). Moreover, the same LOS is provided with the same amount of rolling stock for more passengers.

The aim of **Incident Management Systems** (IMS) is to provide emergency services quicker access to reduce health problems and clear the roadway faster. There is now information available with regards to the health impacts of the IMS system. The highway closure time has dropped by 55%, while the number of secondary accidents decreased by 40%. There is even a fuel efficiency gain and consumers are thankful.

Emergency Management Systems (EMS) are another way of speeding up the response time of ambulances and other emergency vehicles to decrease the negative health related impact of accidents. The notification time decreased by an incredible 200% to 4 500%. The efficiency of ambulances increased (10%-15%), while the public indicated that they felt more secure (70%-95%).

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[6] www.benefitcost.its.dot.gov

Table 3.2 Measured benefits for infrastructure based ITS measures

Application	Safety	Mobility	Productivity	Efficiency	Energy and environment	Customer Satisfaction
Arterial Management Systems	Red-light violations -20% to -70%	Peak period travel time -5% to -11%	Same LOS with less rolling stock	N/A	Fuel consumption -2% to -13%	72% of drivers feel 'better off'
Freeway Management Systems	Reduction of accident due to ramp metering -15% to -50%	Delay -46%	Variable speed limit reduce injury accidents by -20% to -29% (-US$4 mil)	Throughput -14%	N/A	Support for ramp metering 79% to 86%
Transit Management Systems	N/A	On-time bus performance +9% to +23%	Increase share riding +45% (reduction operating costs US$ 0.5 mil)	Same LOS, more travellers, same rolling stock	N/A	Complaints -26%
Incident Management Systems	Secondary incidents On highways -40%	Highway closure time -55%	Average duration of stall incidents -8minutes (US$ 1.4 mil/year)	N/A	Fuel consumption -4.1 gallons/year	Received hundreds of 'thank you' letters
Emergency Management Systems	Notification time emergency vehicles -200% to -4500%	N/A	Ambulance efficiency +10% to +15%	N/A	N/A	70% to 95% of drivers feel more secure
Electronic Payment Systems	Uncertainty about configuration accidents +48%	Delay -85%	Revenues +12% Handling -US$ 2.7 mil	Capacity +100%	Fuel -1.2 mil/year -0.35 tons of VOC/day -0.056 tons NOx/day	Change of behaviour 20%
Traveller Information	Fatalities -3.2%	Reliability +5% to +16%	Early/late arrivals -40% (US$ 60/user/year)	No significant change	-1.5% NOx -25% VOC	Change of behaviour 66% to 86%
Crash Prevention & Safety	Truck accidents -13% Runaway trucks -24%	Delay -6.7%	N/A	N/A	Noise -97%	Useful tool, 70% of truck drivers 85% of car drivers
Road Operations & Maintenance	55% of trucker alerted	Clearance time -44%	Construction costs - US$4.1mil/year	N/A	N/A	Signs accurate and useful
Road Weather Management	Additional decrease in vehicle speed -26%	N/A	Labour costs - 4 hours/person	N/A	N/A	30% of highway maintenance staff used system
Commercial Vehicle Operations	Out-of-service -250%	Commissioning vehicles 60% faster	Credentialing costs -60% to -75%	N/A	N/A	Hazardous material drivers in favour

Source: www.benefitcost.its.dot.gov

Electronic Payment Systems (EPS) aim to speed up the handling of cash in toll situations, therefore, decreasing delays. In general it was found that delays decrease (85%). Moreover, because of an increase in capacity (100%) more revenue is generated (12%). Unfortunately, an increase of accidents (48%) was measured due to drivers being unfamiliar with the new configuration of toll plazas. Finally, it was found that 20% of customers changed their behaviour resulting in an energy and environmental benefit.

Traveller Information systems aim to improve traffic flows by informing customers. It was found that 66% to 86% of customers change their behaviour, resulting in a reduction of fatalities (3.2%), a more reliable transport system (5%-16%), less early/late arrivals (40%) and a reduction in pollution.

The **Crash Prevention and Safety** system that was implemented for truckers, was seen as a useful tool by 70% of truck and 85% of car drivers. There was a reduction in truck related accidents (13%) and runaway trucks (24%). Moreover, delays (6.7%) and noise levels (97%) decreased.

Road Operations and Maintenance systems show clearance time is decreased (44%) and construction costs reduced. Furthermore, customers find the signs useful.

The **Road Weather Managemen**t systems, warning customers of dangerous weather related situations, have proven to drop the vehicle speed by an additional 26%. Moreover, a drop in labour costs was found.

Commercial Vehicle Operations systems show a safety (250% less out-of-service), mobility (60% faster commissioning of vehicles) and productivity (reduction of credential costs of between 60% and 75%) benefit. Hazardous material drivers appear to be very much in favour of this system.

Although not included in the overview of the FHWA, it needs to be mentioned that the Washington State Department of Transport indicates on their website[7] that about one percent to four percent of drivers will move from single occupancy vehicles to **HOV** vehicles.

In the second version of the ITS Handbook (PIARC, 2004), an overview is provided of **Ramp Metering** in the US. The benefits experienced were:

- An increase in motorway (highway) capacity of between 17% and 25%,
- An increase in speed by between 16% and 62%,
- A reduction of accidents by between 24% and 50% and a reduction of injury accidents by 71%, and
- A reduction of pollution by 15% (CO and HC emissions).

The other measure reported on in the ITS Handbook (PIARC, 2004) is **Adaptive Traffic Signal Control**. The findings based on several implementations in Oakland and Toronto are:

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[7] www.wsdot.wa.gov/HOV/DEc2004EvalReport.htm

- A reduction in travel time by seven to eight percent,
- A reduction in the number of stops by 22%,
- A reduction in CO and HC emissions by four to five percent, and
- A reduction in fuel consumption of six percent.

ITS-UK[8] summarised the British ITS experiences recently. Five case studies were described in detail. Table 3.3 summarises the findings.

In the previous section (section 3.4.2), international modelling exercises generally estimated benefits for the implementation of ITS. The analysis of implemented measures confirms that ITS measures, in the US and Europe, have improved the traffic situation. Moreover, the magnitude of US and European experiences are similar.

The only system that was implemented in the US as well as Europe (UK), is a highway management system. Safety improves by 15% to 50% (US), compared to 28% (UK). In the US, the throughput decreased by 14%, while the M25 showed a 15% increase. Without detailed knowledge of the local situation, it is impossible to explain this difference. In both cases, there is support from the public for the measures, 79% to 86% (US) versus 60% (UK).

Table 3.3 British ITS experiences

	Accessibility	Safety	User acceptance	Efficiency
Glasgow Red Light Camera	N/A	• 67% less fatalities • 14% less injuries • 8% lower speed	N/A	B/C ratio of 3.2
Norfolk Interactive Fibre Optic Signs	N/A	• Speed reduction • Potential fatality reduction 21.5%	• 90% of users think system is a good idea	N/A
Durham Road User Charging	• 10% more pedestrians	N/A	• 70% of users think system is a good idea • 85% of visitors consider the city to be safe	• 90% drop in traffic levels
M25 Controlled Motorway	N/A	• 28% less injuries	• 60% of users believe the system has improved	• 15% increase in throughput
London Congestion Charging	• 30% more cyclists	• Reduced accident level	• 55% of users believe congestion has been reduced • 21% of people think parking is poorer	• 30% less congestion • 14% less journey time

Source: ITS-UK, Intelligent Transport systems in Britain, CD, 2003

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[8] Intelligent Transport systems in Britain, CD published by ITS United Kingdom, November 2003

3.4.4 South African estimates of ITS benefits

The SA Society of Intelligent Transport Systems (SASITS) was founded as a Section 21 Company (not for gain) on 20 March 2001 with eight elected board directors representing the public, private & tertiary education sector. Although there was an interest in ITS before SASITS existed, the focus on ITS has clearly increased since. In the period since 2001, seven authors have reported back on conducted modelling exercises. Figure 3.2 provides a summary of the results (see also appendix B).

In eThekweni the effects of ITS on highways was investigated (**e-Mobility**). An integrated system, including incident management providing incident information and ramp metering, was introduced (Mkhizi and Thomas, 2005). The estimates show a decrease in speed (44%-45%, see appendix B) as well as a decrease in travel time (27%-32%).

Roux and Bester (2002) investigated an **HOV** lane in the Cape Town region. The implementation of an HOV lane does not look as promising. Although a substantial decrease in travel time (76%) and an incredible increase in average speeds (+319) were measured, the throughput (40%) of the highway decreased substantially. Many vehicles apparently were not able to enter the highway. It needs to be mentioned that this site is further investigated in this thesis.

De Jongh-Schreuder (De Jongh-Schreuder and Venter, 2005) investigated an **Interchange Control** system (kind of ramp metering) at the junction where the two national roads meet. The aim was to optimise traffic flows on the junction. Generally, a decrease in travel time (1%-19%) and an increase in throughput (2%-37%) were estimated. After manual changes to the settings, the decrease in travel time was between 17% and 46%, while the increase in throughput rose to between three percent and 54% (see appendix B).

A **Public Transport Priority** system was investigated for the Soweto-Parktown corridor (Beer, de et all, 2005). A wide range in results was found. An upgrade of signalised intersections generally did not make the service level good enough to cope with future demand. Travel times for private cars increased by eight percent, while the LOS for public transport increased by up to 20%. Priority for public transport showed to be helpful. A decrease in travel time for private cars (20%), as well as public transport (29%), was estimated. If public transport services were extended to the Soweto-Parktown area, the LOS for private cars, as well as public transport, would be similar as in the current situation. Obviously, the number of vehicles would have increased. As mentioned before, in South Africa the majority of people are dependent on public transport. An additional benefit of improving public transport services is poverty alleviation, as the (urban) poor will have extended access to economic opportunities.

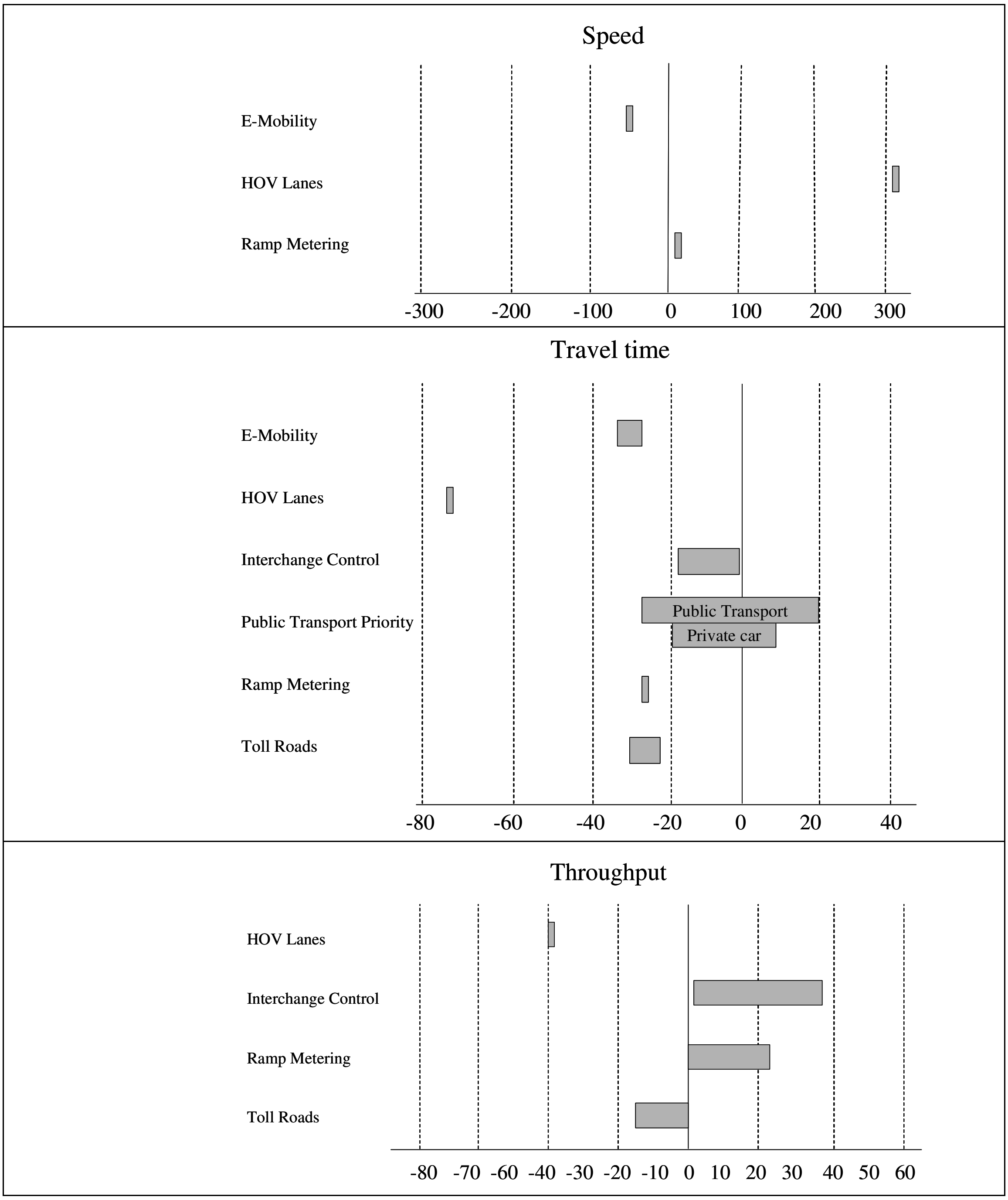

Figure 3.2 National ITS benefits (percentage)

Source: Based on seven international studies[9]

The first published estimate of the benefits of **Ramp Metering** in South Africa (Cloete, 2002) also indicate an increase in speed (+13%) and a decrease in travel time (-28%). In this study, the transferability of developed world models was not investigated. As driver behaviour in the developing world is not necessarily the same as in developed countries, the estimated effects might, therefore, not be completely accurate.

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[9] See also appendix B

As mentioned before, in the developing world the introduction of **Toll Roads** is seen as a means to generate additional revenue. South Africa has already implemented toll plazas. The interest in electronic toll collection is, therefore, obvious. Two authors have reported on toll studies conducted. Oberholzer (Oberholzer et al, 2001) finds that the introduction of toll collection on highways will change driver behaviour. Some drivers will use an alternative route, which will decrease the intensities on highways (decreases up to 16%). Due to this change in behaviour, travel time will decrease by between 23% and 31% (Oberholzer et al, 2001). Venter (Venter et al, 2001), the other author, also finds a demand decrease in the toll road (up to 85%).

Based on the seven studies published with regards to South African ITS systems, the following conclusions can be drawn. A general reduction in travel time was found. The only exception was the public transport priority systems. Obviously, a thorough analysis needs to be undertaken to make sure that public transport priority systems work optimally. Furthermore, interchange control and ramp metering predicts an increase in throughput. HOV lanes show a decrease in throughput due to the reduction in capacity offered. In the case of toll roads, a decrease in throughput is measured due to a reduction in the demand. Some travellers decide to take the non-tolled, but longer road.

Road managers should be concerned about the findings with regards to toll roads and HOV lanes. The diversion of traffic due to toll roads often happens through small towns that cannot cope with the additional traffic. Moreover, diversion of heavy traffic causes additional damage to roads that were not designed to accommodate these vehicles.

HOV lanes aim to generate a shift in the demand from Single Occupancy Vehicles to HOV and public transport. If this shift does not occur, the reduction of capacity in congested areas causes unwanted effects. Vehicles will be ‘trapped’ in the suburbs, not being able to enter the highway, causing an unliveable environment for residents.

3.4.5 Current ITS projects in South Africa

No information with regards to measured benefits has been published in South Africa. Andersen (2004) provides an overview of current IST projects. His overview includes:

- *Ben Schoeman ITS pilot project*
  The South African National Roads Agency Ltd (SANRAL) has embarked on a pilot project to manage congestion and incidents along the Ben Schoeman Highway, thereby also addressing road safety. The project includes the establishment of a Network Management Centre, and the utilisation of technology that includes Variable Message Signs, CCTV camera systems, the establishment of a fibre optic communications backbone, and various traffic detectors,
- *Urban Traffic Control Centres*
  UTC systems are in different stages of development, with well established systems and integrated database management procedures already in place in Cape Town and Durban. Johannesburg is currently implementing an extensive system,
- *Electronic ticketing*
  Pilot project on the public transport system in Cape Town,
- *Automatic Vehicle Location*

Pilot project on inner-city buses in Cape Town,

- *Electronic Toll Collection*
  Electronic toll collection and inter-operability between toll systems,
- *Emergency Management Systems*
  Established systems such as the Huguenot tunnel in the Western Cape and the emergency management system for the Cape Argus Cycle Tour, and
- *Electronic Licensing*
  A unique opportunity for making a difference in vehicle related crime, as well as other related uses. The concept is that each licensed vehicle in South Africa will be identifiable through a tag or electronic means.

Although technological applications are widely recognised as contributing towards solving transportation problems, it is clear that the ITS environment is still extremely fragile. It is important that a National ITS Strategy be put in place, to provide a framework for future development in a co-ordinated and effective way. The ITS standards committee, recently established under the auspices of Standards South Africa (STANSA), has an important role to play in supporting and creating opportunities for the local ITS industry. However, support is required from government to ensure its sustainability (Andersen, 2004).

3.5 Economic evaluation of Intelligent Transport Systems

3.5.1 What do international economic studies indicate?

As indicated before, information about the costs of ITS measures is very limited. Two papers were found describing the applicability of multicriteria-analysis (Brunker, de et al, 2004) and the application and limitations of cost-benefit assessment (Stevens, 2004) for ITS. Unfortunately, both papers offer a theoretical description of how to carry out the assessment and do not provide any empirical results on actual projects. The only international source reporting benefit/cost ratios is the ITS Handbook (PIARC, 1999).

Table 3.4 International benefit costs ratios

ITS project	B/C ratio	Comment
Incident detection	3.8	Repaying investment in a year
Intersectional Signal Control	3.4	Repaying investment in a few months
Area Traffic Control	7.6	Extending existing technology to adjacent towns
Parking management	1.7	Even for stand-alone applications
Emergency vehicle priority	0	No cost saving but faster response time (golden hour) meant fewer people required major treatment
Weight in motion	1.8	Time saving for heavy vehicles

Source PIARC, 1999

The ratio of selected ITS applications in a number of countries have been reported to be in the order of two to eight, with the higher figures relating to urban scenarios (see table 3.4). The implementation of ITS applications, included by PIARC, aim to obtain a capacity, safety, environmental and financial benefit. Moreover, where possible, user satisfaction is included.

Thomas (2001) compares road building (the expansion of a three-lane highway to a four-lane highway) with the implementation of a highway management system. The comparison is based on US averages. Thomas (2001) indicates that an increase of 15% in capacity can be gained by investing R0.5-million (about €55 500) per kilometre road in a highway management system, versus an investment of R5-million (about €555 000) per kilometre road for an additional lane to gain a 33% increase in capacity.

3.5.2 South African economic lessons with regards to ITS

De Jongh-Schreuder (De Jongh-Schreuder and Venter, 2005) reports that the benefit/cost ratio of an automated system is substantially higher than the benefit/cost ratio of the manual system (40.4 versus 140.4). The reason for this difference is the lower costs (mainly maintenance and user costs). As described in section 3.3.4, the volume and travel time gains are higher with a manual implementation.

The Department of Civil Engineering at the University of Cape Town, in South Africa, undertook a cost-benefit analysis comparing the introduction of ITS versus adding more infrastructure. The geographical focus of the study was Cape Town.

In the analysis, the construction and maintenance costs associated with both the building of a new road and the implementation of ITS were considered (Carolus, 2002). The ITS measures were:

1. Driver information and warning signs (VMS). These are installed to inform drivers about accidents ahead, the speed to be travelled on a stretch of road and information about weather conditions e.g. fog. These messages can be altered so that the information can be optimised.
2. CCTV surveillance cameras, which monitor the situation on the roads, provide real-time images of what is happening. These cameras also allow for the collection of traffic data.
3. Incident detection equipment. This includes installing video image processors with cameras and allows for the detection of any incidents. Moreover, fog and weather stations will be placed in strategic places where weather adversely affects the flow of traffic.
4. SOS equipment, which is already installed along the road. This allows commuters to contact emergency services if need be.
5. The control room is basically the brain of the operation. All information collected will go to this area. All cameras and VMS will be linked up to the control room via underground cabling.

Table 3.5 summarises the costs and benefits (in monetary terms), calculated over a 25-year period. It needs to be mentioned that no safety changes are expected if a lane is added. Moreover, special running and insurance costs only occur if an ITS system is implemented. The addition of a lane will lead to a short term reduction of vehicles per lane and, therefore, a travel time benefit. In the long run, this reduction will vanish due to induced traffic.

Table 3.5 Summary of CBA Results (*R 1000, index 2002)

	Adding a lane	ITS
Construction Costs	29 540	30 000
Maintenance Costs	6 506	27 377
Safety Costs (Accidents)		3 263
Pollution Costs	93 529	
Travel Time	176 221	154 559
Running Costs		9 168
Insurance Costs		9 168
Total (NPV)	46 647	98 612
B/C	2.29	2.67

Source: Carolus, 2002

The implementation of an incident management system will have safety, as well as travel time benefits, as the road is cleared faster. Moreover, the implementation of an ITS system should lead to a slight decrease in travel time because of improved efficiency. Unfortunately, it is not possible to quantify, so this benefit is not included in the calculations.

The Net Present Value (NPV) for both the construction of a new lane, as well as the implementation of an ITS system, were both positive - R46.6-million and R98.6-million respectively (8 Rand equals 1 Euro). From this it can be seen that ITS provides a larger benefit to society than roads do. Furthermore, the benefit/cost ratio for ITS is also higher at 2.67. Therefore, in both instances, ITS provides a greater benefit to society. For this reason, ITS may be regarded as a feasible option (Carolus, 2002).

It was found that both ITS, and the provision of a new lane, offer road users substantial benefits. Nevertheless, ITS provides the most benefits in that both the NPV and the benefit/cost ratio are higher.

Based on the findings for the calculated South African case, and the values obtained from the cost-benefit analysis, Carolus (2002) recommends that to cope with the current situation of increased traffic growth, ITS should be introduced to increase road capacity by means other than road building.

In this example, it is clear that ITS are cost-efficient within the South African context. Moreover, the author believes that the maintenance costs of ITS might be overestimated. The results would then be even more promising if the maintenance costs are adapted.

3.6 Résumé

International, as well as South African, sources report a wide range of ITS benefits. Although not in all cases, the general trends were beneficial. Internationally, a drop in speed, a drop in travel time and an increase in throughput were generally found. In South Africa, a general reduction in travel time was found. Throughput result varied; interchange control and ramp metering show an increase in throughput up to almost 40% and HOV lanes and toll roads show a decrease in throughput due to a reduction in the demand of over 20%.

In South Africa, the estimated margins (width of the bars in figures 3.1 and 3.2) for the different ITS measures are generally less (the reader should note that the scales of the different figures vary). An explanation could be that all measures are investigated in one (maximal two) study. Internationally, up to five studies contribute to the margins. Therefore, it can be concluded that estimated benefits in different studies vary substantially.

Although some are negative, in most cases a positive benefit is estimated/measured. Moreover, the economic evaluations of ITS measures all show a positive benefit/cost ratio. One South African study estimates a benefit/cost ratio for the ITS measure that is 100 points higher than the manual implementation of the same measure (De Jongh-Schreuder and Venter, 2005). Even though labour costs are generally low, automating the system is the best option.

ITS systems have the potential to improve mobility and accessibility in South Africa. Improved mobility and accessibility will create economic opportunities for the poor. Moreover, the start of a South African ITS industry would contribute to job creation. It can, therefore, be concluded that on top of transport related benefits, ITS will contribute to poverty alleviation.

Chapter 4
Modelling Traffic Flows

The aim of this chapter is to identify the simulation model that can be used to perform an ex ante evaluation of the effects of ITS measures. ITS systems arose out of the notion that demand-driven planning is not sustainable. Previously, new roads or lanes were built as a reaction to growing demand. ITS measures are meant to improve safety, mobility, efficiency, the environment and customer services (see also chapter three). Models used to assess the change in these criteria, therefore, need to include tactical and operational choices (see also section 4.2) of drivers, such as: their trip planning, route choices, longitudinal and lateral driving behaviour, as well as traffic control systems. Moreover, it has proven to be an advantage to apply models that have been used and tested before.

To be able to analyse the changes due to the introduction of ITS measures, every detail of the traffic flows, vehicle interaction and driver choices need to be known. The aim of this chapter is to answer the following question:

- Is it possible to use developed world models to investigate ITS measures in South Africa?

This chapter starts with some background on modelling (4.1), followed by a section (4.2) describing the level of detail that is included in simulation models. Section 4.3, thereafter, provides modelling principles, followed by a comparison of available models (4.4). The final selection of a model that will be used in this dissertation is described in section 4.5, followed by a résumé of the findings in this chapter.

4.1 Background

Urban transport planning started in the United States in the 1950s with the Detroit and Chicago Transport Studies, and was used to inform decision makers on the transportation system. Urban transport planning analyses the transport system, gives forecasts on future performance of the system and suggests measures to improve this performance in order to meet the desired level.

Transportation modelling is used to support decision making in the transport planning process: decisions on the future development and management of transportation systems, especially in urban areas. Traditionally, models were used as part of an overall transportation planning process which involves a forecast of travel patterns (15 to 25 years) in the future and an attempt to develop a future transportation system that will work effectively. The approach in traditional planning was to predict the demand and provide the needed supply (predict and provide).

As it is generated by the desire to join in activities and not by the desire just to travel, demand for travel is actually a derived demand. The transportation system provides a physical connection (supply) between activities. Traditional models, therefore, use factors influencing activity patterns (i.e. travel time and costs) to describe current demands, as well as predict changes due to planned modifications in the supply (i.e. building a new road).

Over the past couple of years, the planning focus has broadened. The new aim is to utilise the existing infrastructure (supply) optimally. ITS systems have proven that they are able to assist. The requirements with regards to transportation models have, therefore, changed. Traffic flows need to be described in a detailed, dynamic way, taking vehicle interaction into account.

This chapter provides an overview of the type of transport models, the theoretical background, a summary with regards to available micro simulation models and an introduction to Paramics.

4.2 Level of detail of the models

Road users make different types of choices (strategic, tactical and operational) at various moments in times. Strategic choices, such as purchasing a vehicle or making a trip, are made (long) before the road user enters the public space. Tactical decisions, such as the departure time or route choice, are generally made as the trip starts. Some tactical decisions, such as the route choice, may be changed during the trip due to information that becomes available (i.e. congestion). Operational choices, such as accelerating, decelerating, lane changes etc., are constantly made during the trip.

Decision makers operate on different levels. Traditionally, middle- to long-term decision making was required. Based on that planning horizon, the four-step model (the traditional macroscopic model) was developed (see also section 4.3). Over the years, the planning horizon of decision makers changed; more strategic decisions (like changing fuel levies) were required. Tailor-made sketch planning models have been developed for that purpose. On the other hand, there has been an increasing awareness that the predict-and-provide philosophy is not sustainable. Ways to utilise existing capacity in a better manner is one of the new aims. ITS systems are one of the types of measures that is explored, needing real-time or short-term models. Figure 4.1 provides an overview of the type of models available.

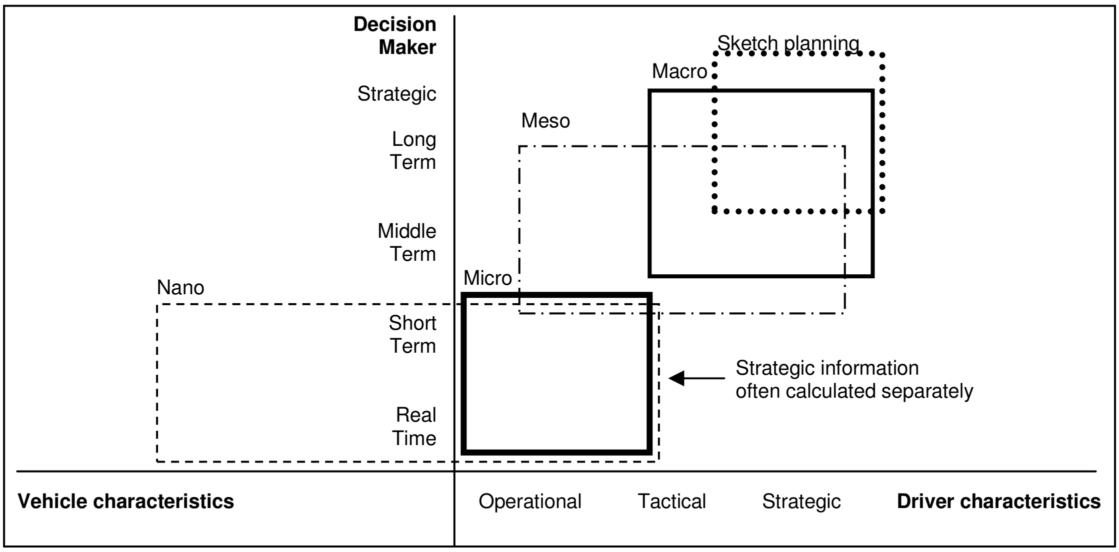

Figure 4.1 Trade-offs between the decision horizon and model characteristics

Based on the flow and traffic dynamics representation, transport models can be divided into five types:

- **Sketch planning models** are, although based on the four-step transport model theory, tailor made for specific questions. In general, a higher aggregation level is chosen. Moreover, often one or more steps are eliminated. Examples of strategic models are the Mobility Explorer (Maarseveen et al, 1987) and WOLOCAS (Clerx and de Vries, 1990). The Mobility Explorer uses overall characteristics (i.e. mobility per population group, car parc and GDP) to predict long-term mobility trends. This sketch-planning model excludes the assignment step. WOLOCAS includes socio-economic and transport system data and uses the first three steps of the four-step model in a specific way to calculate additional trips from a potential settlement. WOLOCAS does not calculate a full OD-matrix, but only additional trips for one cell. As mentioned, the aim of sketch-planning models is to assist policy makers to make strategic decisions (long term) and estimate the overall (often provincial or national) effects. Sketch-planning models are static in nature.
- **Macroscopic models** are based on the four-step transport model. Individual vehicles are not recognised in macroscopic models. The network representation is based on links, notes and attributes. Aspects, such as traffic controllers, are included as a note delay. Common outputs include: link volumes, average speed contours, total delays, total travel times and aggregated fuel consumption/pollution statistics. Outputs are generated for the average peak hour or work day. Changes of traffic flows in time are not included in these models. Macroscopic models are static.
- **Mesoscopic models** include a representation of individual vehicles (or small ‘packages’ of vehicles with similar characteristics). Traffic dynamics are based on fluid approximation and queuing theories. The network representation is link and lane based (often for a corridor). Traffic control systems are detailed models based on aggregated capacity equivalents. Mesoscopic models are continuous in space (vehicles theoretically could queue on top of each other) and discrete in

time (the OD-matrix is separated in small chunks; often 15-minute periods). Mesoscopic models are often referred to as semi-dynamic as they include time aspects and are, therefore, able to make a rough estimate with regards to congestion. Nevertheless, the main calculation features are static.

- **Microscopic models** include a representation of individual vehicles and traffic dynamics through vehicle interaction and movement. Driver behaviour is included in a more detailed way (often via driver classes). Departure times of vehicles are available for every one to five minutes. During every calculation time step (e.g. 0.1 sec), the position of all vehicles in the network is calculated. The outputs provide possibilities to follow vehicles, identify shock waves etc. Strategic driver information is often not included in microscopic models. Information, mostly the OD-matrix from other models (mesoscopic or macroscopic), is used as a starting point. Microscopic models are dynamic.
- **Nanoscopic models** are micro-simulation models that also include vehicle dynamics, such as turning radius and acceleration power. Nanoscopic models are developed for situations where microscopic models are not detailed enough. Many nanoscopic models are tailor made by car manufacturers. Nanoscopic models are also dynamic.

Due to the specific features, the models mentioned are often used for different geographical scales. Sketch-planning models have been developed to calculate national, provincial or metropole-wide changes. Macroscopic models were developed for main road networks (highway systems and other primary roads). Mesoscopic models are mostly used for corridors and include, as mentioned, traffic controller calculations, as well as secondary roads. Microscopic and nanoscopic models are generally used for any type of road or corridor where knowledge of the interaction of vehicles is needed. Generally, the research area will be smaller than for macroscopic and mesoscopic models.

4.3 Modelling principles

Years of experimentation and development have resulted in a general structure, which has been called the classic transport model. It resulted from practice in the 1960s and has remained more or less unaltered, despite major improvements in modelling techniques in the 1970s and 1980s (Ortúzar and Willumsen, 1994).

At the outset it may be desirable to define certain terms (Davinroy et al, 1963):

- *Trip generation*: the determination of the number of trips associated with an area of land or other generating unit.
- *Trip distribution*: the determination of the interchange of a given number of trips among land areas in a region.
- *Modal split*: the division of trips between alternative modes of transport.
- *Trip assignment*: the allocation of traffic flows to the routes available between the origin and destination of a trip.

The classic transport model (macroscopic model) is presented as a sequence of four sub-models (trip generation, trip distribution, modal split and assignment). However, travel decisions are rarely taken in this sequence. A contemporary view is that the location of each sub-model in the sequence depends on the form of utility function assumed to govern travel choices.

The need to investigate congestion (and other modern life) problems, has added the requirement to model time effects and individual travel choices to the classic transport model. In the late 80s and early 90s, several models were developed to do so. Models adding (some) dynamics to the classic four-step model, have added disaggregate travel-choice models for individuals rather than for households or zones, as well as driver behaviour at vehicle level.

In the case of mesoscopic models, an attempt is made to add time in a semi-dynamic way using the theory of static model. Generally, the OD-matrix is split between different departure time matrices. This provides an opportunity to obtain a rough idea of congestion problems. Microscopic models, on the other hand, have improved the assignment by making it completely dynamic. Driver choices are modelled, in small time steps, taking vehicle interactions into account. Nanoscopic models (see also figure 4.1), operate on the same level as microscopic models, but add vehicle characteristics.

It can be concluded that the assessment of the effects of ITS systems requires the modelling of longitudinal and lateral behaviour of vehicles. Sections 4.3.1 and 4.3.2 will describe the theory.

4.3.1 Longitudinal driving behaviour

Cumming (1963) categorised the various sub-tasks that are involved in the overall driving task and paralleled the driver’s role as an information processor (Rothery, 1992). To model ITS systems requires the modelling of longitudinal (car following) and lateral behaviour of vehicles.

In car following, inertia also provides direct feedback data to the driver, which is proportional to the acceleration of the vehicle. Inertia also has a smoothing effect on the performance requirements of the operator, since the large masses and limited output of drive-trains eliminate high frequency components of the task.

Car following models have not explicitly attempted to take all of these factors into account. The approach that is used assumes that a stimulus-response relationship exists that describes, at least phenomenologically, the control process of a driver-vehicle unit. The stimulus-response equation expresses the concept that a driver of a vehicle responds to a given stimulus according to a relation (Rothery, 1992):

$$Response = \lambda\ Stimulus \qquad (4.1)$$

Where:
λ is a proportionality factor.

Stimulus is composed of many factors: speed, relative speed, inter-vehicle spacing, accelerations, vehicle performance, driver thresholds (i.e. alertness, aggression) etc.

What is generally assumed in car following modelling is that a driver attempts to: (a) keep up with the vehicle ahead and (b) avoid collisions.

These two elements can be accomplished if the driver maintains a small average relative speed, U_{rel} over short time periods, so that δt is kept small (Rothery, 1992).

$$AVE\ (U_l - U_f) = AVE\ (U_{rel})\ \frac{1}{\delta t} \int_{t-\delta t/2}^{t+\delta t/2} U_{rel}\,(t)dt \tag{4.2}$$

Where:
U_l is the speed of the leading vehicle.
U_f is the speed of the following vehicle.
U_{rel} is the relative speed between a lead and following vehicle.
δ is short finite time period.

This ensures that collision times are kept large and inter-vehicle spacing would not appreciably increase during the time period δt (Rothery, 1992).

$$t_c = \frac{S(t)}{U_{rel}} \tag{4.3}$$

Where:
S(t) is the inter-vehicle space.
t_c is the collision time.

The duration of δt will depend in part on alertness and the ability to estimate quantities, such as spacing, relative speed and the level of information required for the driver to assess the situation to a tolerable probability level (e.g. the probability of detecting the relative movement of an object, in this case the lead vehicle). It can also be expressed as a function of the perception time (Rothery, 1992).

Based on the driver characteristics, the relative speed should be integrated over time to reflect the recent time history of events, i.e. the stimulus function should have the form of function 4.4 and be generalised so that the stimulus at a given time t, depends on the weighted sum of all earlier values of relative speed.

$$AVE\ (U_l - U_f) = AVE\ (U_{rel}) = \int_{t-\delta t/2}^{t+\delta t/2} \sigma\,(t - t^{1})\ U_{rel}\,(t^{1})\ dt \tag{4.4}$$

Where:
σ (t) is a weighting function.

This function reflects a driver's estimation, evaluation and processing of earlier information (Chandler et al, 1958). The driver weights past and present information and responds at some future time (Rothery, 1992).

4.3.2 Lateral driving behaviour

Gap acceptance and lane changing are the main aspects with regards to the modelling of lateral driving behaviour. Gap acceptance with regards to overtaking generally estimates if the space available in the bordering lane is enough for the vehicle to move into and back. The required space is dependent on the characteristics of the driver, the vehicle and the road. The available space depends on the characteristics of the vehicles in the bordering lane (might be oncoming) and the vehicle in front. Drivers have to perceive all these characteristics, process them and come to a decision.

Humans differ in perception capabilities, e.g. the ability to estimate distances can vary substantially between persons, and they differ in the acceptation of risk. The total acceptance process depends on many factors, of which only a subset is observable. This has lead to the introduction of stochastic models (Hoogendoorn et al, undated).

The modelling of gap acceptance is done in several ways. Possible components included are the mean gap, the critical gap, the offered gap, the accepted gap, the acceleration gap and the rejected gap. For the modelling of these gaps, a distribution is applied. An example of the distributions is provided in table 4.1.

Table 4.1 Distribution of the gap acceptance indicators

Main gap (class)	Distribution critical gap	Number of offered gaps	Number of accepted gaps	Distribution of accepted gaps	Number of rejected gaps	Distribution of rejected gaps
5	0.00	0	0	0.00	0	0.00
7	0.00	30	0	0.00	30	0.50
9	0.33	30	10	0.11	20	0.83
11	0.67	30	20	0.33	10	1.00
13	1.00	30	30	0.66	0	1.00
15	1.00	30	30	1.00	0	1.00
Sum		150	90		60	

Source: Brilon et al, 1997

Mandatory lane changes, desired lane changes and overtaking movements are generally included in lane-changing models (see figure 4.2). The desired lane change between cross-sections a and b is carried out in order to get into a better starting position for the mandatory lane change between cross-sections b and c. A driver is prepared to accept a higher risk at a mandatory lane change than at a desired lane change (Hoogendoorn et al, undated).

An overtaking, see figure 4.3, will primarily be carried out to maintain the desired speed or to deviate less from it. The overtaking consists of two parts: a lane change to the left and a lane change to the right (assuming that driving takes place on the right-hand side). These are more or less independent manoeuvres (Hoogendoorn et al, undated).

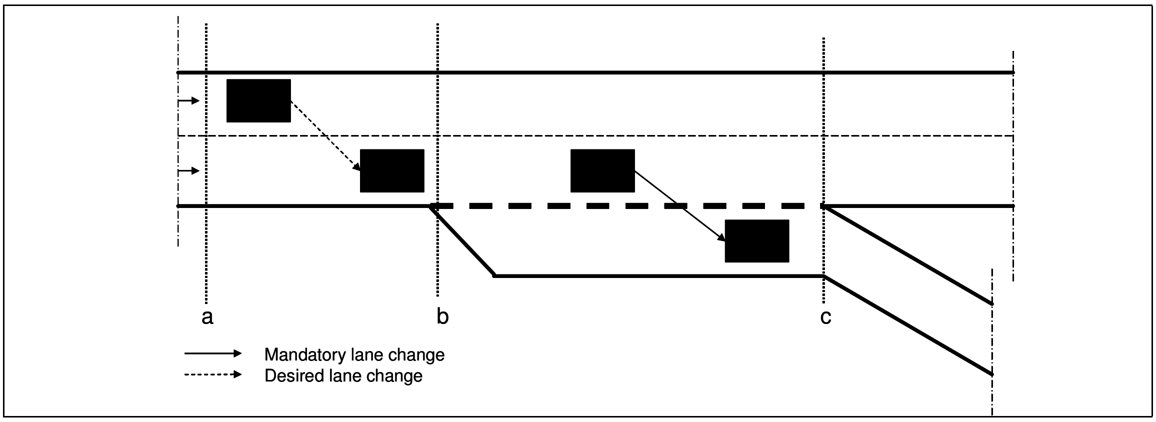

Figure 4.2 *Mandatory and desired lane change*
Source: Hoogendoorn et al, undated

As mentioned, nanoscopic models add vehicle characteristics to the dynamics included in microscopic models. These vehicle characteristics are, for example, the way the vehicle reacts in a curve. For the aim of this study, it is not necessary to add vehicle characteristics. Nanoscopic models are, therefore, not discussed any further in this thesis.

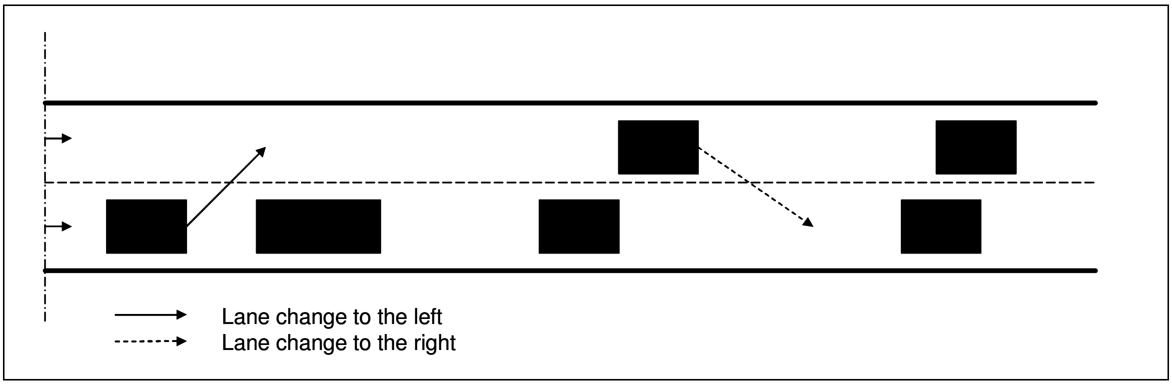

Figure 4.3 *Lane changes at an overtaking*
Source: Hoogendoorn et al, undated

4.4 Comparison of commercially available models

During a European study, researchers were asked to identify which type of ITS measures should be included in modern (microscopic) models (Hugosson, et al, 1997). The results are shown in figure 4.4. In total, 16 measures were identified. The inclusion of traffic signals, detectors and priority for public transport, were considered most important, closely followed by ramp metering, VMS systems, incident management, dynamic route guidance and motorway flow control.

One of the widely used (over 700 locations) macroscopic models, EMME/2[1], has tried to adapt to the new requirements for modelling. Aspects, such as short- and long-term changes in transportation services, environmental impact and energy consumption,

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[1] http://www.inro.ca/en/products/emme2/e2brengl.pdf

traffic restrictions or privileges (for example trucks, HOV lanes and toll roads on an urban, regional or national level) are included.

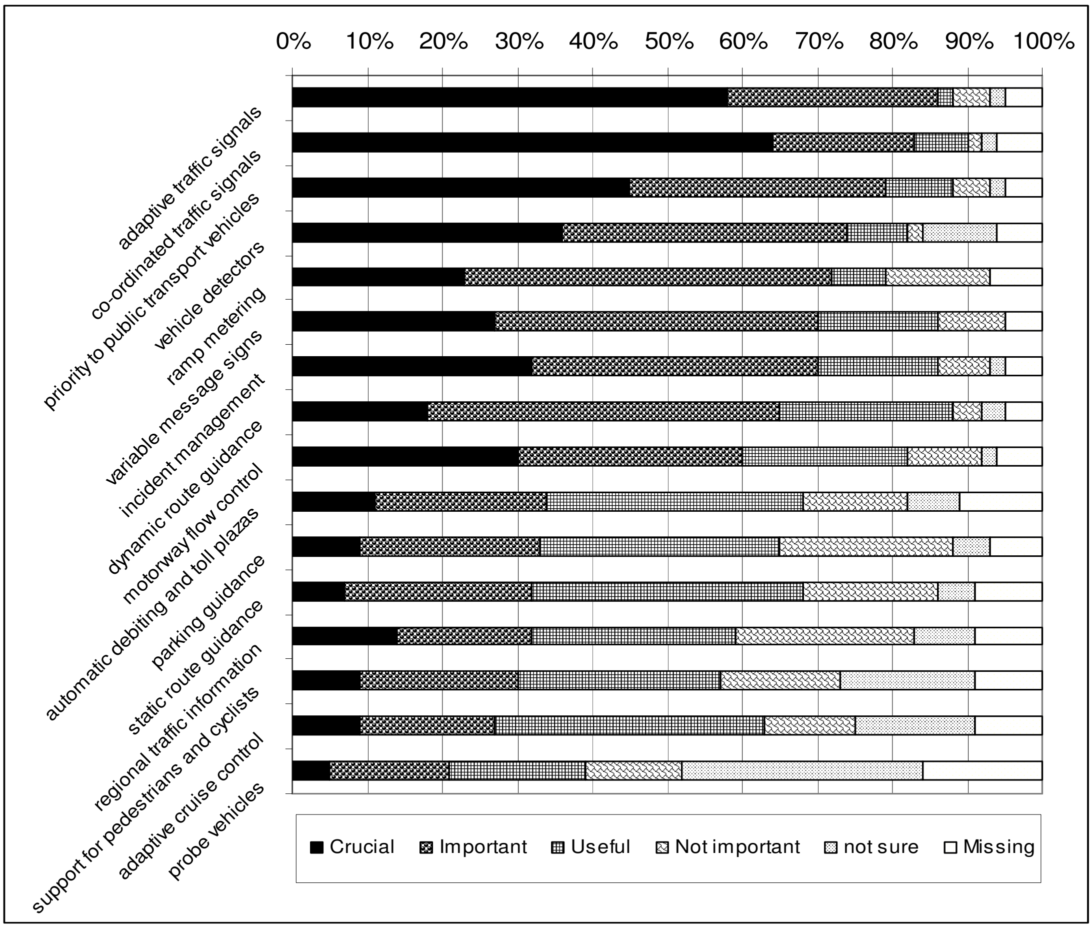

Figure 4.4 Overview of reported ITS-requirements for simulation tools (n=44)
Source: Hugosson, et al, 1997

Mesoscopic and microscopic simulation models, in which the dynamic behaviour of individual agents is explicitly simulated over both time and space to generate aggregate system behaviour, has been applied with increasing frequency over the past decade or more in the field of transportation systems analysis. Perhaps the best developed application is in the area of transportation network simulation models, in which a number of operational (and often commercially supplied) software packages exist, which model second-by-second operations of individual road and/or transit vehicles over very high fidelity representations of urban transportation networks (Miller et al, 2004). Examples (but a far from complete list) of such models include TRANSIMS (Barrett et al, 1995), Paramics (Quadstone, 2002), INTEGRATION (Aerde, van and Yager, 1988a and Aerde, van and Yager, 1988b), DYNASMART (Hu and Mahmassani, 1995 and Mahmassani et al., 1994), DynaMIT (Ben-Akiva et al., 1998 and Ben-Akiva et al., 1999) and VISSIM (PTV, undated).

Subsequently, much research has focussed on the comparison of various ITS measures using non-traditional models (mesoscopic and microscopic simulation models). A summary table of work done by a European consortium (Schmidt and Lind, 1999) is presented in Table 4.2.

Table 4.2 ITS measures available in different simulation models

Measure	CORSIM	AIMSUN2	INTEGRATION	CONTRAM-I	EMME/2
Adaptive Urban Traffic Control	Some US features could be used for Swedish conditions. *SCORE: 1*	Some good features, DLL could be used for truly VA control. *SCORE: 4*	As for AIMSUN2 but with possible external interface. *SCORE: 3*	No explicit modelling. Delay impact as input. *SCORE: 2*	No explicit modelling. Network effects if combined with microscopic model? *SCORE: 2*
Motorway Flow Control	Lane blockage, but not MCS, could be modelled. *SCORE: 2*	Could be realised, but not to the level of safety indicators. *SCORE: 3*	Very good, without the need for explicit modelling. *SCORE: 4*	New V/D function needed. Bad queuing representation need. *SCORE: 2*	No queuing representation. *SCORE: 1*
Incident management	By changing incident duration. No rubbernecking effects. *SCORE: 3*	By changing incident duration. No rubbernecking effects. *SCORE: 4*	By changing incident duration. No rubbernecking effects. *SCORE: 4*	By changing capacity, incl. Rubbernecking effects. *SCORE: 3*	By changing capacities and splitting O/D, but no dynamics. *SCORE: 1*
Pre-trip information via radio	No explicit modelling. Departure time impact as input. *SCORE: 1*	No explicit modelling. Frequency of updating can be used. *SCORE: 2*	No explicit modelling. Capacity constraints can be used. *SCORE: 2*	No explicit modelling. O/D-matrices for 5-min periods can be used. *SCORE: 3*	Not possible to model. *SCORE: 0*
Planning and evaluation of Variable Message Signs (VMS)	Does not contain a route choice model. *SCORE: 0*	Prepared for VMS control algorithms but route choice model dubious. *SCORE:* 3	Behaviour and control algorithms cannot be modelled. *SCORE*: 2	Can be modelled by manipulation. *SCORE:*2	Cannot model reference case without information but some aspects of VMS can be modelled. *SCORE*: 1
Route choice effects of road pricing	No route choice. *SCORE: 0*	No equilibrium assignment. No generalised cost. *SCORE: 1*	Equilibrium assignment with generalised cost possible but not validated. *SCORE: 2*	Equilibrium assignment with generalised cost possible. *SCORE: 4*	Equilibrium multi-class generalised cost assignment. *SCORE: 5*
Dynamic speed control	No explicit modelling. *SCORE: 1*	No explicit modelling. A new ISA[2] vehicle can be introduced. *SCORE: 3*	No explicit modelling. *SCORE: 1*	Not possible to model. *SCORE: 0*	Not possible to model. *SCORE: 0*

Source: Schmidt and Lind, 1999

The microscopic models CORSIM, AIMSUN and INTEGRATION, the mesoscopic model CONTRAM-I and the macroscopic model EMME/2 were compared. In some instances, special features were added to the model to equip it for ITS simulations. The

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[2] ISA = Intelligent Speed Adaptation

investigators (Schmidt and Lind, 1999) scored the different models on a scale from zero to five[3].

For the investigated models, it can be concluded that AIMSUN2, INTEGRATION and CONTRAM-I are most equipped to model the investigated ITS measures. Classic transport models are not equipped to simulate all different ITS measures and driver behaviour changes caused by ITS due to their static way of operating. Their focus is on long-term planning (although EMME/2 tries to accommodate other planning horizons as well). Based on this, it has been concluded that a macroscopic model should not be used in this dissertation.

Other important conclusions reported by the European consortium (Schmidt and Lind, 1999) were:

- Handling of input data takes more time with microscopic simulation models than for assignment (classic) models.
- Basic behavioural models for car following etc. are good, but not sufficiently adapted to ITS.
- With proper calibration, mesoscopic and microscopic simulation models can be very useful in understanding the dynamic nature of traffic.
- It is very risky to use untried microscopic (and mesoscopic) simulation models for new areas, and when working under pressure.
- Graphical interfaces are helpful when searching for efficient input data and to understand the simulation results.
- Microscopic simulation programmes are well adapted and can be recommended for traffic control measures.
- Microscopic simulation is, in principle, good for trip planning, navigation, guidance and cruise control but important modules are missing (see also requirements published by Hugosson (Hugosson, et al, 1997)).
- Macroscopic and mesoscopic assignment models are still better than dynamic models for the study of debiting systems (Schmidt and Lind, 1999).

Mesoscopic and microscopic traffic simulation models are becoming an increasingly important tool for transport systems analysis and management. They allow the traffic engineer to study and evaluate the performance of transport network systems at the tactical and operational level, under various alternative management options.

4.4.1 Input variables

In the previous section, a description is provided of the differences between macroscopic, mesoscopic, microscopic and nanoscopic models. It was indicated that the major differences are in the assignment step. In practice, most mesoscopic, microscopic and nanoscopic models will not carry out all four steps. Many will only calculate the last step, using input from classic four-step models or other sources, providing the required input information, including Origin-Destination (OD) information and mode choice.

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[3] Score 0 = model not equipped to simulate this measure at all
Score 5 = measure can be simulated by the model very well

Due to the dynamic aspect of microscopic models, the following information is required for the assignment step:

- Information with regards to the *zones* (areas of land),
- A road *network* that contains the physical and geometric aspects of the network (nodes, links, curves, kerb points, stop lines, ramps),
- An *OD-matrix* specifying the demand (segregated over time),
- *Vehicle type* information (private vehicles, public transport vehicles and often information with regards to the occupancy of the vehicle) providing modal split and vehicle characteristics (i.e. length),
- *Driver information,* including, for example, how familiar the driver is with the network, the gap acceptance, target headway and reaction time, and
- *Time related information* like the time steps in which the calculations need to be carried out and the percentage of traffic that will be released onto the network per time step (profiles).

4.4.2 Transport telematics included in microscopic simulation models

The choice of microscopic simulation model will be based on the ITS measures that it is able to model. The European consortium Smartest (1997b) carried out a thorough comparison between different microscopic simulation models. One issue investigated was the ability of models to include transport telematics (=ITS measures).
The telematic functions included in their comparison are:

1. Co-ordinated traffic signals
2. Adaptive traffic signals
3. Priority or public transport vehicles
4. Ramp metering
5. Motorway flow control
6. Incident management
7. Zone access control
8. Variable message signs
9. Regional traffic information
10. Static route guidance
11. Dynamic route guidance
12. Parking guidance
13. Public transport information
14. Automatic debiting and toll plazas
15. Congestion pricing
16. Adaptive cruise control
17. Automated highway systems
18. Autonomous vehicles
19. Support for pedestrians and cyclists
20. Probe vehicles
21. Vehicle detectors

Table 4.3 provides the results of the Smartest investigation.

Table 4.3 Transport telematics function included in microscopic simulation models

Model	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
AIMSUN 2	X	X		X		X	X	X		X	X			X							X
ANATOLL															X						
CASIMIR*		X																			X
CORSIM	X	X	X	X	X	X															
DRACULA	X	X	X												X						X
FLEXSYT II	X	X	X	X	X	X	X							X					X		X
FREEVU																				X	X
FRESIM				X	X	X															X
HUTSIM	X	X	X	X				X		X				X		X		X	X	X	X
INTEGRATION	X	X	X	X	X	X		X		X	X		X	X	X					X	X
MELROSE	X	X		X	X		X			X	X			X	X	X	X	X		X	X
MICROSIM		X		X						X	X										
MICSTRAN	X	X	X	X			X			X	X	X			X						X
MITSIM	X	X		X	X	X		X		X	X			X						X	X
NEMIS	X	X	X			X	X	X		X	X					X				X	X
PADSIM	X	X					X				X					X				X	X
PARAMICS	X	X		X	X	X	X	X	X	X	X			X	X		X			X	X
PHAROS	X																				
PLANSIM-T	X	X	X	X			X	X	X	X	X	X		X	X		X			X	X
SHIVA																X	X	X			X
SIGSIM	X	X	X	X	X	X							X			X		X		X	X
SIMDAC																X					
SIMNET	X	X	X	X		X		X		X	X	X				X					X
SISTM				X	X			X		X											X
SITRA-B+	X	X	X			X				X	X	X								X	X
SITRAS	X	X				X				X	X										X
THOREAU	X	X		X				X		X	X									X	X
VISSIM	X	X	X	X	X									X					X	X	X

Source: Based on Smartest 1997b

4.4.3 Output variables

The data that microscopic simulation models generate as a result of the calculations is generally related to different attributes. These include the following:

- Link related information, such as volumes, average speed and densities (per lane),
- Detector information, such as the occupancy (time that the loop is occupied by a vehicle), gap between vehicles, headway between vehicles, speed for each passing vehicle, as well as the volume and average speed, and
- Vehicle information, which includes vehicle behaviour (acceleration and deceleration), the route followed, travel time etc.

More information with regards to these outputs can be found in chapter six.

An overview of the outputs that different micro-simulation models generate is provided in table 4.3. Appendix C provides the details of the developers/suppliers of these models.

Table 4.4 provides an overview of the output criteria included in the models. Abbreviations have been used to summarise the information into one table.

Table 4.4 Outputs of different microscopic simulation models

Model	**Efficiency**							**Environment**			**Safety**						**Comfort**		**Technical Performance**		**Others**
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**V1**	**V2**	**V3**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**F1**	**F2**	**T1**	**T2**	
AIMSUN 2	X	X		X			X	X											X		
ANATOLL					X		X														
ARTEMIS								X													
ARTIST																					
CASIMIR*		X					X												X		Number of stops
CORSIM		X	X	X	X		X	X				X							X		
DRACULA		X	X					X											X		
FLEXSYT II		X	X	X	X	X	X	X	X		X								X		
FREEVU		X	X	X																	
FRESIM		X	X	X				X				X							X		
HUTSIM		X	X	X	X		X	X			X			X	X	X			X		
INTEGRATION		X	X	X	X			X											X		Number of stops
MELROSE		X		X	X		X									X					
MICROSIM			X	X			X														
MICSTRAN		X	X	X	X	X	X		X	X	X					X					
MITSIM	X	X	X	X	X		X				X	X			X						
NEMIS		X	X	X	X	X	X	X			X		X				X				
PADSIM				X	X		X														
PARAMICS		X	X	X	X	X	X	X		X	X								X		Shock waves
PHAROS							X														
PLANSIM-T	X	X	X	X	X	X	X	X											X		
SATRUN		X		X		X	X														
SHIVA		X		X	X						X	X	X								
SIGSIM		X	X	X	X	X	X														Delay; Degree of saturation
SIMDAC				X							X		X	X	X		X				
SIMNET		X	X	X	X		X	X											X		
SISTM		X	X	X	X		X				X	X									
SITRA-B+		X	X	X	X	X	X														
SITRAS		X		X	X		X														VKT; Delay
THOREAU		X	X	X	X		X				X										Time spent stopped or creeping; Amount of acceleration
TRACKS																					
TRANSIMS	X	X	X	X	X	X	X	X	X		X	X							X	X	
TRAF-NETSIM		X	X	X	X		X	X											X		
VISSIM	X	X	X	X	X	X	X	X			X	X	X			X			X		Transit delay due to signals; Passenger delay

* Note that this model is no longer maintained by INRETS; Sources included: Smartest, 1997b and Koutsopoulos, 2004

The abbreviations stand for:

Efficiency	E1:	Modal split
	E2:	Travel time
	E3:	Travel time variability
	E4:	Speed
	E5:	Congestion
	E6:	Public transport regularity
	E7:	Queue length
Environment	V1:	Exhaust emissions
	V2:	Roadside pollution level
	V3:	Noise level
Safety	S1:	Headway
	S2:	Overtaking
	S3:	Time-to-collision
	S4:	Number of accidents
	S5:	Accident speed/severity
	S6:	Interaction with pedestrians
Comfort	F1:	Physical comfort
	F2:	Stress
Technical performance	T1:	Fuel consumption
	T2:	Vehicle operating cost

4.5 Model selection

Based on section 4.4, it can be concluded that mesoscopic or microscopic models are preferred to estimate the impact of different ITS measures.

The original aim was to use both a mesoscopic and microscopic model in this dissertation. The fact that mesoscopic models are less data hungry would probably have suited the South African situation better. Microscopic models have the advantage that they have been applied more often (in different situations all over the world). A comparison of the two models, as well as an indication of the suitability of both types of models in a developing world setting, would have added insight into the understanding of these models from a perspective not studied before.

The mesoscopic model available to the author is still under development at the Massachusetts Institute of Technology (MIT). Although MIT has conducted studies with earlier versions of the model, it proved to be impossible, with the software and information provided, to run the model. After 10 months of intensive work trying to run this mesoscopic model, the idea to include this model in the dissertation had to be abandoned.

The interest in these kinds of models, including their applicability in the South African context, remains. The author hopes to proceed with this work in the future.

On the basis of tables 4.3 and 4.4 it was decided to purchase the software package Paramics. Paramics includes travel time (variation), speed, congestion levels, public transport regularity, queue length, emissions and noise levels, headways, overtaking and fuel consumption as outputs. Moreover, the range of transport telematics functions that Paramics includes is wide spread. These functions include: co-ordinated traffic signals, adaptive traffic signals, ramp metering, motorway flow control, incident management, zone access control, variable message signs, regional traffic information, route guidance, dynamic route guidance, automatic debiting and toll plazas, congestion pricing, automated highway systems, probe vehicles and vehicle detectors (Smartest, 1997b). Finally, it needs to be mentioned that Paramics has the option to buy a module, programmer, which allows the user to write specific code (software) to adapt the calculations and/or outputs to meet local requirements.

Given the wide range of outputs and telematics functions and the additional possibilities provided, it was decided to apply Paramics in the South African context.

4.6 Résumé

Models are developed to serve different purposes. Macroscopic simulation models are developed to assist long-term planners and a static approach is used to develop macroscopic models. They are, therefore, not suitable to estimate the impacts of ITS measures.

Mesoscopic, microscopic or nanoscopic simulation models have been developed over the last couple of years at various research institutions and universities. One of the aims for the development of these models is the introduction of technology on roads.

Mesoscopic models have added time to the classic models and are, therefore, able to calculate the effects of (some) ITS measures in a semi-dynamic manner.

Microscopic and nanoscopic models include longitudinal and lateral driving behaviour. Moreover, nanoscopic models also include vehicle characteristics. Generally, this is done via the inclusion of car-following, gap-acceptance and lane-changing models.

It was concluded that mesoscopic and microscopic, as well as nanoscopic simulation models, can be used to model ITS measures. All models investigated have their strengths and weaknesses.

It was concluded that the vehicle characteristics included in nanoscopic models are not needed for this investigation. Moreover, the required amount of data for these models is so large, that it distracts from the purpose of this study.

One of the original aims of this study was to compare a mesoscopic and microscopic simulation model. Unfortunately, the mesoscopic model purchased appeared to have many software problems. The fact that DynaMIT is still under development is one (if not **the**) reason for these problems. As recommended by Schmidt (Schmidt et al, 1999), software should have been applied and tested before using it. It is very risky to use untried simulation model. Obviously, the testing by MIT was not extensive enough. The idea to include this model in this dissertation was, therefore, abandoned.

The microscopic simulation model, Paramics, appeared to provide the type of modelling and programming possibilities needed for this dissertation. Moreover, as the model is commercially available, it has been used and tested before. Software problems are expected to be limited. Therefore, this model was purchased and used to model ITS measures in the developing world.

Chapter 5

Selection of the case studies

One of the aims of this dissertation is to investigate the impact of different ITS measures in the South African context. Analysing the knowledge levels in South Africa and considering literature on transport studies and experiments in the developed world, it appears to be beneficial to focus on highway related systems. The question that needs to be answered is:

- What data needs to be available to use developed world models in the South African context?

Based on the identified knowledge gaps in South Africa and the available data, case studies are selected. This chapter describes the rationale behind the choice of case studies and the selection of the case studies. First, some background information on these case studies is provided (section 5.2). Then a description of the data collection process is presented (section 5.3), which includes an indication of the data availability problems, as well as a description of the availability of data for the case studies. Moreover, an overview is provided with regards to the data processing that had to be carried out in order to meet the requirements of the traffic simulation tool Paramics. A final description of the case studies is provided in section 5.4, followed by a summary of the findings and experiences (section 5.5).

5.1 Background

South African road traffic problems are concentrated in the urbanised agglomerations. Most large South African municipalities use (co-ordinated) traffic signalling systems (e.g. SCOOT) to manage traffic flows on secondary roads and urban street networks.

Internationally, research with regards to SCOOT systems has been done for more than 20 years. Moreover, practical experience with regards to SCOOT systems in South Africa is available. It was, therefore, decided not to focus on these parts of infrastructure management.

The implementation of ITS measures on highways is lacking in South Africa. Currently, only a few pilot studies have been introduced, or are about to be started. Moreover, the understanding of the systems, as well as knowledge with regards to the potential impacts in the South African situation, is very limited.

Due to the limited understanding of the impact of ITS on highways, the fact that the knowledge with regards to SCOOT is sufficient, and other ITS measures for secondary roads are not widely implemented in other parts of the world, it was decided to focus on ITS measures for highways in this dissertation.

5.2 Selection of the case studies

The highway network in South Africa consists of 239 kilometres of six-lane highways and 1 154 kilometres of four-lane highways (NDoT, 2002). The aim of the highway system is to connect the major cities of South Africa (see also figure 2.1). In many cases, the highways go through or into the (inner) cities; for example in Cape Town and Mangaung. In some cases, like Tshwane and Johannesburg, a highway ring system has been realised.

Road traffic in South Africa has many problems. Congestion, pollution and road safety are by far the most important problems. Road accidents claim between 13 000 and 14 000 lives annually in South Africa. Road safety problems occur on rural as well as urban highways. Throughout South Africa the reasons for the high fatality rates are speeding and alcohol abuse. On urban highways, conflicts between different types of road users (pedestrians, who are not supposed to be on the highway and vehicles) are an additional cause. On rural roads, overtaking on single carriage highways without physical barriers causes head-on accidents.

Research with regards to pollution is carried out on a municipal level. It has been reported that Cape Town experiences episodes of visual pollution, which are associated with calm atmospheric conditions and low-level inversions. These conditions give rise to a visible brown haze, which has been a cause for concern for many years (based on information available on: www.capetown.gov.za).

Daily congestion only happens on urban highways in South Africa. The capacity on rural highways is far greater than the demand. During peak hour, congestion problems on urban highways are similar to European situations. Due to the lack of a safe, comfortable and reliable public transport system, travel demand growth has mainly taken place with regards to private vehicle travel. In Cape Town, for example, peak demands increase by an average of six percent each year. Similar to the developed world, supply can not meet this additional demand.

European traffic experts' observations indicate that driving behaviour in South Africa is different from the developed world. Traffic rules with regards to lane use are disobeyed, and minibus taxis use the on and off ramps to overtake. Moreover, large differences in speed have been observed.

It has been concluded that South African traffic flows, in comparison to the developed world, are more chaotic (see figure 5.1). The hypothesis is that this leads to less efficient use of the road space.

Figure 5.1 Chaos on the Settlers Way (Cape Town)
Photo: Made available by the City of Cape Town.

As indicated, it has been decided to focus on highway related systems. To limit the need to collect data, the availability of secondary data (collected by others for different purposes) was investigated.

The South African Road Agency Pty Ltd (SANRAL) collects loop data from about 500 fixed stations and 300 mobile stations on a daily bases. Moreover, ad-hoc stations are added when required. The majority of loops can be found in urbanised areas, and most loops are situated in the proximity of intersections (junctions). The distance between loops is as little as 400 metres. The stored data includes information about the date, time of the day, lanes and the vehicle type. SANRAL stores data in 15-minute intervals, but availability of loop data for shorter periods is extremely limited. Data stored by SANRAL can be purchased for a small handling fee. Because the calibration possibilities of microscopic simulation models based on 15-minute intervals is limited, additional information needs to be collected.

Apart from traffic demand and flow data, another problem is the availability of road networks in digitised format. Neither the central government agencies nor the municipalities have digitised road networks that are appropriate for microscopic modelling. Despite comprehensive expertise at the University of Cape Town in teaching and research in Geographical Information Systems (GIS), the GIS databases of the South African road network appeared to be useless. Companies offering tracking systems do have the majority of the South African road network digitised. Unfortunately, the budget for this study did not allow for the purchasing of that digitised network.

The next step was to look at specific projects that might offer useful data. The most extensive ITS study has been carried out in Gauteng. One of the major bottlenecks between Tshwane and Johannesburg is the Ben Schoeman Highway (BSH). Since 2002, modelling studies have been carried out for the BSH by the Tshwane branch of Innovative Traffic Solutions (Pty) Ltd (a South African consulting firm) for SANRAL. Currently (July 2005), a pilot implementation of incident management is planned. SANRAL and Innovative Traffic Solutions both agreed to make their collected data available for this dissertation.

The severity of traffic problems on the BSH and the availability of data led to the conclusion that (part of) the BSH should be one of the case studies considered in this dissertation. A map of the area and the location of the BSH can be found in figure 5.2.

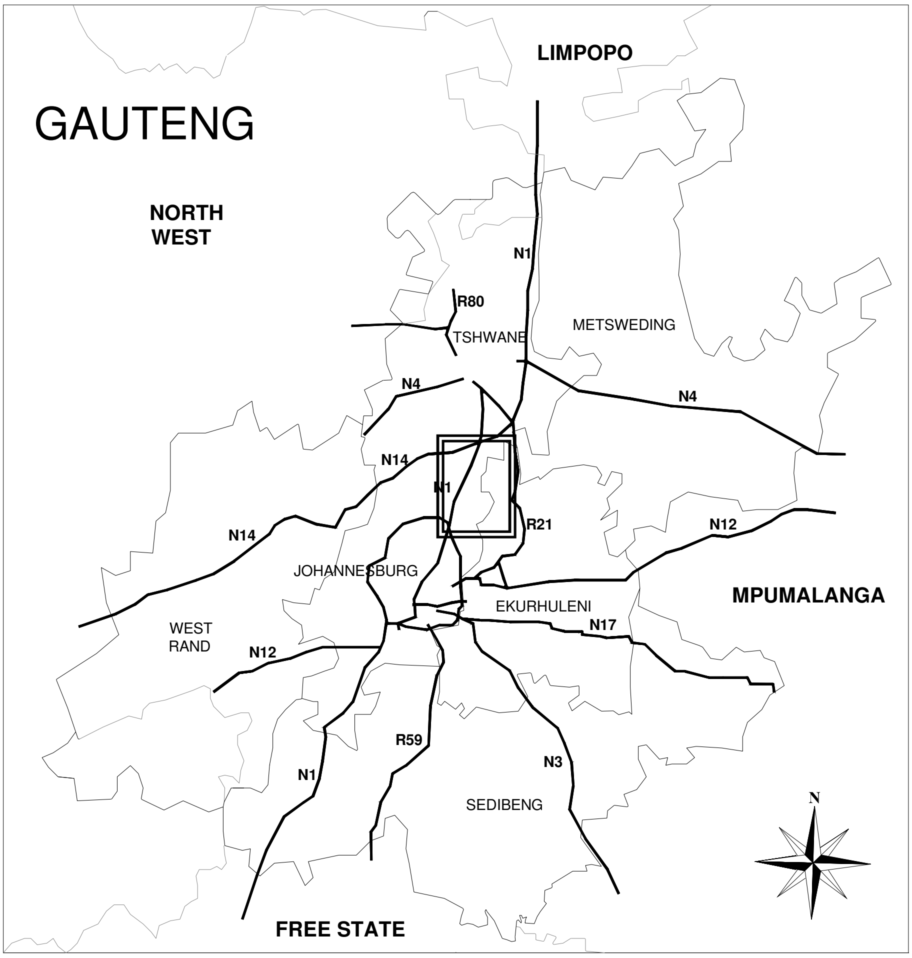

Figure 5.2 The Gauteng Province road network

Unfortunately, no other projects were carried out in South Africa that could provide the type of data needed for a highway orientated, microscopic simulation study. For any other case study, an extensive data collection study would be needed. It was decided that at least one additional case study would be preferable for three reasons:

1. To not be dependent on a single case study that always generates the impossibility of generalisation of results.
2. To have a (though limited) base for comparison between case studies.
3. To be able to test alternative ITS measures.

As the University is located in Cape Town, it is practical to collect data in this area. Cape Town has three highways that suffer from serious congestion during morning peak: the N1, N2 and M3 (see figure 5.3).

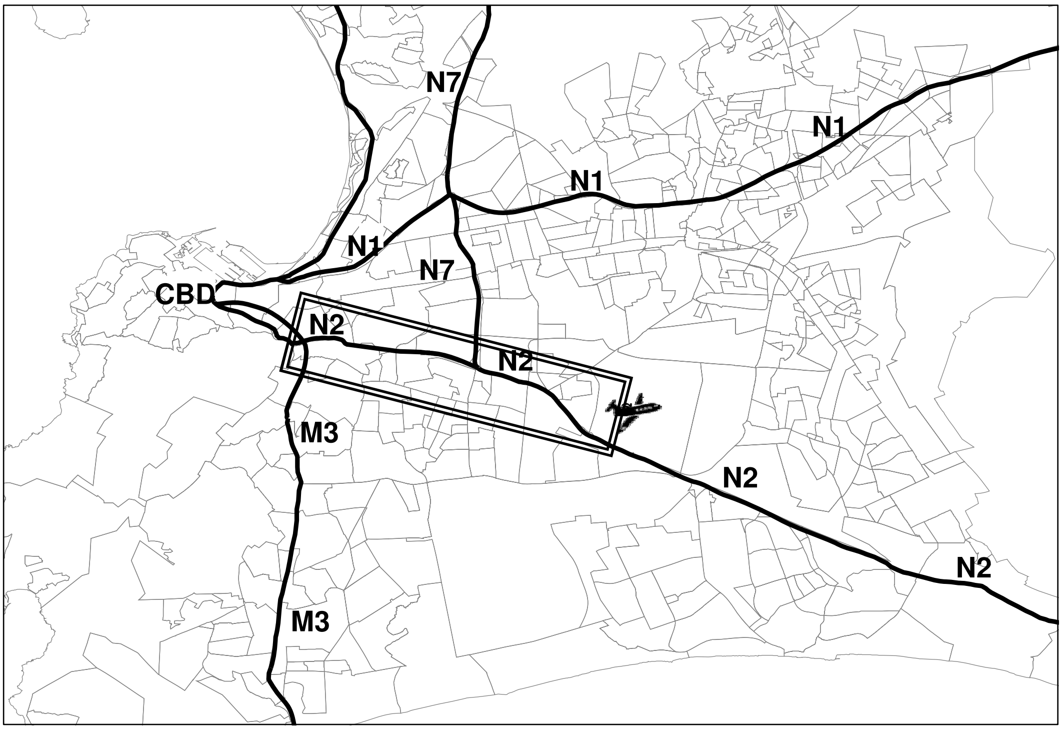

Figure 5.3 The Cape Town road network

In December 1995, the City of Cape Town added a bus lane to the N2. Unfortunately, enforcement never took place. Currently, the bus lane is used by all traffic. Moreover, traffic volumes have increased severely since December 1995. Congestion is witnessed on all lanes, including the bus lane. In interviews with the City of Cape Town, it became clear that there is major interest in the N2 due to the increase in traffic congestion and extension plans for the existing bus lane. Moreover, there is a strong need for an enforcement programme. Unfortunately, the city has not been able to undertake a thorough ex ante evaluation study with regards to their planned interventions. It was, therefore, decided to choose the N2 in Cape Town as the second case study and to collect traffic demand and supply data for this highway. It was also decided that the simulation of a bus lane should be part of the research.

5.3 Case study description

5.3.1 The Ben Schoeman Highway

The part of the BSH network included in this study is between the Brakfontein and Buccleugh interchange (see figure 5.4) in the direction from Tshwane to Johannesburg.

The corridor is 25.5 kilometres long and has seven interchanges. The shortest distance between an on and off ramp is 1.5 kilometres, while the longest distance is three kilometres. The weaving areas, as is the norm in South Africa, are generally short.

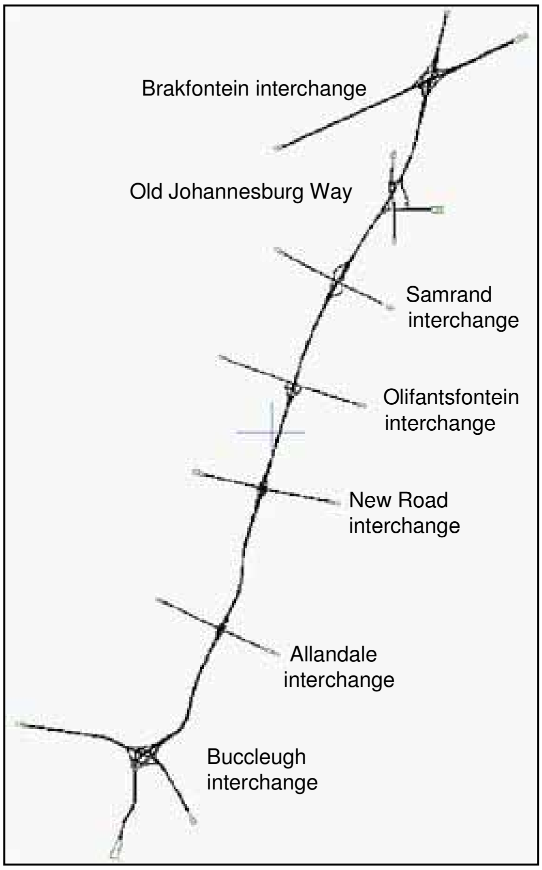

Figure 5.4 Ben Schoeman Highway

The researched corridor of the BSH consists of three lanes. The maximum measured volume is 6 600 vehicles or 2 200 per hour per lane. The BSH has three considerable inclines, followed by considerable declines and four slight inclines, followed by slight declines, which influence, mainly heavy (five percent), vehicles.

It needs to be mentioned that the traffic lights on the secondary roads crossing the BSH often create a backup on the off ramps. Information on the traffic light settings was not available. It is assumed that the information provided by Innovative Traffic Solutions (Pty) Ltd is accurate.

5.3.2 Existing data used for the Ben Schoeman Highway

The Ben Schoeman Highway (BSH) has been under investigation since 2002, and preliminary microscopic simulation modelling was done. Between 2002 and 2004, Innovative Traffic Solutions collected additional data to extend the research corridor.

Innovative Traffic Solutions also used Paramics as the microscopic simulation software package. It was, therefore, possible to use all input files. Innovative Traffic Solutions provided an OD-matrix, profiles (see also section 4.5.1), a digital network and vehicle information. Unfortunately, it was not always clear how the information in these files was established. Validation of the information was, therefore, needed.

Hand counts for all intersections crossing the BSH, collected by MIKROS (a South African traffic count specialist), were also made available. Moreover, five-minute loop data, collected by SANRAL, was provided. This data was used in the validation process.

Comparing the zero case (current situation) provided by Innovative Traffic Solutions with the loop and hand counts, it was concluded that the size of the differences between the simulation model and the empirical data was unacceptable. Detailed analysis of (turning) volumes for the 3.5-hour peak period shows that the model underestimated the total number of vehicles by up to 100%, while there is an overestimation of up to 286% in other cases.

Inspection showed that loop and hand counts were only provided for the middle part of the network. As no verification material was available, it was decided to reduce the network provided by Innovative Traffic Solutions in the north and south. The geometry of the network was verified and adapted using Google Earth information.

This dissertation does, therefore, not use the extended network provided by Innovative Traffic Solutions. The reduction of the network and presumed limited quality of the available OD-matrix were incentives to conduct more detailed analyses of the OD-patterns and to design an update of the matrix using the hand counts. The OD-matrix provided by Innovative Traffic Solutions was used as a starting point (base matrix). For the origins and destinations between the Brakfontein and Buccleugh interchanges, the hand counts were used to verify the OD-matrix. For some cells, the hand counts provided a more accurate volume. If the information in the original OD-matrix differed from the data collected manually, the volume was adapted to the information of the hand counts.

In other instances, the hand counts provided volumes from different zones to the all southern or northern zones. If the totals in the OD-matrix differed from the hand count, the Furness method (Furness, 1962 and 1963, and Ortúzar and Willumsen, 1994) was applied to re-calculate particular cells in the OD-matrix. The Furness method is a standard technique in four-stage transport models that calculates growth factors based on the differences between measured (in this case) or estimated production and attraction trip end rates in a base OD-matrix. In general, several iterations, adapting growth factors every time, are carried out to match the measured and estimated productions and attractions of the OD-matrix to the other information source.

In Paramics, the trips in the OD-matrix are proportioned into vehicle types (defined in Vehicles Manager) and can be profiled by five-minute time periods (Quadstone, 2005). Profiles (the release of vehicles onto the network per five minutes) apply to origins.

It was not possible to verify the profiles used by Innovative Traffic Solutions. It was, therefore, decided to estimate new profiles based on the hand counts. The hand counts provide five-minute counts for links close to origins. In the north, no hand counts were available. It was, therefore, decided to use loop counts instead to establish the profile for these origins.

For Innovative Traffic Solutions, as well as the University of Cape Town, it appeared to be impossible to find road safety data that applies to the corridor. Innovative Traffic Solutions was given information with regards to radio announcements in Gauteng and this data was used to select the information that applies to the BSH corridor

Table 5.1 Incidents announced on the radio for the BSH

Announcement	**Frequency**
Traffic signals out of order/no arrow at traffic signal/does not show green	4
Road works	0
Stationary vehicle/broken down vehicle/vehicle on fire	19
Accident	25
Accident involving pedestrian	0
Slow-moving traffic	4
Truck overturned	3
Animal on the freeway/object on freeway/pedestrian	7
Pointsman not on duty	3
Other (e.g. rail, hail etc)	4
Total	**69**

Note: Data collected on weekdays from 30 August to 12 November 2004.

5.3.3 The N2 in Cape Town

Before any investigation can start, a decision is needed with regards to the corridor under investigation and its boundaries. It was decided to select the N2 in the direction of Cape Town, from the International Airport to Hospital Bend during the morning peak period. This corridor includes the current bus lane, as well as the planned extension. Moreover, congestion problems hardly occur upstream of the Airport onramp. A map of the corridor is provided in figure 5.5.

The N2 is a 9.8 kilometre corridor. On and off ramps are generally close to each other. The shortest distance between an on and off ramp is 90 metres, while the longest distance is 1.3 kilometres. Similar to the BSH, on and off ramps are short.

The corridor is considered flat terrain. For the first 7.6 kilometres, there is a slight incline of 25 metres. For 2.2 kilometres, the road gets close to Table Mountain and slopes up another 55 metres. For heavy vehicles, this last incline is sometimes a problem. Nevertheless, most vehicles (93%) are private vehicles, which are not influenced in a substantial way by the geometry of the road.

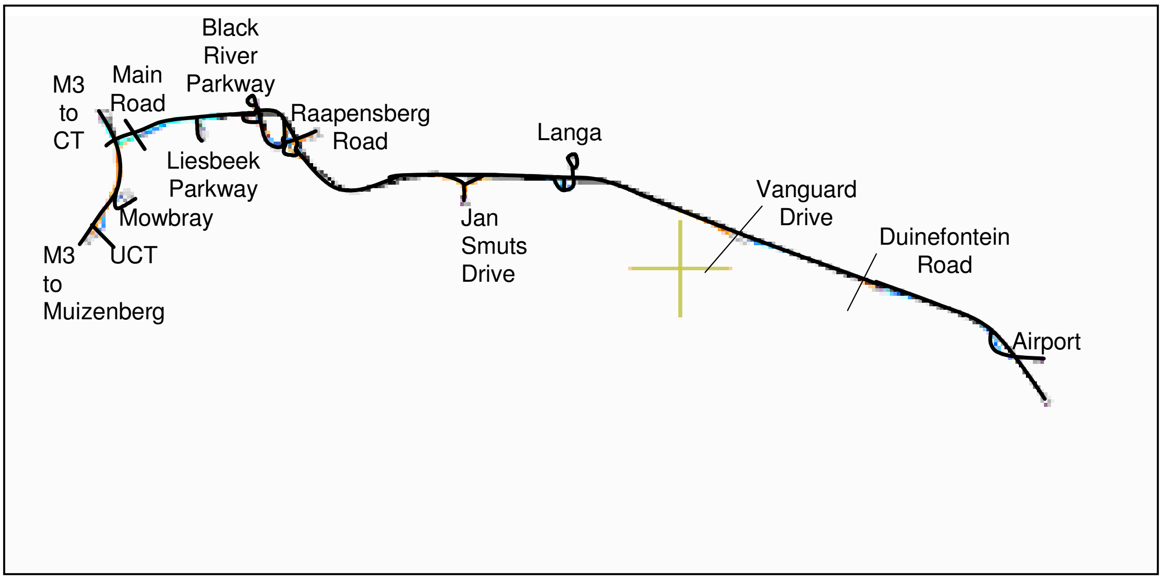

Figure 5.5 N2 corridor in Cape Town

The first 1.1 kilometres of the corridor consist of two lanes. Thereafter, the corridor has three lanes. At the end of the corridor (Hospital Bend), one lane goes south in the direction of Muizenberg, while the other two turn in the direction of the CBD (T-junction). Data collected on the three-lane parts indicate that the maximum volume is 5 400 vehicles or 1 800 vehicles per hour per lane.

Analysis of the road safety data, provided by the City of Cape Town, indicates that on this 9.8-kilometre corridor, five fatalities, 12 major injuries, 22 minor injuries and 12 damage-only accidents occur, on average, each year.

5.3.4 Data collected for the N2

No other projects have been carried out for the N2 that provided useful data for this dissertation. It was, therefore, necessary to build all files needed to run Paramics.

Site inspections, several paper and digital maps and Google Earth were used to build the digital network for the N2. The gradients were estimated based on maps purchased from the Department of Land Affairs, Chief Directorate: surveys and mapping. Field trips were made to verify details, including the signposting.

Originally the City of Cape Town provided five minute count loop data for the corridor. Unfortunately, this data was not accurate or extensive enough. SANRAL was contacted and it was ascertained that MICROS had collected five-minute counts for the N2 during October 2004. It was decided to purchase this data.

Hand counts were planned for March 2005. A local consultant, AGMAC Consulting c.c., was hired to assist with the data collection. On 10 March 2005 more then 40 UCT students counted vehicles (per type) on the N2 corridor, between 06h00 and 10h00. At the same time, four vehicles drove up and down the N2 from the Airport onramp until the Main Road off ramp. They recorded their travel times, as well as the location and time of congestion they encountered. AGMAC Consulting coded all the data.

Inspection of the results showed that some errors were made in the manual counts. It was, therefore, necessary to do additional counting on selected spots. These were carried out by two UCT students during early April. At the same time, data was collected with regards to the occupancy of vehicles on the N2. Table 5.2 provides an overview of the data collected.

Table 5.2 Vehicle type distribution and vehicle occupancy on the N2 (%)

	Distribution	Distribution passenger vehicles
Private vehicle with 1 passenger	52.6	61.0
Private vehicle with 2 passengers	24.1	28.0
Private vehicle with 3 passengers	3.0	3.5
Private vehicle with more than 3 passengers	6.5	7.6
Buses	1.8	
Minibus taxis	7.5	
Light commercial vehicles	2.0	
Heavy commercial vehicles	2.5	

Note: This data was collected between 06h40 and 10h00.

During the data collection, it became clear that the influence of traffic lights, as well as the counter flow on the N2, is very limited. It was, therefore, decided to exclude these details from the study.

To estimate an OD-matrix, origin and destination information of Cape Town's EMME/2 model was used as a starting point (base matrix). Loop and hand count data were added. Moreover, partial information with regards to the OD-matrix was available for trips to the University of Cape Town (UCT) along the M3 to Muizenberg (figure 5.5), based on home addresses of students and staff.

Hand counts, collected by AGMAC Consulting., were on a five-minute basis and could, therefore, be directly translated into Paramics profiles.

5.5 Résumé

Data availability is a problem in South Africa as structural collection of data is limited. Moreover, in cases where data collection takes place like, for example, the loop data collected by SANRAL, the level of detail of the data is not appropriate for use in microscopic simulation models.

A wide range of individuals, companies and institutions have been willing to share data that was collected in various research projects. The availability of this data was very useful for this dissertation project. Nevertheless, as the data was collected with other objectives in mind, a detailed inspection and verification program had to be carried out, as well as a substantial amount of reprocessing. For the second case study, most of the data collection had to be carried out.

It was concluded that the BSH between Tshwane and Johannesburg, as well as the N2 near Cape Town, are case studies that represent the congestion and safety problems experienced on urban highways in South Africa. Safety problems are equally severe on rural highways and in urban areas. Nevertheless, congestion does not occur on rural highways. Rural highways were, therefore, not considered in the selection process.

The characteristics of the BSH and the N2 are very different. The BSH corridor is 25.5 kilometres long, has many gradients and the distance between the on and off ramps is between 1.5 and three kilometres. The N2 is a smaller corridor of 9.8 kilometres. The only visible gradient is at the end of the corridor, the T-junction with the M3. On and off ramps are closer together than the BSH, with an interspacing of between 90 metres and 1.3 kilometres.

Chapter 6

The calibration process

This chapter starts with a theoretical description of possible indicators. Section 6.2 provides a description of the indicators selected for the calibration process. It needs to be mentioned that indicators included in this description will focus on the application on a microscopic level, although some more aggregated information is included. Thereafter, a description is given of common parameter settings (section 6.3) for driving behaviour, followed by a description of the way Paramics models driving behaviour (section 6.4). In section 6.5 an indication is provided with regards to the appropriateness of the parameter settings in Paramics. The actual calibration of the model is described in section 6.6, followed by a summary of the findings in this chapter. This chapter aims to answer the following question:

- How can different driving behaviour be included in transport models?

6.1 Theoretical background

The goals of ITS vary. As indicated in section 3.2, the objectives of implementing ITS measures may focus on aspects such as safety, mobility, efficiency, productivity, energy, environment and customer satisfaction. It is not possible to measure these goals directly. Different indicators such as throughput, speed and, if possible, other traffic flow parameters need to be identified to measure the impact of ITS measures. For this reason, it is preferable to use the same indicators in the calibration process; calibration is the process of estimating model parameters in such a way that the simulation model produces satisfactory results compared to measured data from the real world in the current situation (base year).

6.1.1 Speed

Speed is the distance travelled by a vehicle during a unit of time. It can be expressed in kilometres per hour (km/h), miles per hour (mi/h), metres per second (m/s) and feet per second (ft/s). The speed of a vehicle at any time, *t*, is the slope of the time-space diagram for that vehicle at time *t* (figure 6.1). The time headways (see section 6.1.3) are indicated with h_1, h_2 etc. and $D_{3\text{-}4}$ is the physical distance between vehicle three and vehicle four.

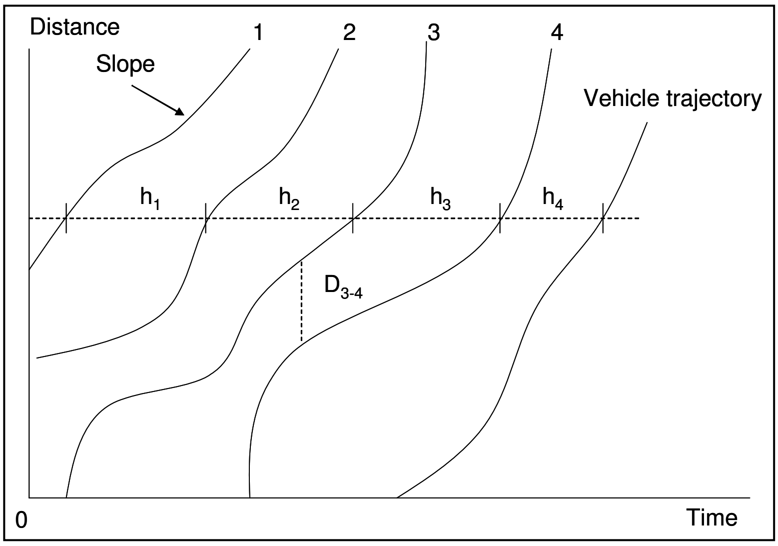

Figure 6.1 Time-space diagram

Source: Based on Koutsopoulos, 2004

Speed can refer to the velocity of an individual vehicle at a point in time, as in the time-space diagram. However, speed can also be aggregated and averaged over a number of vehicles. Examples are the space mean speed (averaging speeds of vehicles over a highway section at an instant of time) and time mean speed (averaging speeds of vehicles over a time period at a particular spot).

Traditionally, the analysis of traffic flows was very much based on the relationship between the aggregated variables speed (S), density (K) and volume/flow (Q). So called fundamental diagrams describe the relationship. The calculation of the volume was originally based on the space mean speed (S_s).

$$Q = S_s * K \tag{6.1}$$

Where:
Q is the volume.
S_s is the space mean speed.
K is the density.

6.1.2 Volume

Volume or flow is the equivalent hourly rate at which vehicles pass a cross section on a highway. The density, sometimes referred to as concentration, is the number of vehicles travelling over a unit length of the highway per unit time. The unit length is usually one kilometre, thereby making vehicles per kilometre (veh/km) the unit of density. Figure 6.2 provides a simplified version of the relationship between speed, flow and density, as firstly proposed by Greenshields and Weida (1952).

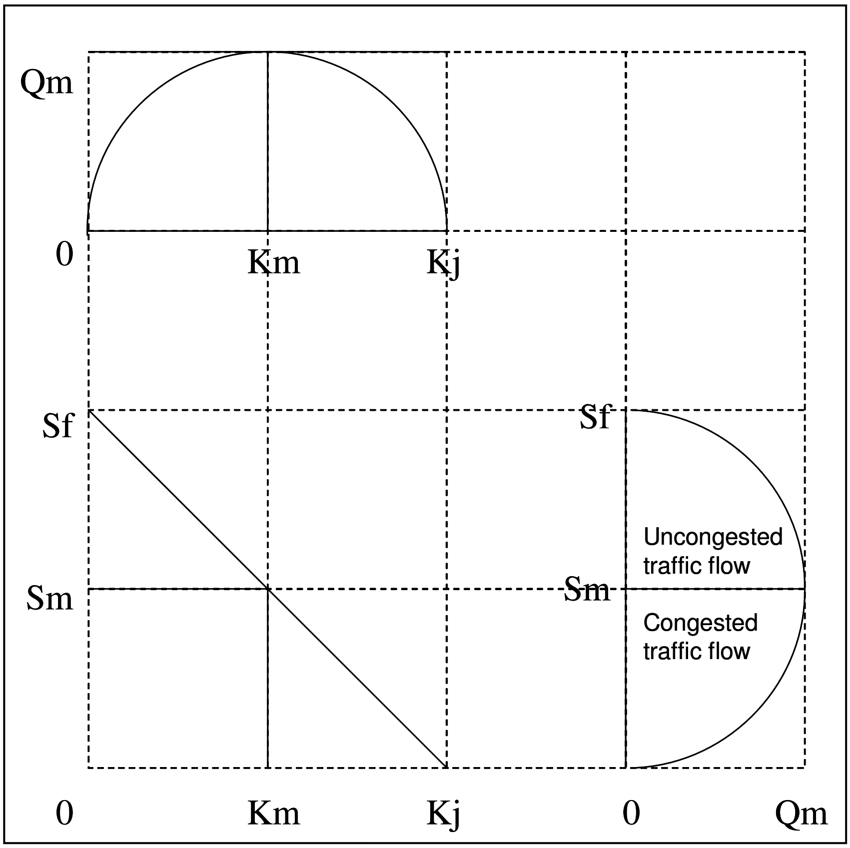

Figure 6.2 Speed, flow and density relationship
Source: Based on Greenshields and Weida, 1952

Where:
Q_m is the optimal traffic flow (veh/h).
S_m is the speed corresponding with the optimal flow (km/h).
U_f is the free flow speed (km/h).
K_m is the density corresponding with the optimal flow (veh/km).
K_j is the jam density (veh/km).

The relationship between the density (veh/km) and the corresponding flow of traffic on a highway is generally referred to as the fundamental diagram. The following theory has been postulated with respect to the shape of the curve depicting this relationship (Garber and Hoel, 2001).

1. When the density on the highway is zero, the flow is also zero because there are no vehicles.
2. As density increases, flow increases and speed tends to decrease.

3. However, when density reaches a maximum value, generally referred to as the jam density (K_j), the flow must be zero because vehicles will tend to come to a complete standstill (so no flow).
4. It follows that as density increases from zero, the flow will initially increase from zero to a maximum value (Q_m). Further continuous increases in density will then result in a continuous reduction of the flow, which will eventually be zero when the density is equal to the jam density. Note that the shape of the curve is parabolic in the Greenshields (Greenshields and Weida, 1952) model (see figure 6.2, top left-hand corner). Several other models for the fundamental diagram have been proposed but they all show the above properties, except for some models that allow for the occurrence of discontinuities in flow.
5. Speeds that are/can be realised on the freeway are directly related to the fundamental diagram (included in figure 6.2).

The shape and values of the curves (figure 6.2) depend on the prevailing traffic and roadway conditions on the segment of the road under study and on its length in determining the density. Moreover, actual data generally shows discontinuities in the neighbourhood of the capacity level (maximum flow). These discontinuities are a result of aggregation of the data and the fast transition from freely moving traffic to congestion in practice.

6.1.3 Headways

Time headway is one of the indicators for traffic safety. Time headways have been defined as the elapsed time between the front of the lead vehicle passing a point on the roadway and the front of the following vehicle passing the same point (Evans, 1991). The time headway between vehicle *i* and *j* at a certain point is calculated as follows (see also figure 6.1):

$$H_{ij} = t_i - t_j \tag{6.2}$$

Where:
H is the time headway between vehicles i and j (s).
t_i is the passing time of the leading vehicle (s).
t_j is the passing time of the following vehicle (s).

In some countries, fines are generated if short headways occur. Different countries have slightly different rules with regards to the legal or recommended safe following headway. In the US, several driving training programs (Michael et al, 2000), state that it is impossible to follow a vehicle safely with a time headway of less then two seconds. In Germany, the recommended minimum distance (space headway) is ‘half the speedometer’, which means a car travelling at 80 km/h should keep a distance of at least 40 metres. This rule corresponds with a recommended time headway of 1.8 seconds. Fines are imposed when the time headway is less than 0.9 seconds. In Sweden, the National Road Administration recommends a time headway of three seconds in rural areas and the police use a critical time headway of one second as an orientation for imposing fines (Vogel, 2003).

6.1.4 Time-To-Collision

Another ex ante road safety assessment indicator is the Time-To-Collision (TTC). The time–to-collision was first introduced and applied by Hayward (1972). A TTC value at an instant *t* (*t* could be when a loop is passed or at set intervals, i.e. every minute for example) is defined as the time that remains until a collision between two vehicles would have occurred if the collision course and speed difference remained the same (Hyden, 1996). The higher the TTC, the safer the situation is. Two different TTCs can be calculated; the distance based TTC and the time based TTC.

The distance based TTC of a vehicle combination *ij* at time *t* with respect to a leading vehicle *i* can be calculated with:

$$TTC_{ij} = \frac{X_i(t) - X_j(t) - l_i}{S_j(t) - S_i(t)} \qquad \text{for } S_i(t) < S_j(t) \qquad (6.3)$$

Where:
S is the speed (m/s).
X the position (m).
l the vehicle length (m).

The time based TTC calculation is comparable. The difference is that the calculation is based on the time gap between the vehicles and their speed. Generally, the time based TTC is calculated because loop data and cross section measurements in micro simulation models provide the speed and gap information. The time based TTC of a vehicle combination *ij* at time *t* with respect to a leading vehicle *i* can be calculated with

$$TTC_{ij} = \frac{S_j}{S_j - S_i} G_{ij} \qquad \text{for } S_i(t) < S_j(t) \qquad (6.4)$$

Where:
S is the speed (m/s).
G_{ij} is the time gap between vehicles i and j (s).

Figure 6.3 provides an illustration of the TTC with two vehicle trajectories. It illustrates graphically the relationship between the distance and time based TTC.

To determine how safe a situation is, or if a scenario is safer than another, a TTC threshold value is needed. Hirst and Graham (1997) indicate that the TTC of four seconds could be used to discriminate between cases where drivers unintentionally find themselves in a dangerous situation from cases where drivers remain in control. The same study indicates that a TTC warning system at four to five seconds produces many false alarms. The TTC warning system seems to work optimally at three seconds. A study investigating Intelligent Cruise Control (ICC) found that a minimum TTC value of 3.5 seconds is needed for non-ICC drivers and 2.6 seconds for ICC drivers. Nevertheless, the 2.6 seconds value is regarded as a safety concern (Hogema and

Janssen, 1996). Based on this literature, it can be concluded that a TTC of less than three seconds is regarded as a safety risk.

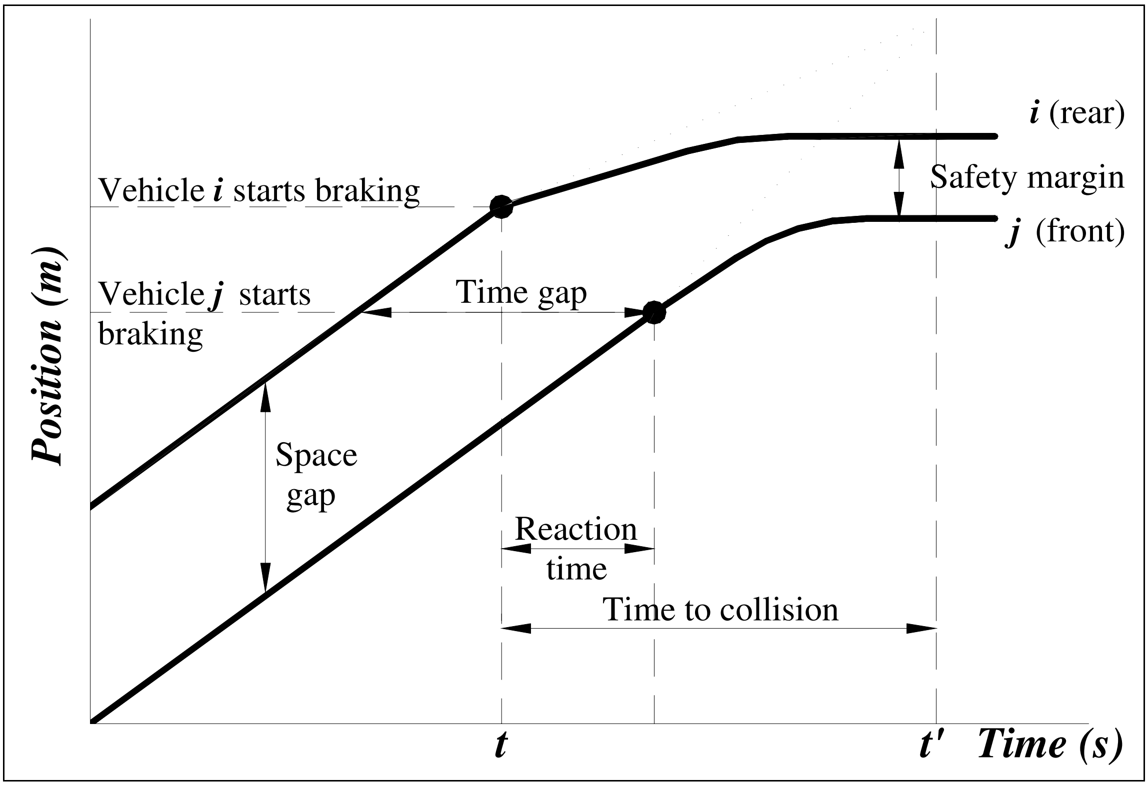

Figure 6.3 Time-To-Collision notion illustrated with vehicle trajectories
Source: Adapted from Minderhoud and Bovy, 2001

6.1.5 Headways versus Time-To-Collision

A comparison of the equations shows that more variables have to be known to determine TTC than to determine headways. The relationship of these two measures is as follows:

$$TTC_{ij} = \frac{S_j}{S_j - S_i} H' \qquad \text{where} \qquad H' = H - \frac{O_i}{S_j} = gap \qquad (6.5)$$

Where:
S is the speed (m/s).
H is the time headway (s).
O is the occupancy (s).

To obtain TTC, the speed of both vehicles involved has to be known, in addition to the time gap. An interesting difference between the two indicators exists with respect to traffic safety. It could be formulated such that the time headway is ‘a step further away’ from a crash than TTC (Vogel, 2003).

The TTC can never be smaller than the time gap. Vogel (2003) compares the TTC to the headways. Extensive analysis for different situations and relationships between the headway and TTC were carried out.

Although there is a theoretical relationship between time based TTC and headway, based on her experiments and analysis, Vogel (2003) concludes that time headway and TTC are not correlated for following vehicles. Vogel recommends that headways should be used by authorities as an indicator of tailgating, while the TTC should be used if the actual safety of a situation has to be evaluated. Within this dissertation time headways, as well as time based TTC, will be considered as indicators.

6.1.6 Shockwaves

Given the bottleneck theory (Verhoef, 2001), instability of traffic flows is a crucial phenomenon. Moreover, instability is also the key factor determining the type of congestion that occurs after free-flowing traffic has broken down (Tampère, 2004). These instabilities can provide an indication of the safety risk.

In traffic flow, platoons of vehicles occur. Platoons are sequences of one leader (who drives unconstrained) followed by a number of constrained following vehicles. The distance between the last vehicle of the one platoon and the first vehicle of the next is the inter-platoon gap (Tampère, 2004). A platoon is, by definition, asymptotically stable if a consecutive follower-leader pairs in the platoon with decreasing amplitude (Leutzbach, 1988). Local stability is necessary but there is no sufficient requirement for asymptotic stability, also referred to as platoon stability (Tampère, 2004).

The fundamental diagram of traffic flow for two adjacent sections of a highway with different capacities (maximum flows) describes the phenomenon of backups and queuing on a highway due to a sudden reduction of the capacity of the highway, known as a bottleneck condition (Garber and Hoel, 2002). The sudden reduction in capacity could be due to accidents, a reduction in the number of lanes, restricted bridge sizes, work zones, the presence of on- and off-ramps (entering vehicles) etc. The drop in capacity is illustrated by a change from C_1 to a lower C_2 (figure 6.4), with a corresponding change in optimal density from K_0^a to K_0^b.

When such a condition exists and the normal flow and density on the highway are relatively large, the speed of the vehicles will have to be reduced while passing the bottleneck (Garber and Hoel, 2002).

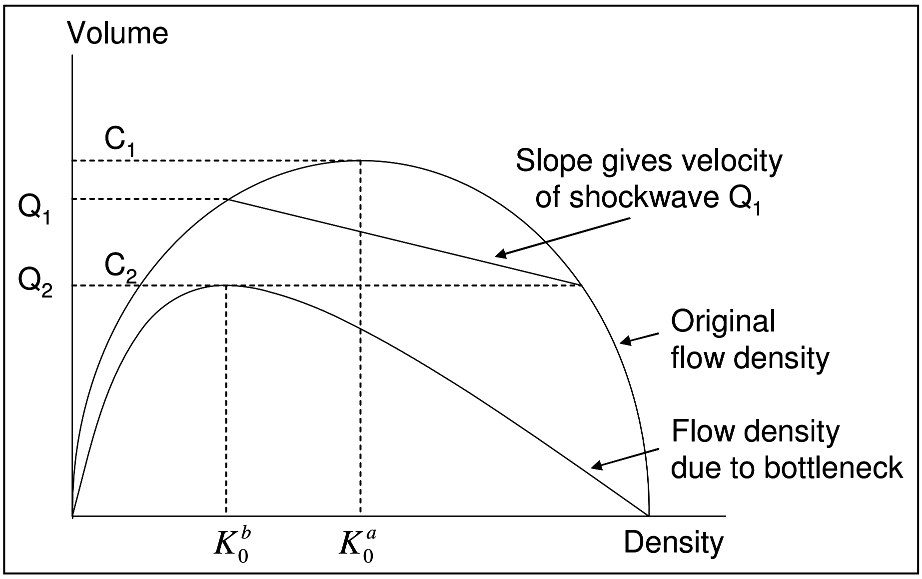

Figure 6.4 Shockwave related to flow-density curve
Source: Based on Garber and Hoel, 2002

It is also possible to identify shockwaves based on the vehicle trajectories. Figure 6.5 provides an illustration thereof.

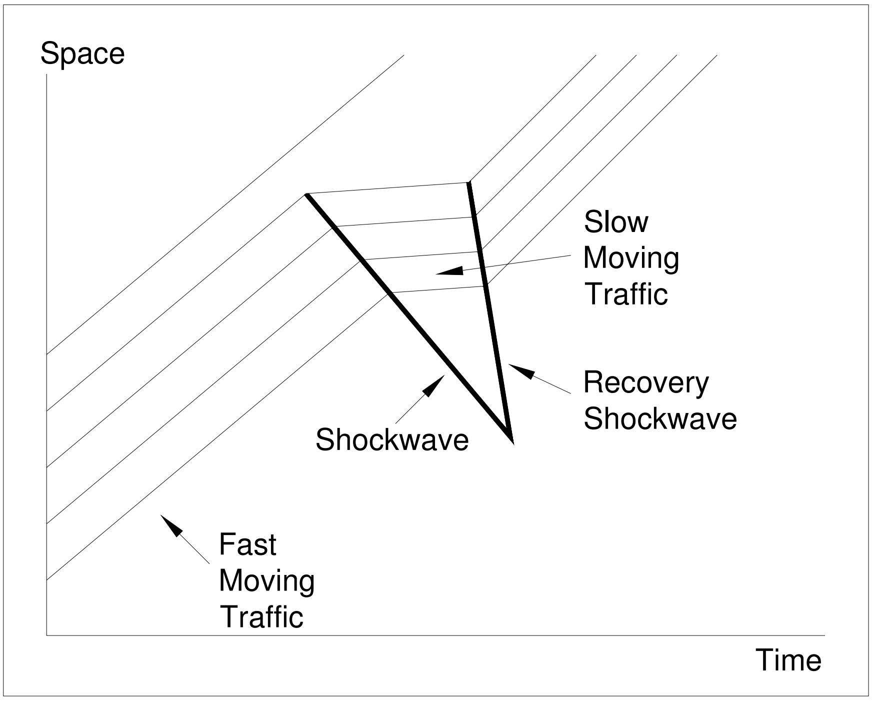

Figure 6.5 Shockwave illustration based on vehicle trajectories
Source: Based on Koutsopoulos, 2004

The area in the triangle between the first vehicle speed slope, the shockwave line and the recovery shockwave gives an indication of the severity of the shockwave. Shockwaves, depending on the slope of the shockwave and the recovery shockwave, can ‘travel’ forwards or backwards.

6.2 Selection of calibration criteria

Criteria used during the calibration process are categorised based on the objectives of ITS measures described in section 3.2. Moreover, the indicators described in section 6.1 are reviewed. Indicators, for which actual data is available, either for one or both corridors, are included as calibration criteria.

In section 3.2, it has already been mentioned that the fatality crash rates and injury crash rates are an objective way to measure **safety** impacts. Unfortunately, most models can not estimate these impacts. Other ways need to be found to estimate the risk reduction of implemented measures. Many microscopic simulation models include speed distributions, headways, TTC and shockwaves as an indication for the risk.

Criteria included in microscopic simulation models that provide an estimate for the **mobility** impact are queuing, delays and travel times.

An important aspect of simulation models is the estimation of **efficiency** impacts. Typical efficiency criteria are: total volumes, the distribution of volumes over time (for example per five minutes), the volume distribution over the different lanes and the densities.

Productivity criteria are related to the costs and benefits of different measures. The estimation of these criteria can be done using a Cost/Benefit Analysis (CBA) or Multi Criteria Analysis (MCA). These calculations are not part of the microscopic simulation process but happen at a later stage. The results of microscopic simulations are input to a CBA or MCA.

Some microscopic simulation models include **energy and environmental** criteria. Generally, fuel consumption and pollution indicators such as CO, CO_2, NO_x and particles are included.

Customer and provider satisfaction are not included in microscopic simulation models. After the implementation of new systems, questionnaires are generally used to measure satisfaction levels.

As mentioned, some criteria are not included in microscopic simulation models. They, therefore, fall outside the scope of this study. Within the calibration process, there is another problem. It is often not possible to collect real world data with regards to all indicators. Table 6.1 provides an overview of data available for the calibration process for the BSH and the N2.

Table 6.1 Availability of calibration data

Criteria	Indicator	BSH	N2
Safety	Speed	--	--
	Headways	☺	--
	Time-To-Collision	--	--
	Shockwaves	--	--
Mobility	Queuing	--	--
	Delays	--	--
	Travel times	--	☺
Efficiency	Total volume	☺	☺
	Volume distribution	☺	☺
	Lane distribution	☺	☺
	Densities	--	--
Environment	Fuel consumption	--	--
	Pollution	--	--

The calibration in section 6.6 will, based on the available data, focus on efficiency. Nevertheless, all available data will be used in the calibration process.

6.3 Common parameter settings in microscopic simulation models

Young (Young et al, 1998) pointed out that most of the parameters used in microscopic simulation models have implications for safety – even a parameter as seemingly neutral as the simulation interval will have an impact on safety if, as is commonly the case, it effectively defines the driver’s reaction time.

Most of the listed parameters in traffic simulation models appear in sub-models representing car-following, gap-acceptance and lane-changing behaviour. Typical values for different parameters in the sub-models are provided by Bonsall (Bonsall et al, 2005). The information in this section is based mostly on these authors (see table 6.2). If a description is based on a different author, this will be indicated.

Desired speed

The desired speeds of drivers are modelled as input parameters and are often directly made equal to the free-flow speeds on the link or road. The latter may vary according to the character of the road. For example, a dual-carriage road and a wider road may lead to higher free-flow speeds than residential streets. City-centre streets where there are lots of pedestrians and pedestrian crossings will force the free-flow speeds down, as would excessive curvature or gradient. Speed limits are used as a proxy for free-flow speeds.

Table 6.2 Parameters commonly included in microscopic simulation models

Parameter	Type	Notes	Typical value
Desired speed	Behavioural and political	Generally link-specific, should reflect the speed limit, the road layout and frontage and the amount of pedestrian activity	Legal speed limit; Speed of vehicles that have headways >6s
Desired headway	Behavioural	May be expressed in units of time or distance	1.5–2.5s; 2.12s (s.d. of 0.86) 5.96s for truck; 6.5m
Reaction time (s)	Physiological	May not be explicitly represented (may be inherent in the simulation interval)	0.57-3.0
Rate of acceleration (m/s^2)	Behavioural (constrained by vehicle performance)	May distinguish between normal rate of acceleration and maximum rate of acceleration, may differ depending on vehicle type	1.5-3.6 (max); 0.9-1.5 (normal) 1.2-1.6 (buses)
Rate of deceleration (m/s^2)	Behavioural (constrained by vehicle performance)	May distinguish between normal deceleration and emergency braking, may differ by vehicle type	1.5-2.4 (emergency) 0.9-1.5 (normal) 3.0 (theoretical)
Critical gap (s)	Behavioural	From the back of one vehicle in the target stream to the front of the following vehicle in that stream	3.5-8.5
Stimulus required to induce use of the reduced gap	Behavioural	Time spent waiting for acceptable gap or number of rejected gaps	Various
Minimum gap (s)	Behavioural		1.0
Willingness to create gaps to assist other vehicles to merge, cross or change lanes	Behavioural	May be expressed as a percentage of the priority traffic stream who stop accelerating or even start decelerating once they "see" a vehicle attempting to merge, cross or enter the lane	20% if the other vehicle is a car 70% if the other vehicle is a bus
Rules for mandatory lane change	Behavioural and political	May simply reflect traffic regulations but may vary depending on enforcement policy	Various
How far ahead the driver anticipates the need to change lanes	Behavioural and political	The behavioural element may be constrained by sight lines, etc.	1 to 2 links or 500m
Minimum acceptable gap when changing lanes	Behavioural	As in gap-acceptance model	As gap acceptance model
Variation in the gap depending on the urgency of the desire to change lanes	Behavioural	May depend on size of time advantage or distance remaining before mandatory change must be completed	50-100m 5-10s
Willingness to create gaps to assist other vehicles to change lanes	Behavioural	May be expressed as a percentage of the traffic in the target lane who stop accelerating/start decelerating once they "see" a vehicle attempting to enter the lane	20% if the other vehicle is a car 70% if the other vehicle is a bus
Level of compliance	Behavioural and political	May vary for different types of regulation. Should vary depending on enforcement policy	50-100%
Distribution of aggressiveness	Behavioural	The proportion of drivers of several preset categories	n.a.

Source: based on Bonsall et al, 2005

Note: Bonsall based the information in this table on a wide range of sources

Desired headway

Car following algorithms assume a minimum safe headway that a following vehicle wishes to keep. This may be represented as either a time or distance headway. When the following and lead vehicle driver are at the same speed, the time headway represents the time available to the driver of the following vehicle to reach the same level of deceleration as the lead vehicle in case it brakes.

Reaction time

Reaction time is a key dimension in both car-following and lane-changing models. It represents the driver's ability to react to stimuli and make particular decisions.

Normal and maximum acceleration

Drivers may apply a smaller acceleration in a more relaxed following situation, while they may apply the full acceleration power of their engine when trying to overtake or pass through a green light.

Normal and maximum deceleration

Drivers may apply a gentler deceleration when approaching a known obstacle or an obstacle visible a long way upstream, such as approaching a traffic light or a slower moving vehicle. A harsher deceleration may be applied for emergency breaking, such as in response to a sudden deceleration of the vehicle in front or to a sudden lane-changing from adjacent traffic.

Gap acceptance

Gap acceptance models deal with the process by which a driver finds an acceptable gap in a traffic stream when he wants to cross or merge into that stream. They are fundamental in representing conflicts between high and low priority flows and in determining how a vehicle from a low priority flow will cross or merge into a higher priority flow.

Critical gap

A driver or pedestrian will accept a gap in the traffic stream to contemplate his intended manoeuvre if the gap is longer than the critical gap (Hewitt, 1983).

Gap reduction and minimum gap

Some gap acceptance models use a fixed value for each driver, while others allow critical gaps to be situation dependent in order to reflect the phenomenon of impatient drivers for whom the critical gap decreases with each passing gap (Kimber, 1989). This gap reduction behaviour can be recognised by observing drivers who reject a gap, which is longer than the one eventually accepted. The stimulus required to induce the decrease of critical gap has been modelled as the number of passing gaps (e.g. Mahmassani and Sheffi, 1981).

Gap creation

Some gap acceptance models allow for the fact that drivers in the priority flow may take pity on drivers waiting for a gap and may deliberately slow down in order to create a gap.

Lane changing

Lane changing models consider the individual driver's intention and ability to change lanes. An *intention* to change lanes will reflect the advantage to be gained (e.g. an increase in speed or an avoidance of delay) or the need to do so (e.g. in order to comply with a traffic regulation, to avoid an incident in the current lane, or to prepare for a turning movement). The intention to make a lane change may be triggered when the time advantage to be gained by changing lanes exceeds some *critical value*. Some models may allow drivers to anticipate the need for a lane change, in which case a parameter will be required to determine how far ahead the drivers anticipate.

The *ability* to change lanes will be a function of the lane space available and the relative speeds and locations of surrounding vehicles, and is modelled in a way which is analogous to a gap acceptance model. The parameters controlling this model will thus include the minimum acceptable gap in the target lane together, perhaps, with parameters which allow for variation in the gap, depending on the urgency of the desire to change lanes (Taylor et al, 2000) and the willingness to create gaps by kind-hearted drivers in the target lane.

This factor is rarely introduced into models. Adherence to traffic regulations may be modelled using assumed *levels of compliance*—these may vary for different types of regulation and should, ideally, be treated as policy variables reflecting different levels of enforcement (Bonsall et al, 2005).

6.4 Driving behaviour parameters in Paramics

Although transportation models are based on the same theory, every model is unique with regards to the details. Paramics does not include a parameter for desired speed, for example. Desired speed of a vehicle is based on the maximum speed and the vehicle age. All gap related parameters (i.e. minimum, critical, creation) are included in the Mean Target Headway (MTH) and Mean Reaction Time (MRT). Moreover, the level of compliance is included in the aggression and awareness of drivers.

The only two parameters identified by Young (Young et al, 1989) that are not included in the Paramics model are “rules for mandatory lane change” and “how far ahead the driver anticipates the need to change lanes” (see table 6.2). Users of Paramics could programme these parameters themselves. Nevertheless, this would be changing the model that is commercially available.

In short, when in Paramics a vehicle catches up with another vehicle or reaches an obstacle, such as a junction or bottleneck, a car following and lane changing algorithm takes effect. Several algorithms determine how the (trailing) vehicle will respond to the current circumstances. The vehicle path is also controlled by a dynamic cost finding algorithm depending on time, distance and toll coefficients.

The three implemented individual vehicle movement models in Paramics (vehicle following, gap acceptance and lane changing) are strongly influenced by two key user specified parameters (Gardes et al, 2002): the Mean Target Headway and Mean Reaction Time. Moreover, based on the experience of Paramics users, the model includes the parameters awareness and aggressiveness (on which Paramics distinguishes itself from other models).

Mean Target Headway

Increasing or decreasing the MTH changes the overall behaviour of the model. The default value of the MTH is set at one second and has been calibrated against UK traffic conditions. Decreasing the MTH value will result in an increased number of vehicles on the road, due to the acceptance of smaller gaps.

No information was found with regards to the desired headway or Mean Target Headway of South African drivers. It was concluded that this parameter needs further investigation.

Mean Reaction Time

Similar to the MTH, the MRT influences the three individual movement models. The default value of the MRT is set at one second as well. A decrease in the MRT implies that drivers are more aggressive and less aware. Probably, this results in more lane changing and lower anticipation of obstacles (Vreeswijk, 2004). The MRT is also used to obtain the correct volumes and speeds on a specific link.

No information is available in the literature with regards to South African driver reaction time. It was concluded that this parameter needs further investigation.

Awareness and Aggressiveness

Awareness and aggression are key factors in Paramics where driver behaviour is concerned. Research at the UK Transport Research Laboratory found that driver behaviour can be sufficiently described by these two parameters (Quadstone, 2003). Every vehicle released onto a Paramics network is randomly assigned its own characteristics and values of aggression and awareness. These behavioural parameters have an effect on quantities such as target headway, top speed, propensity to change lanes and gap acceptance of the individuals. The user of Paramics can change the values across the driver population to reflect regional variations in driver behaviour. However, it is recommended to retain the normal distribution of aggression and awareness and to change the average values of parameters, such as the target headway (Quadstone, 2003).

Section 2.8 indicates that, based on the different cultures in South Africa, a wide spread of general behaviour can be witnessed. It was concluded that aggression and awareness need further investigation. Paramics provides a normal distribution, as well as a squared distribution (a driver is equally likely to be assigned any of the values) for awareness and aggression. Both distributions will be tested.

Besides the four parameters (MTH, MRT, awareness and aggression) more parameters can be used for the calibration of driver behaviour. However, the other parameters do not influence driver behaviour in a direct way but are more a means of manipulating driver behaviour. The other parameters that can be used to influence driver behaviour are: speed, acceleration, deceleration, driver familiarity, visibility distance, signposting distance, number of calculations per time step and the seed value.

Speed, acceleration and deceleration

Other parameters influencing driver behaviour, which are included in the Paramics model are top speed, maximum acceleration and maximum deceleration. There was no indication that these parameters needed to be changed. Table 6.3 includes an overview of these parameters per vehicle type. No changes were made to these values.

Table 6.3 Top speed, maximum acceleration and deceleration per vehicle type

	Top speed	Maximum acceleration	Maximum deceleration
Car	158.5	2.5	4.5
LGV	126	1.8	3.9
OGV1	104.4	1.1	3.2
OGV2	118.8	1.4	3.7
Coach	126	1.2	3.7
Minibus	61.2	1.1	3.2
Bus	61.2	0.9	3.2

Source: Quadstone, 2005

Driver familiarity

The familiarity or unfamiliarity of drivers can be set as a percentage of the total driver population. It affects the route choice of familiar drivers because they receive dynamic feedback of the current situation on the network. However, driver familiarity not only influences the route choice but also driver behaviour, in terms of awareness and look-ahead reaction times for car following behaviour. Obviously, because the driver has to receive more information about the current situation on the network, these values will then increase for the familiar drivers. The author has no information that warrants changing the driver familiarity default values. Moreover, the influence of this parameter is limited as route choice is not included in this dissertation.

Adherence to regulations

The Paramics model assumes 100% adherence (levels of compliance).

Visibility distance

The visibility distance on the approach link will influence the lane changing behaviour of vehicles on a road and especially with turning movements at intersections. When the visibility distance is increased, vehicles will anticipate obstacles sooner. For instance, through earlier lane changing movements or allowance of wider gaps between two vehicles for the lane changing movements of other vehicles. There was no reason to change default Paramics settings.

Signposting distance

Signposting distances have the same theory as visibility distance and driver familiarity. Similar to the previous two parameters, it provides information about the obstacles on the road (such as intersections). An increase in the signposting distance makes drivers more aware of the upcoming obstacles that they can now anticipate earlier. Allowing wider gaps between vehicles and earlier lane changing are examples of the possible changes in driver behaviour. For highway situations the standard signposting distance is 750 metres. The default values of Paramics were not adapted.

Calculation of time steps

More time steps per second increase the number of calculations per second on which the detail of vehicle movements increase. Especially in congested situations, vehicles will see more opportunities for lane changing because of the more developed and visible gaps between the vehicles. The author tested smaller time steps for the South African situation. It was found that two, five, seven, 10 and 20 time steps per second do not make a significant difference.

Seed value

The seed value is the starting point of a simulation, chosen by a random number generator and directly influencing the outcome of a simulation. During a certain test, it was found that the seed value does influence the results. For the purpose of this study, it was concluded to use three different seeds per run to eliminate coincidences.

6.5 Applicability of Paramics parameters

Traditionally, driving behaviour was researched, measuring speeds and headways on the road. In South Africa, this type of research is completely lacking.

During the last 10 years or so, a new field of research, using self-reported driving behaviour via questionnaires, has emerged. The original driver anger scale (DAS) was developed in the United States by Deffenbacher (Deffenbacher et al, 1994). Since, the original DAS or similar self-reporting questionnaires have been used in many countries. Examples of countries where these studies have been conducted are: the United States (Miles and Johnson, 2003), Great Britain (Parker et al, 1998 and Underwood et al, 1999), New Zealand (Sullman, 2005) Israel (Shinar, 1998 and Yagil, 2001) and Turkey (Özkan and Lajunen, 2005). Moreover, researchers like Golias (Golias and Karlaftis, 2001) and (Özkan et al, 2006) report on international comparisons of self-reporting questionnaires of up to 19, mainly European, countries. In a study conducted in 2005 (Sukhai, 2006), a comparison of 10 countries, including South Africa, was carried out. South Africa appeared to have the highest aggression levels. Due to the recent availability of this study, the result could not be used in the simulations described in this dissertation.

The literature review indicates that there is a lack of driving behaviour research in South Africa. A sidestep to general behaviour literature was, therefore, made (section 2.7). It was concluded that that there are large differences between the different cultural groups in South Africa. The problem is how this knowledge can be used in micro simulation modelling.

Lajunen and Summala (1995) used Levenson's (Levenson, 1981) extensive assessment and provided measures such as Internality (individual differences in control), Chance (an external orientation), Powerful Others (such as doctors and therapists) and Self-esteem (influenced by personal mastery experiences) scales, which include subscales, each comprising of eight items in a seven-point format. Table 6.4 provides a selection of their work applicable to this research.

The reliability of the correlations in table 6.4 varies. The correlations for aggression (between 0.22 and 0.48) indicate that different attitudes to chance, power and self-esteem will provide different levels of aggression on the road. Chance as identified in this study (Lajunen and Summala, 1995) could be correlated to the concept of uncertainty avoidance as identified by Hofstede (1991). Moreover, powerful others and self-esteem is related to power distance (Hofstede, 1991), individualism (Trompenaars and Hampden-Turner, 1998) and status (Trompenaars and Hampden-Turner, 1998).

Table 6.4 Correlation between personality and traffic measures

	Traffic specific measures	
	Aggression	**Alertness**
Internality	-0.27*** -0.33***	0.06 0.09
Chance	0.42** 0.48***	0.09 0.02
Powerful others	0.22* 0.23*	0.21* 0.10
Self-esteem	-0.30*** -0.34***	-0.02 -0.06

* p<0.05; ** p<0.01; *** p<0.001
Source: Lajunen and Summala, 1995

Based on the above, it can be concluded that aggression and alertness (reaction time) are two important parameters in the South African setting. During the calibration, extensive tuning of these parameters is needed.

6.6 Calibration results

Based on section 6.4, it was concluded that the seed value, target headway (MTH), reaction time (MRT), aggression and awareness need to be investigated during the calibration process. This further investigation was conducted in the following manner:

- Seed value: every setting of parameters was run for three different seed values.
- MTH: based on previous work by Innovative Traffic Solutions (unpublished) and Vreeswijk (2004) it was concluded that the MTH, for the South African situation, will be close to 0.5. The trial and error approach to fit the MTH, therefore, used 0.5 seconds as a starting point.
- MRT: based on previous work by Innovative Traffic Solutions (unpublished) and Vreeswijk (2004) it was concluded that the MRT should be 0.35.
- Aggression and awareness: can have a normal distribution (the majority of people will act in an average manner) or a squared distribution (25% of people are not aggressive or alert at all, 25% of people are slightly aggressive or aware, 25% of people are quite aggressive or aware and 25% of people are very aggressive or aware). All combinations of normal/squared distributions for aggression and awareness were tested.

It needs to be mentioned that Paramics provides the possibility to change the 'steepness' (the standard deviation σ) of the normal distribution. This is done using a multiplier. A single multiplier is used for the normal distribution, while a multiplier of two or four leads to 'steep' distributions. In this dissertation, all settings (over 50 different ones) were tested. With regards to the multiplier, it was concluded that the normal setting (single multiplier) performed best. Similar results were found in the literature (Jansen, 2005) where speed limit differences for the different multipliers were not significant.

Paramics can also use a skewed distribution (setting A and B). It was found that a skewed distribution does not represent South African driving behaviour. Distribution A overestimates the speed of vehicles, while distribution B underestimates the driving speed. Again, this result is similar to the results found by Jansen (2005).

It was concluded that either the normal (with single multiplier) or squared distribution best represents South African driving behaviour. Table 6.5 provides a selection of the results for these settings. To be complete, a default run with default settings (run: default) for MTH, MRT, aggression and awareness was calculated. The results show that the volume and lane distribution are very different from the actual measured values. It was, therefore, concluded that it is not appropriate to accept the default settings, neither for the BSH nor for the N2.

Before using Paramics for the corridors, the effect of increasing the OD-matrix was investigated. It was concluded that the effect is minimal and that this is not the way to increase volumes on the road.

During the calibration process, it was found that a normal distribution for aggression and a squared distribution for awareness are most appropriate for the BSH. For the N2, a squared distribution for aggression, as well as awareness, proved to be better.

Analysing the results for the BSH with a MTH of 0.50, 0.55 and 0.60, it was found that all volumes are higher than the actual volumes. The difference for a MTH of 0.50 and 0.55 is limited and accounts for future growth. The volumes estimated for the runs using a MTH of 0.60 are too high. It was, therefore, concluded that a MTH of 0.50 or 0.55 needs to be used in the sequel of this dissertation.

Analysing MTHs of 0.50, 0.55 and 0.60 for the N2 gave minimal differences. For a MTH of 0.60 the utilisation of the middle lane is slightly higher, which is undesirable. Modelling a MTH of 0.50 results in a utilisation for the fast lane that is slightly lower than the results for the 0.55 MTH. Although the distribution over the different lanes does not meet the equal distribution requirement on the N2, it was concluded that a MTH of 0.55 and a MRT of 0.35 should be used.

Based on section 2.8, indicating that there are large behavioural differences in South Africa, it is not surprising that a squared distribution was found for awareness. South Africans from different cultural backgrounds score differently with regards to awareness.

A squared distribution for aggression represents the large variance in driver behaviour and experience (based on expert analysis, as well as the fact that one out of five licences are fake[1]) as well as the large variance in vehicle quality (about 10% of all accidents are caused by vehicle factors (NDoT, 2003)). It is striking that the results for the BSH show that a normal distribution best represents local driving behaviour, while a squared distribution performs best for the N2. This confirms the difference between drivers from the Gauteng province (Vaalies) and Cape Town drivers (Capies) often communicated

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[1] www.wheels24.co.za/News/

by the general public. Moreover, the representation of drivers with different cultural backgrounds is not equally distributed. There are differences between Gauteng and Cape Town as well as between the urban wealthy and the urban poor.

Table 6.5 Volume and lane distribution calibration

Input								Output			
CASE	RUN	SEED	OD-MATRIX	TARGET HEADWAY	REACTION TIME	AGGRESSION	AWARENESS	VOLUME	LANE DISTRIBUTION (percentages)		
									Lane 1	Lane 2	Lane 3
BSH	Actual		2001 2002					16 916 17 437	28.6 30.7	35.3 33.6	36.1 35.7
	Default		100%	1.0	1.0	N	N	15 572	33.2	36.6	30.3
	OD8A OD8B OD8C	1111 2222 3333	100%	0.50	0.35	N	Sq	18 128 17 940 18 418	30.1 30.0 30.5	35.4 35.8 35.8	34.5 34.1 33.7
	OD9A OD9B OD9C	1111 2222 3333	100%	0.55	0.35	N	Sq	17 673 18 015 18 086	31.0 30.6 30.5	35.1 35.9 35.7	34.0 33.5 33.7
	OD10A OD10B OD10C	1111 2222 3333	100%	0.60	0.35	N	Sq	19.800 18.081 18.353	30.5 30.5 30.7	35.4 35.7 35.6	34.0 33.8 33.7
N2	Actual	Loop 3 Loop 4	2004					15 190 14 510	31.6 31.9	34.9 35.5	33.5 32.6
	Default	1111 2222 3333	100%	1.0	1.0	N	N	12 166 12 038 11 823			
	JL3A JL4A	Loop 3 Loop 4	100%	0.50	0.35	Sq	Sq	15 305 14 725	31.4 30.8	40.8 40.5	27.7 28.7
	KL3A KL4A	Loop 3 Loop 4	100%	0.55	0.35	Sq	Sq	15 299 14 781	31.4 30.7	40.6 40.7	28.0 28.6
	LL3A LL4A	Loop 3 Loop 4	100%	0.60	0.35	Sq	Sq	15 223 14 661	31.2 30.3	41.0 41.0	27.8 29.6

Note: The grey background indicates that the results were not accepted based on that parameter

A superficial analysis with regards to lane distribution on the N2 was carried out for the peak period (between 06h30 and 08h00). It was found that the slow lane carried 29.8%, the middle lane 38.3% and the fast lane 31.9%. This distribution is acceptable, as it is close to the measured distribution.

To identify the final settings for the BSH, a headway analysis was carried out. Unfortunately, headway information is not available for the N2. International literature (see section 5.1.4) indicates that headways of less than three seconds generally belong to followers. Therefore, the analysis focussed on headways shorter than three seconds (see table 6.6).

Table 6.6 Analysis of follower's headways (<3s) for the BSH

INPUT							Output						
RUN	SEED	OD-MATRIX	TARGET HEADWAY	REACTION TIME	AGGRESSION	AWARENESS	VOLUME	AVERAGE HEADWAY (seconds)			HEADWAY FOLLOWER (<3s)	VARIANCE HEADWAY FOLLOWER (<3s)	HEADWAY PEAK
								Lane 1	Lane 2	Lane 3			
Actual		2001 2002					16 916 17 437	28.6 30.7	35.3 33.6	36.1 35.7	1.62	0.36	1.2-1.8
Default		100%	1.0	1.0	N	N	15 572	33.2	36.6	30.3			
OD8A OD8B OD8C	1111 2222 3333	100%	0.50	0.35	N	Sq	18 128 17 940 18 418	2.95 2.96 2.92	2.51 2.49 2.46	2.50 2.59 2.62	1.37 1.40 1.40	0.51 0.52 0.52	0.4-0.8 0.4-0.8 0.4-1.0
OD9A OD9B OD9C	1111 2222 3333	100%	0.55	0.35	N	Sq	17 673 18 015 18 086	2.95 2.90 2.94	2.57 2.49 2.48	2.68 2.64 2.63	1.39 1.36 1.38	0.50 0.50 0.51	0.4-1.0 0.4-1.0 0.4-1.0
OD10A OD10B OD10C	1111 2222 3333	100%	0.60	0.35	N	Sq	19.800 18.081 18.353	2.93 2.91 2.88	2.54 2.49 2.46	2.59 2.60 2.59	1.35 1.38 1.38	0.49 0.49 0.49	0.6-1.0 0.4-1.0 0.4-1.0

Note: The grey background indicates that the results were not accepted based on that parameter

The headways for followers in the model are slightly shorter than the headways of actual followers measured on the BSH. The modelled variance in follower headways is slightly larger than those measured on the BSH. The differences between the different parameter settings (runs: OD8A-OD10C) is minimal. Based on the headway peak analysis, it was concluded that a target headway of 0.55 seconds, a reaction time of 0.35 seconds, a normal distribution for aggression and a squared distribution for awareness provides modelling results very similar to the actual measurements. In the next chapter these settings are referred to as the base case.

Based on the analysis, it was also concluded that the seed number does influence the results. All scenarios will, therefore, be calculated for three different seed values.

Finally, changes in volume over time are compared with the average volumes (seed average) for the base case. The results are included in figure 6.6.

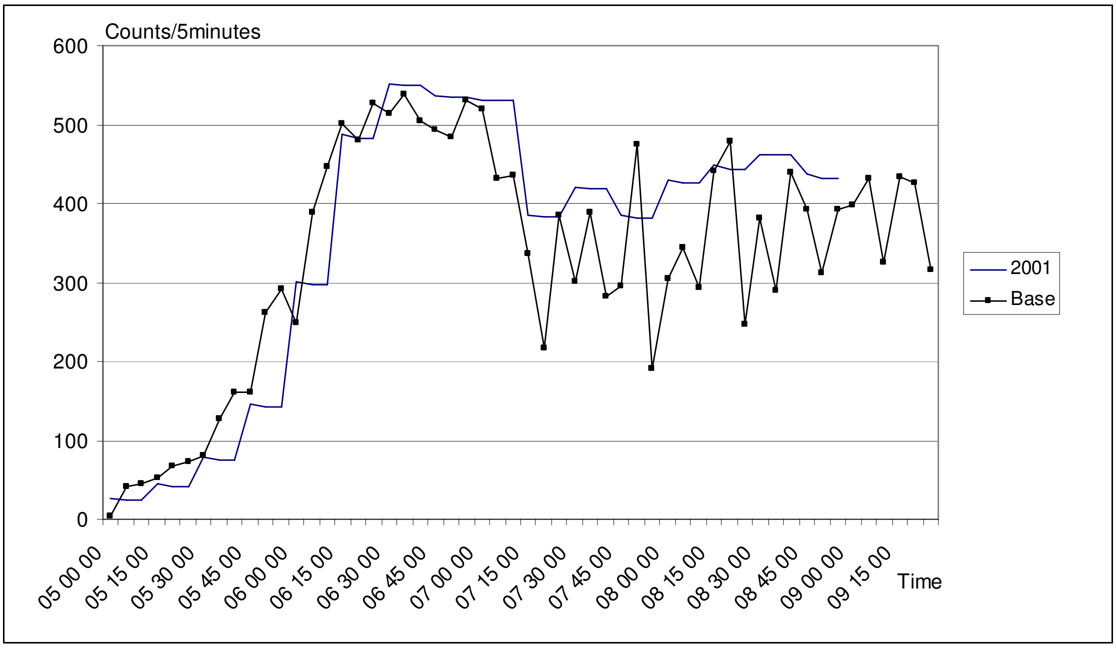

Figure 6.6 Comparison of actual and modelled volumes over time for the BSH

It can be concluded that the modelling results follow the actual measurements very well, especially for the first two hours. Thereafter, the modelling results alternate quite a bit. Unfortunately, this is typical for microscopic simulation results in congested conditions. The results were accepted. During the rest of this dissertation, these results will be referred to as the base case for the BSH.

The traffic volumes over time per five minute intervals for the N2 were checked. Figure 6.7 provides a graphical overview of the findings. It was concluded that the average base case (seed results averaged) follow the measured profile perfectly. As congestion on the N2 is less severe than congestion on the BSH, the alternation of five minute results, as witnessed for the BSH, do not occur.

As indicated in section 6.2, travel time information is also available for the N2. It was, therefore, decided to identify a vehicle travelling from the airport on ramp to Main Road per five minute intervals. Figure 6.8 provides a comparison of the measured travel times and the modelled travel times.

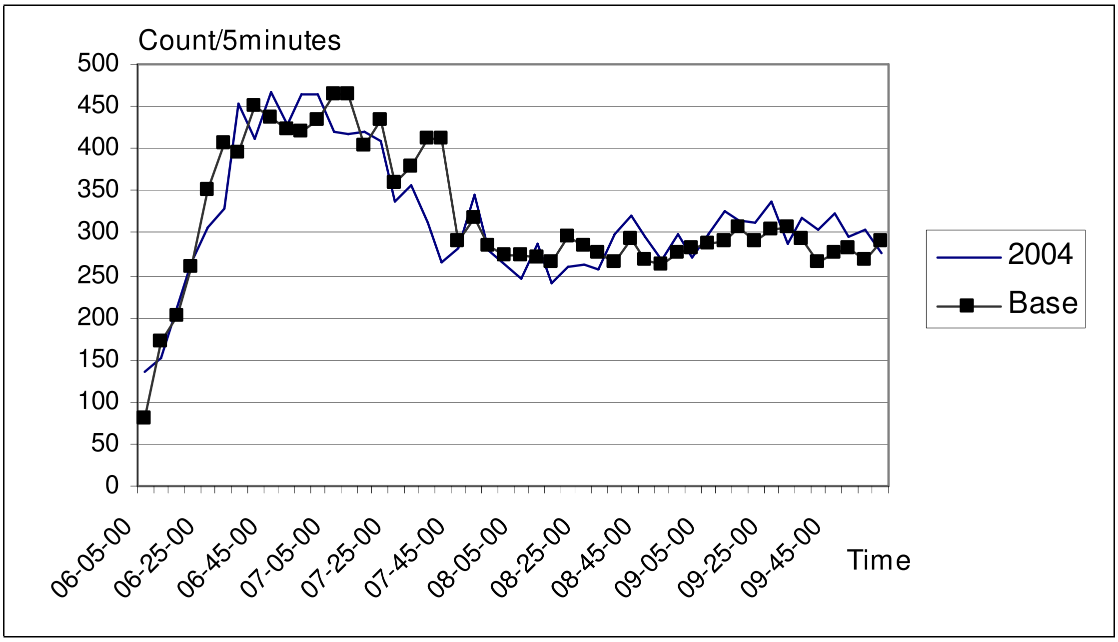

Figure 6.7 Comparison of actual and modelled volumes over time for the N2

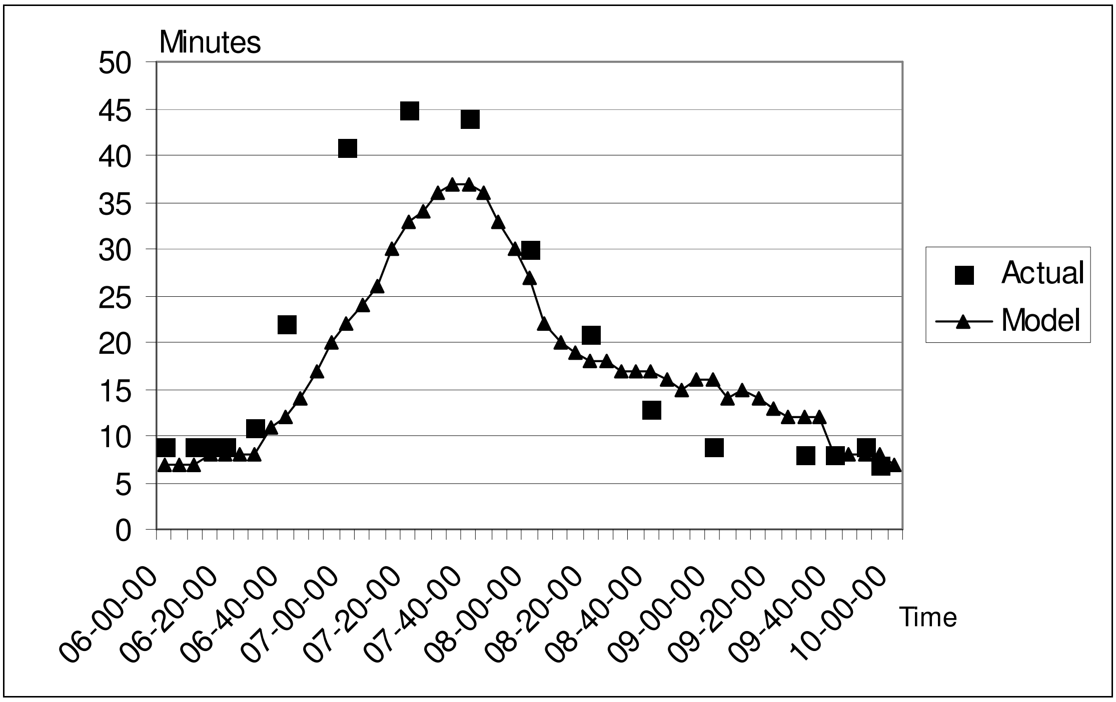

Figure 6.8 Travel time comparison for the N2

A travel time analysis shows that the build up of traffic in the model is slower than it actually happens on the N2. Moreover, during the peak period, travel times are about 10 minutes less than measured. The lack of accurate lane changing behaviour is probably responsible for these findings. In addition, minibus taxis abuse on and off ramps, causing disturbances of the traffic flow that the model will not include.

During the tail of the peak period, the model calculates travel times that are slightly higher than measured. Nevertheless, the maximum difference is five minutes, which is acceptable.

It can be concluded that the modelling results follow the actual measurements very well. During the rest of this dissertation, the results for the N2 will be compared with this base case, using 0.55 for the MTH, 0.35 for the reaction time and a squared distribution for aggression and awareness.

6.7 Résumé

During the calibration process it was concluded that the default settings used by Paramics, which are based on UK driver behaviour, do not represent South African driving behaviour.

Car following, gap acceptance and lane changing are core attributes in microscopic simulation models with regards to driver behaviour. The microscopic simulation model, Paramics, uses the parameters MTH, MRT, aggression and awareness to model driver behaviour.

It was established in chapter 2 that there are large behavioural differences between South Africans within different cultural backgrounds. Literature introduced in this chapter (Lajunen and Summala, 1995) underpins the assumption that personal characteristics influence driving behaviour. The large variety of general behaviour indicates that South African driver behaviour does not follow a normal distribution.

The data available for the two case studies introduced in this chapter (the BSH and the N2) differ. The BSH was calibrated using volumes (per lane), volume distributions over time and headways (including the distribution). For the N2, the volumes (per lane and distribution) and travel times were used.

The assumption, based on general South African behaviour literature (see section 2.8), that South African driver behaviour does not follow a normal distribution, was underpinned during the calibration process. For the BSH, it was found that a MTH of 0.55, a MRT of 0.35, a normal distribution for aggression and a squared distribution for awareness best fitted the measurements (see table 6.7). For the N2 the parameter settings were the same, except for aggression that best fitted the measurement with a squared distribution.

Table 6.7 Summary of the base case settings

Parameter	BSH	N2
Mean Target Headway	0.55	0.55
Mean Reaction Time	0.35	0.35
Aggression	N	Sq
Awareness	Sq	Sq

It appeared to be impossible to fit the distribution over the lanes for the N2 case study. Further investigation of the peak traffic showed a better fit. Nevertheless, it can be concluded that the current parameter values do not represent off-peak lane distributions in South Africa.

Analysis of the travel times shows that the model builds up the peak at a slower pace. Moreover, it underestimates the maximum travel time by about 10 minutes. On the other hand, travel times at the tail of the peak period are overestimated by about five minutes.

The Paramics structure and algorithms are calibrated for UK driver behaviour. It was concluded that the way Paramics models off-peak lane distributions, lane change behaviour and overtaking does not represent South African behaviour. The only way to overcome this difference is to re-programme part of the Paramics code. Re-programming Paramics falls outside the scope of this investigation.

Chapter 7

Ex ante evaluation of ITS scenarios

This chapter provides an overview of the estimated effects of different ITS measures. The effects are based on ex ante calculations conducted with the microscopic model Paramics. In chapter six, parameter settings for MTH, MRT, aggression and awareness were found that closely represent South African driving behaviour and traffic flows. These parameter settings will be used in this chapter. This chapter will contribute towards answering the following questions:

- What is the magnitude of impacts of potential ITS measures in the South African context?
- Is the magnitude of impacts of ITS measures in South Africa different from international experiences?
- Should ITS measures be implemented in the South African context?

Based on the ITS scan (see chapter 3), it was decided to model the following scenarios for both corridors, the BSH as well as the N2 near Cape Town:

- a bus and HOV lane,
- homogenising traffic flows via speeds limits using VMS, and
- ramp metering.

Different indicators can be used to compare scenarios (see also table 6.1). The comparison in this chapter includes the efficiency indicators volume (including distribution over the lanes), the mobility indicator travel time, as well as the safety indicators speed and time headways. Although the literature review (see section 6.1.5) indicated that time headways and TTC provide different results and should both be included in the analysis, in this study it only makes sense to analyse time headways as the TTC provided by Paramics is highly correlated and almost identical to time headways. Nevertheless, the TTC is used to analyse speed differences between leading and following vehicles.

As mentioned before, the seed number of the microscopic simulation can have a substantial impact on the results. It represents the inherent stochastic nature of the simulation process. In order to reduce the impact of the seed number, it was decided to analyse the average results for three different seed numbers per scenario. Ideally, multiple runs (i.e. 100) would be required to eliminate the stochastic nature of the simulation process (different seed numbers). Moreover, analysis of the different results for the seed numbers would add insight to the robustness of the model. Analysis of the differences per seed number falls outside the scope of this dissertation and would most probably warrant a separate PhD study. Moreover, the limited amount of data available to compare modelling results with, limits the validation possibilities.

It needs to be mentioned that the data analysis is carried out more or less in the middle of both corridors. In both cases, the traffic problems become more severe towards the end of the corridor. This is due to more traffic joining the highway than leaving it. Microscopic models often have problems simulating ‘over capacity’ traffic flows. It was, therefore, decided to focus on areas where traffic volumes are close to capacity. Moreover, the potential gain is highest in this situation.

7.1 Bus and HOV lane

A dedicated bus- and HOV lane is an infrastructural measure. ITS systems are needed to take care of enforcement. In this scenario, it is assumed that the enforcement of the bus and HOV lane is 100%. Studies with regards to the effects of HOV lanes focus on a change in travel time. A travel time reduction of up to eight percent is estimated for ex ante studies where an HOV lane is added (Dahlgren, 1998). In cases where an existing lane is used to create an HOV lane, the travel time increases with up to 200% (Johnston, 1996).

South Africa has shown an interest in bus lanes. Part of the N2 near Cape Town currently includes a dedicated bus lane. Nevertheless, this bus lane is not enforced and the lane is, therefore, abused by private vehicles. To get an idea of the effects of a bus and/or HOV lane, it was decided that the bus/HOV lane on the N2 would be enforced. As the road changes from a two-lane highway into a three-lane highway, no bottleneck is created.

On the BSH one of the existing lanes will be converted into a bus/HOV lane. For private vehicles the road will change from a three-lane road to a two-lane road. Traffic is informed timely that they have to divert to the slow and middle lane. This obviously creates a bottleneck. Buses and HOVs are supposed to use the third lane. In all scenarios the buses can use the dedicated lane. The HOVs that are allowed in the lane vary (more than three people versus more than two people versus more than one person). Moreover, a final scenario with a shift of five percent from Single Occupancy Vehicles (SOV) to HOV is included. In this scenario it is assumed that two drivers carpool. With the current service level of public transport, it is unlikely that car owners will shift to public transport. Due to the shift, there is a 2.5% decrease in vehicles that will be assigned to the network.

South Africa does not have a specific policy with regards to the lane that should be used as bus/HOV lane. An important issue that has been identified is that if the slow lane is used, the risk of abuse would be large due to the fact that vehicles entering the highway need to cross the bus/HOV lane. The fear is that many would use the lane and indicate that they just entered the highway.

Figures 7.1a and 7.1b include a map of both highways at the start of the bus/HOV lanes.

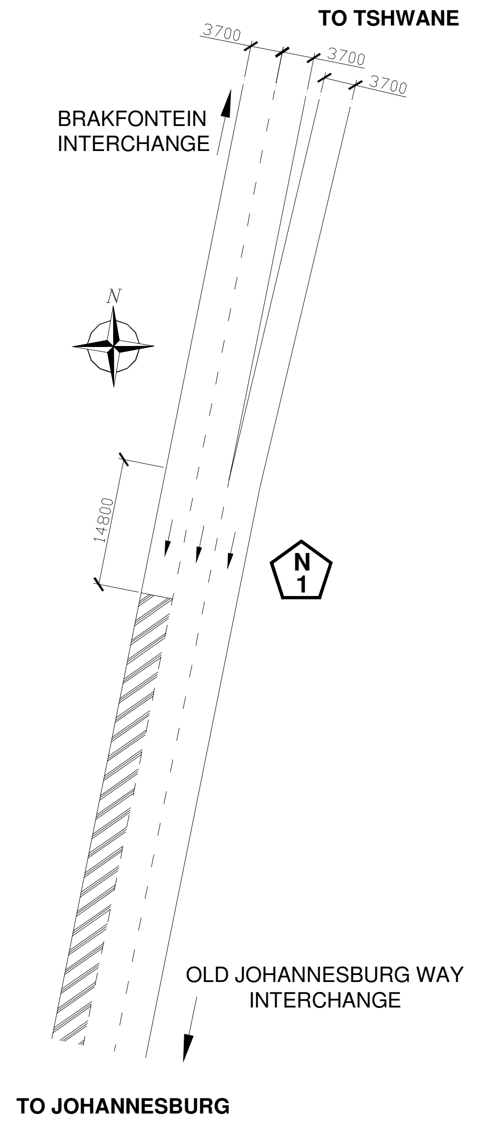

Figure 7.1a Position of the HOV lane on the BSH

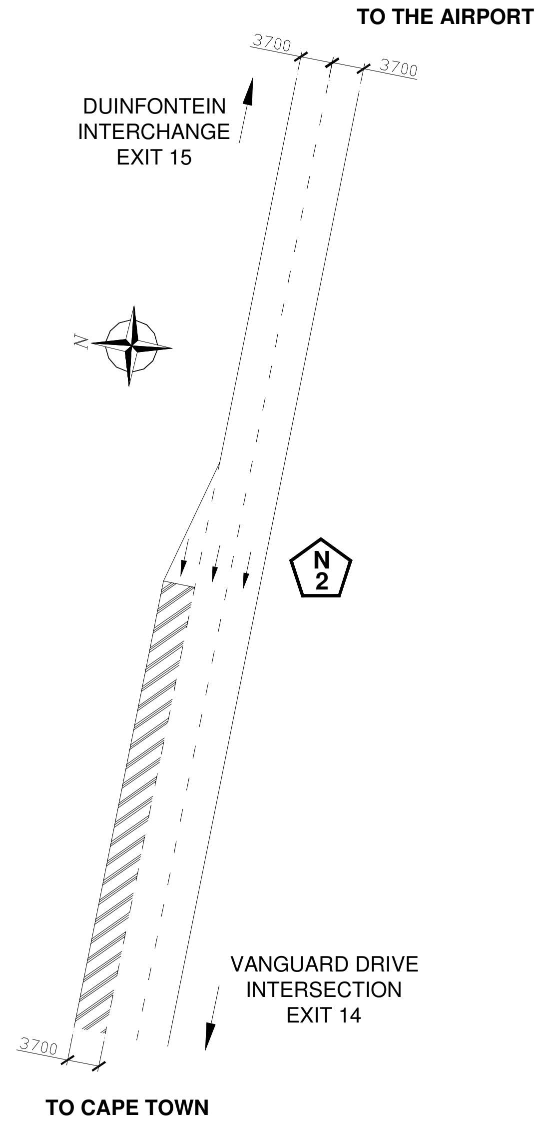

Figure 7.1b Position of the HOV lane on the N2

7.1.1 Comparison of traffic volumes

Traffic volumes on both the BSH and N2 decrease if a bus and/or HOV lane is introduced. For the BSH, the decrease is unacceptable. Table 7.1 provides an overview of the results. Up to 47% of vehicles would not be able to use the highway. Even if every vehicle with more than one person is allowed on the dedicated lane, traffic flows are still more than 30% lower than the base case. Analysis of the peak hour shows similar results, although the HOV lane for more than one person (and a shift of five percent of the Single Occupancy Vehicles (SOV)) shows a decrease of only 19% to 21%. Based on European and USA practice, a shift of maximal four percent has been witnessed if no other major public transport improvements are carried out. The two and three percent difference in the reduction of vehicles between the HOV >1 and the HOV >1 and a five percent shift from SOV, is due to an overall reduction in vehicles in the later scenario. It can be concluded that both the HOV >1 scenario and the HOV >1 and a five percent shift perform similar with regards to volumes.

Table 7.1 Traffic volumes for bus and HOV lane scenarios

Scenario	Ben Schoeman Highway				N2 near Cape Town			
	Peak period (05:00 – 09:30)		Peak hour (06:20-07:20)		Peak period (06:00 – 10:00)		Peak hour (06:30-07:30)	
	Abs	%	Abs	%	Abs	%	Abs	%
Measured traffic volume	17 437		6 200		15 190		5 048	
Base case	17 788	100	5 412	100	15299	100	5 011	100
HOV lane with > 3 people	9 471	-47	3 093	-43	13 866	-9.5	3 730	-26
HOV lane with > 2 people	11 655	-34	3 608	-33	14 240	-7	3 915	-22
HOV lane with > 1 person	12 422	-30	4 386	-19	15 361	+0.4	4 709	-6
HOV lane with > 1 person and a 5% shift from SOV	11 784	-33	4 278	-21	14 945	-2.3	4 160	-17

Note: On the BSH the loop is located seven kilometres and on the N2 two kilometres after the introduction of the bus/HOV lane.

Traffic volumes on the BSH are close to capacity. A slight disturbance can create major problems. Based on the results in table 7.1, it can be concluded that the HOV lane on the BSH creates a severe bottleneck. The traffic volumes drop by more than one third due to the dedicated lane. Implementation of a HOV lane on the BSH in the way it is suggested in this study is, therefore, not recommended. Figure 7.2 provides an overview of the blockage created.

The remaining part of this section will mainly focus on the analysis of the HOV lane for the N2. The BSH is only used for TTC and headways, as actual information on these indicators is available.

The reduction of traffic volumes on the N2 is less severe than on the BSH. The fact that the N2 changes from two lanes into three lanes when the bus/HOV lane starts, eliminates the creation of the severe bottleneck that is witnessed on the BSH.

The loss in traffic handled by the highway system is up to 29%. Nevertheless, the HOV >1 shows a small increase. Moreover, the 2.3% decrease for the scenario with a five percent shift is again due to the decrease of total vehicles by 2.5%. Effectively, this scenario has a 0.2% increase. Unfortunately, analysis of the N2 for the peak hour is less promising. The loss in throughput is between six percent and 26%.

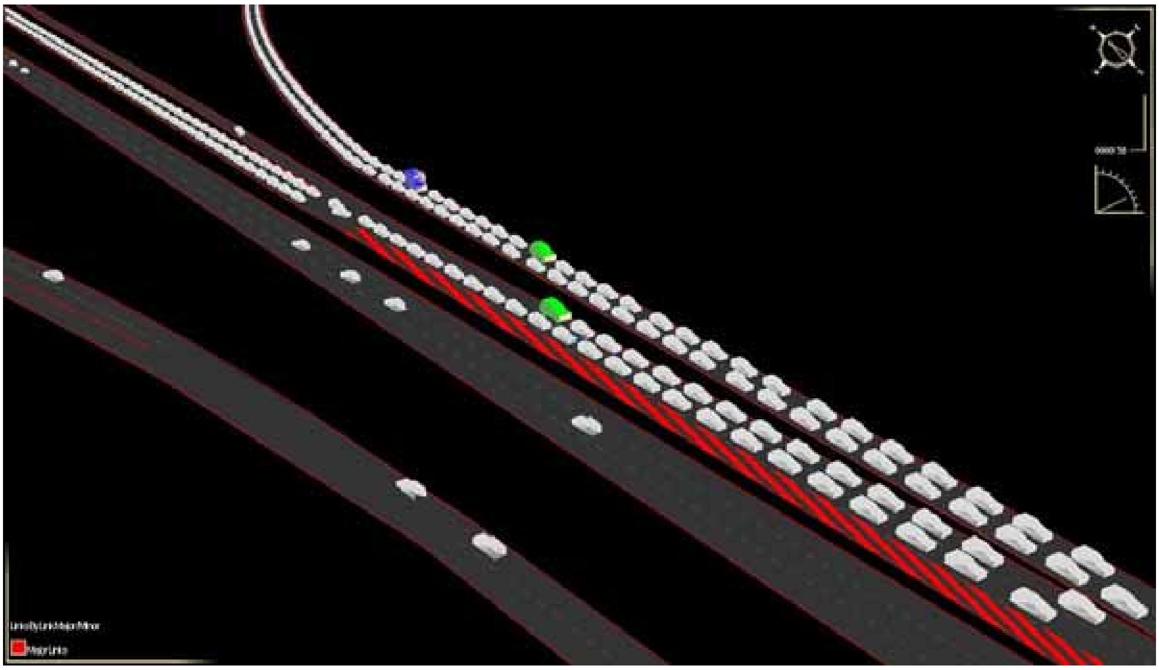

Figure 7.2 Picture of the blockage on the BSH due to the HOV lane

A further analysis of the volumes per five-minute intervals shows that the volume effect during the peak is not necessarily negative. It appears that the peak period smoothens (see figure 7.3).

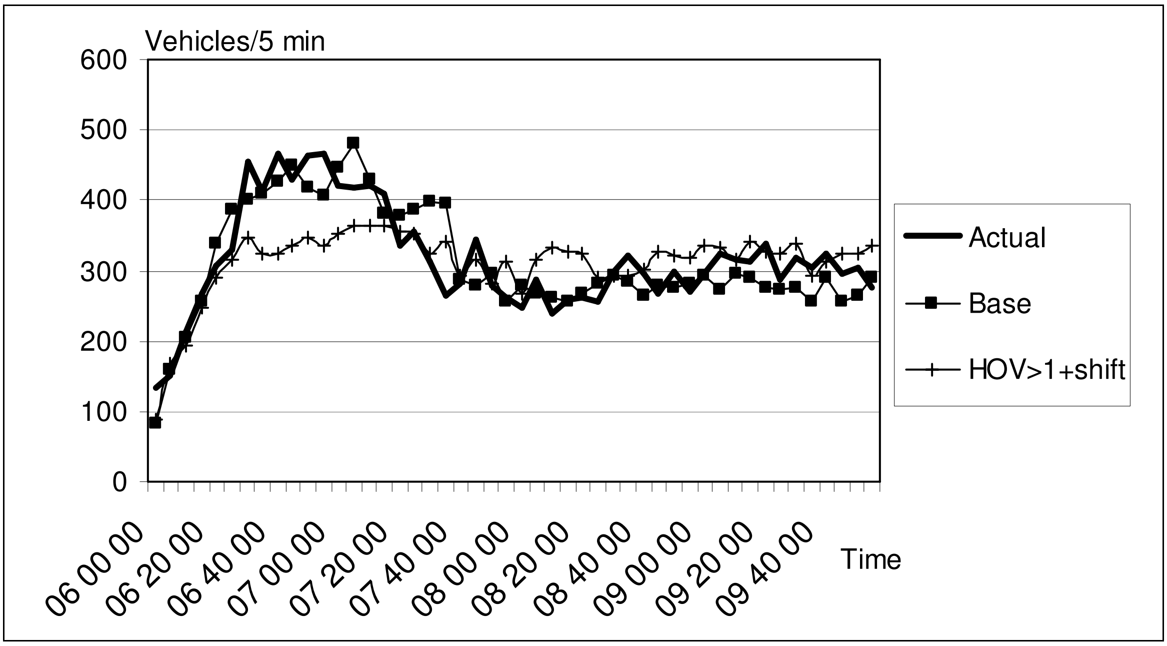

Figure 7.3 Peak period volume of HOV scenarios for the N2 (%)

Analysis of peak-hour volumes per lane for the base scenario indicates that the maximum throughput on the N2 is between 1 550 and 1 650 vehicles in the slow and fast lanes, while the middle lane carries up to 2 000 vehicles. It is common that the fast lane does not carry the maximum number of about 2 000 vehicles per hour. It was found that the maximum volume of 1 650 vehicles in the slow lane is due to the high number of on and off ramps on this corridor.

Although a comparison of the volume distribution over the lanes during peak hour for different scenarios provides very interesting findings, this analysis does not provide insight with regards to the HOV scenarios due to the smoothening of traffic over the peak period. It was, therefore, decided to analyse the percentage of traffic per lane for the peak period (figure 7.4).

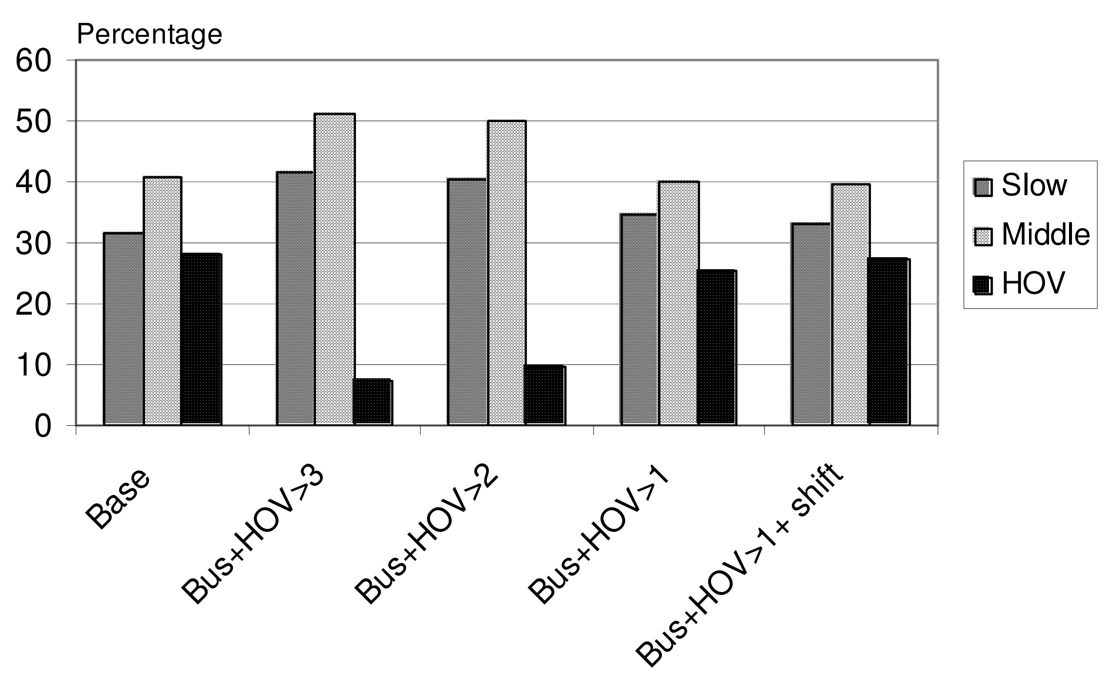

Figure 7.4 Lane distribution of HOV scenarios for the N2

For the base case scenario, the middle lane carries about 40% of all traffic, while the slow and fast lane carry between 28% and 32%. It appears that the middle lane carries up to 50% of all vehicles during the peak period if the HOV lane is introduced. The volumes of the slow lane increase up to 40%, depending on the performance of the bus/HOV lane. The bus/HOV lane, in comparison, carries as little as eight percent of the traffic if only vehicles with more than three occupants are allowed in this lane.

The lane distribution for the HOV>1 and HOV>1 + shift are very similar to the base case. Allowing vehicles with two or more occupants into the HOV lane shows optimal utilisation, as a third lane is created (as is the case on the N2).

Although the demand shift of five percent is common, special demand measures and a major improvement of the public transport system might encourage more drivers to carpool or take the bus. Obviously, this would change the presented results (most likely better results).

7.1.2 Travel time comparison

During the calibration (chapter 6), it was found that Paramics underestimates travel time for the N2 in the current situation. Although a more accurate estimate of the travel time is required, a comparison of the estimated travel time for the current situation with the bus/HOV scenarios will provide insight into the effectiveness of the bus/HOV lane.

Unfortunately, it is not possible to analyse travel times per lane. It was, therefore, decided to compare the travel time of SOVs and buses. In all scenarios the buses will use the HOV lane, while the SOVs in all scenarios will use the slow or middle lane.

Analysing the differences in travel time (figure 7.5) between the base case and the bus/HOV scenarios, for the N2, show that SOVs have a substantially longer overall travel time than the base case scenario. The HOV vehicles that are allowed into the dedicated lane show an improvement in travel time. If more vehicles are allowed in the lane, this benefit decreases.

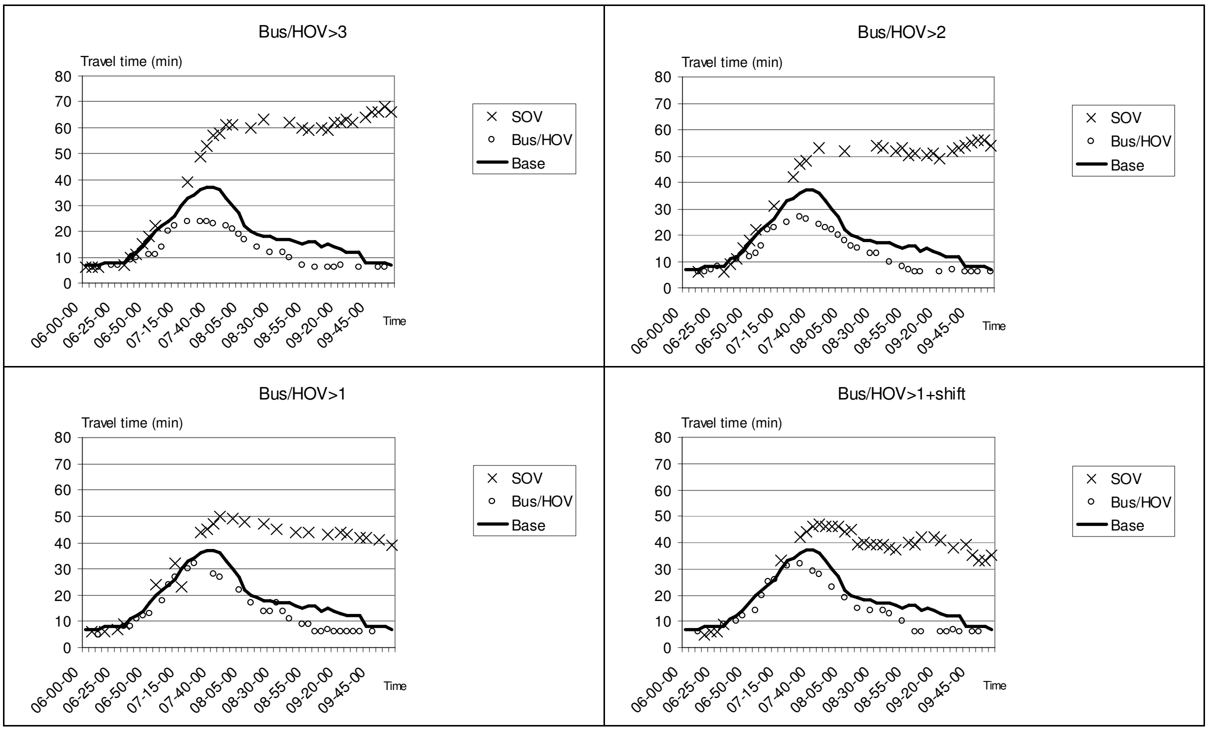

Figure 7.5 Travel time comparison between SOVs and HOVs for the N2

The travel time analysis clearly indicates that the introduction of a bus/HOV lane leads to an improvement in the service level for this category of vehicles, while the service level (capacity) for other vehicles decreases. In reality, this will lead to blockages on the road leading towards the N2. The liveability of the different suburbs will be affected and congestion will occur. The municipality needs to make a decision whether either of these scenarios should be implemented.

7.1.3 Speed comparison

Speed and travel time are strongly correlated. Nevertheless, travel time provides an indication of the service level with regards to the mobility (and comfort) criteria, while speed is a safety indicator. Analysing detailed speed data shows that the average speed profiles for different scenarios before the start of peak hour (06h30) are equal. Differences only occur after the start of the peak period. Analysing the average speed for the whole period indicates that all scenarios show an average drop in speed (see table 7.2).

Table 7.2 Average speed for the peak period of HOV scenarios on the N2

Scenario	Average speed (km/h)			
	Overall	Slow	Middle	Bus/HOV
Base case	113	99	110	115
HOV lane with > 3 people	104	88	91	113
HOV lane with > 2 people	104	89	90	111
HOV lane with > 1 person	104	89	92	107
HOV lane with > 1 person and a 5% shift from SOV	91	87	87	94

All scenarios show a drop in speed, but the drop in speed varies over the lanes. The drop is smallest on the HOV lane. The smaller number of vehicles obviously allows maintenance of higher speeds. For public transport vehicles, this means maintaining the maximum speed (as that is lower than 115 km/h).

The overall drop in average speed is a minimal nine km/h. The international rule of thumb (www.swov.nl) is that each kilometre reduction in speed will reduce the number of fatalities by five percent. The City of Cape Town (www.capetown.gov.za) uses the same number. Applying this number to the drop in average speed, it can be assumed that the number of fatalities would almost halve.

This speed analysis is obviously very crude. Based on the data provided by Paramics, it is possible to refine the analysis. It was decided to focus on the BSH as actual speeds are available. With regards to safety, only vehicles with a TTC of less than three seconds are worth analysing. Vehicles with a TTC longer than three seconds are not included in this analysis. Moreover, if the follower is driving slower than the leader, the data is also excluded. Table 7.3 provides an indication of the number of potential conflicts. As the simulation uses several runs and has, therefore, more vehicles, only the percentages are analysed.

Comparing the base case with the actual situation for the BSH, it is clear that the base case underestimates the number of vehicles with a TTC of less than three seconds and a speed difference of at least 20 km/h. On the other hand, vehicles with a TTC of less than one second and a speed difference of at least 20 km/h are slightly overestimated.

Table 7.3 Vehicles with a TTC of less than three seconds for HOV scenario on the BSH (percentage)

	Actual	Base case	HOV >1 person	HOV >1 person + 5% shift
TTC < 3 sec and ΔSpeed ≥ 20 km/h	12.6	9.3	4.1	6.6
TTC < 1 sec and ΔSpeed ≥ 20 km/h	2.1	2.8	0.1	0.1

Comparing the BSH base case with the other scenarios, it is clear that the scenario with the Bus/HOV lane utilised by more than one person, performs much better. The number of potential conflicts is clearly less. In the scenario with a five percent shift, the risk for vehicles with a TTC of less than three seconds is higher than for the bus/HOV > 1 scenario. Further analysis is needed to establish if this indicates a higher risk.

It was decided to graphically compare the following and leading vehicle. Figure 7.6 provides the graphs.

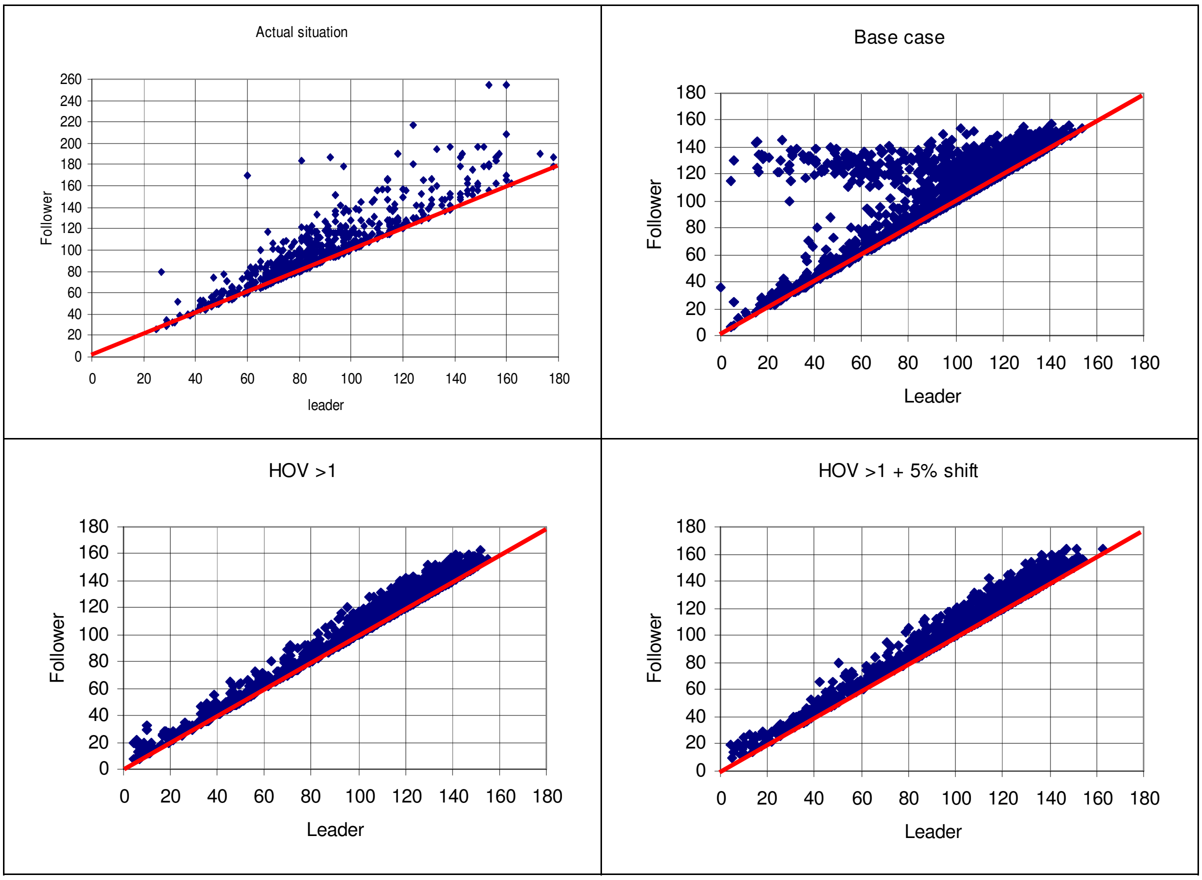

Figure 7.6 Comparison of leading/following vehicle speed with a TTC < one second of HOV scenarios for the BSH ($\forall_{ij}$: $S_i(t) < S_j(t)$)

It is obvious that the speed differences between the leaders and followers, in the measurements and base case, are not the same. The base case shows a band of vehicles that drive faster than the leader between 120 km/h and 160 km/h. The measurements do not show this band. Nevertheless, the speed differences are much higher. Speeds of followers up to 260 km/h have been measured. It needs to be mentioned that these measurements have been witnessed in the developed world as well. They are considered measuring errors and should not have been included. In this dissertation, it was decided to show the data as it was provided.

A detailed analysis of the band with high speed differences in the base case shows that in many cases the follower is decelerating already, although the speed difference at the loop is still high. This means that Paramics does avoid accidents. Nevertheless, these high speed differences between leaders and followers indicate that the traffic flow is not homogeneous.

Despite the difference between the base case and the actual situation, comparing the scenarios with the base case will provide an indication of the change in safety risk. Figure 7.6 clearly shows that the HOV scenarios are less risky than the base case. The differences between the two HOV scenarios included are not significant.

7.1.4 Headway analysis

Another safety related indicator is the headway. As a first step, the average headways were analysed. It appeared that the influence of the different seed numbers was so large that wide ranges of average headways were found. An analysis of the headway distribution, therefore, seemed a better indicator. The view on what a safe headway is (see section 6.1.3) varies between 0.9 seconds and three seconds. From the literature, it can be concluded that headways shorter than one second are dangerous. Figure 7.7 provides an overview of the headway distribution for the BSH.

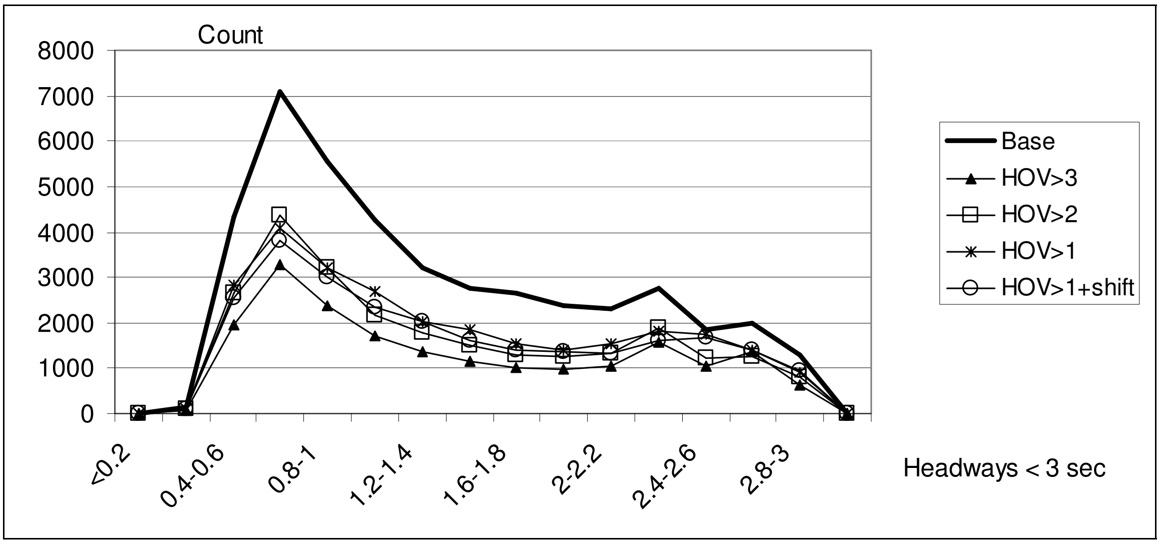

Figure 7.7 Headway distribution of HOV scenarios for the BSH

It is clear that the HOV scenarios decrease the number of short headways and, therefore, the safety risk. It can be concluded that the majority of vehicles that are not able to utilise the highway because of the reduced capacity and created bottleneck had short headways. Moreover, in the base case three lanes are available for all vehicles. This creates more opportunities for overtaking. Short headways are often measured before overtaking. An analysis of the headway differences for the fast lane should provide more insight (figure 7.8).

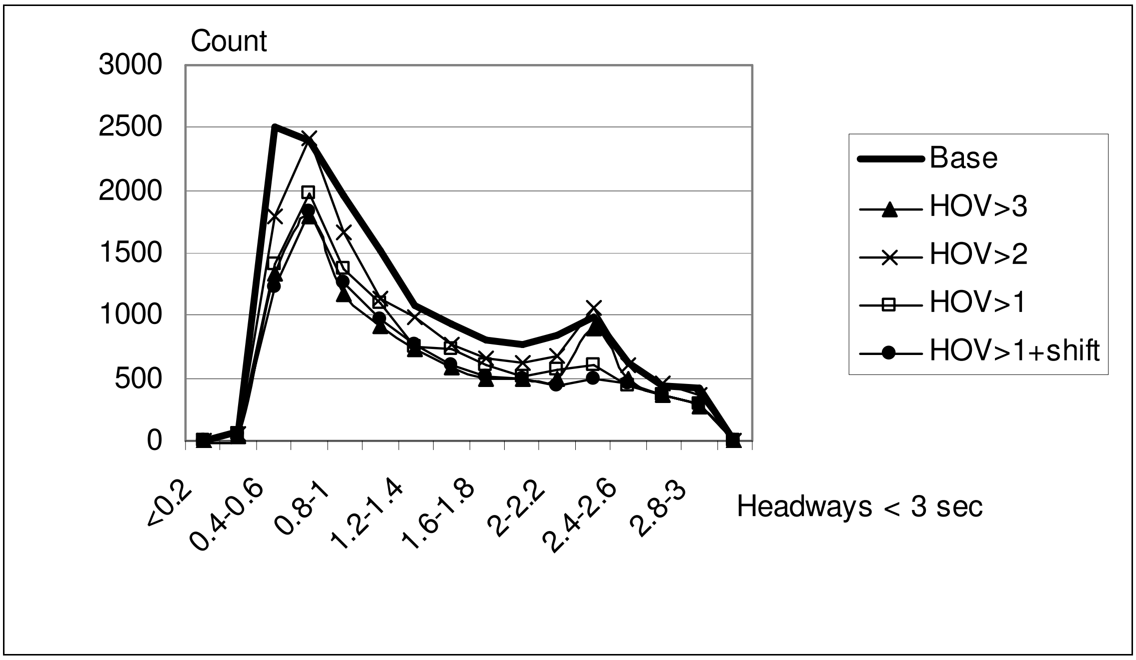

Figure 7.8 Headway distribution for fast lane of HOV scenarios for the BSH

Although the decrease in the number of short headways is less severe, all scenarios show a decrease compared to the base case. Based on the speed, TTC and headway analysis, it can be concluded that the HOV scenarios are safer than the base case.

7.1.5 Overall results

Both the BSH as well as the N2 generally show a drop in throughput if a bus/HOV lane is introduced. The only scenario that shows an increase is the bus/HOV lane for two or more people on the N2 during the peak period. Unfortunately, even this scenario shows a decrease during the peak hour. Based on this analysis, it can be concluded that the bus/HOV lane scenarios do not provide an efficiency benefit to road users.

The reduction in throughput on the BSH is much higher than on the N2. The different way of infrastructurally introducing an HOV lane (see also figure 7.1a and 7.1b), is the main cause of the higher drop in throughput for the BSH. Adding a lane appears to be more appropriate and will result in less throughput problems. Nevertheless, both corridors show the creation of a bottleneck just before the bus/HOV lane.

Field trips have shown that a lot of congestion occurs in the suburbs before vehicles get to the BSH, as well as the N2. A drop in throughput on the highway will lead to an increase of queuing in the suburbs and the liveability of the suburbs will, therefore, decrease.

All bus/HOV scenarios for the BSH show an increase in travel time. Where travel times start decreasing at the end of the peak period for the base case, travel times still increase for the bus/HOV scenarios at the end of the peak period.

In Cape Town, travel times stabilise at the end of the peak hour. Nevertheless, they are significantly higher than the travel times for the base case, which decrease after peak hour. The only scenario for the N2 that gives travel time results similar to the base case is the HOV lane for two or more people.

For both corridors, it appears that the HOV>1 and the HOV>1 with a five percent shift towards HOV have no significant differences with regards to mobility and safety indicators. The total demand in the HOV>1 with a five percent shift scenario is slightly (2.5%) lower. This is not sufficient to generate a significant improvement compared to the HOV>1 scenario. Demand management encouraging more than five percent of drivers to change their behaviour might well show better results. Within the current South African situation it is not likely that more than five percent of drivers will change their behaviour. A larger shift was, therefore, not included in this dissertation.

An analysis of the travel times for vehicles with two occupants shows the same trends. It is, therefore, questionable whether the introduction of the HOV lane will provide a mobility benefit to users. Although some international studies show small mobility benefits (eight percent decrease of travel time), many also find that HOV lanes do not provide mobility benefits. As mentioned, Johnston (1996) finds an increase in travel times of 200%.

With regards to speed, a drop in the average speed of between nine km/h and 25 km/h was found. This provides the first indication that the bus/HOV scenarios are safer than the base case. Further analysis of speed differences between the leading and following vehicle confirm this.

The only way to make bus/HOV lanes a success is by increasing the number of people using public transport and/or carpooling. To realise a shift towards public transport, the service level needs to be improved. Currently, public transport is only used by the urban poor who do not have another option.

7.2 Homogenising traffic flow via speed limits

Bonsall (Bonsall et al, 2005) estimated that speed limit compliance increases the throughput during peak by between 2.9% and 5.7%. The modelling exercise by Stemerding (Stemerding et al, 1999), unfortunately, did not result in clear trends. The authors suggested that the limits of the software influenced the results. Nevertheless, in the Netherlands and the USA many homogenising systems are put in place because the impacts appear to be large. Measured speed reduction in the Netherlands is between five and 14 kilometres per hour. The percentage of drivers speeding is reduced by between 25% and 31%. The SWOV (NL) estimates a reduction in accidents of around 20% (www.swov.nl). The USA (www.benefitcost.its.dot.gov) has measured injury accident reductions of between -20% and -29% (an estimated benefit of US$4-million).

An increase in throughput and reduction in injury accidents would be a considerable benefit in the South African situation. It was, therefore, decided to estimate the effects of homogenising traffic flows for the BSH and N2.

Several algorithms to lower the speed were tested. It appeared that the differences in results were minimal. This thesis, therefore, focuses on the most promising algorithm (the VMS shows a maximum speed of 80 km/h if the flow is 1 500 vehicles per hour per lane and 60 km/h if the flow is 1 800 vehicles per hour per lane). Moreover, as the differences were so low, it was decided to compare the homogenising traffic flow attempt via VMS with a scenario where the maximum speed is lowered to 80 km/h. In this scenario the ITS measures focus on 100% enforcement.

7.2.1 Comparison of the volumes

The first indication of the efficiency benefits of a VMS or reduction in the overall speed limit to 80 km/h can be gained by analysing the overall volumes (see table 7.4).

From table 7.4 it can be concluded that the change in volume for the BSH, as well as the N2, for both the peak period and peak hour, is minimal. Generally, a decrease in volume of up to about 3.5% is witnessed. Nevertheless, it appears that the efficiency is slightly better during the peak hour when implementing a VMS on the BSH, as well as the N2 (up to 1.9%).

Table 7.4 Traffic volumes of homogenising scenarios

Scenario	Ben Schoeman Highway				N2 near Cape Town			
	Peak period (05:00 – 09:30)		Peak hour (06:20-07:20)		Peak period (06:00 – 10:00)		Peak hour (06:30-07:30)	
	Abs	%	Abs	%	Abs	%	Abs	%
Measured traffic volume	17 437		6 200		15 190		5 048	
Base case	17 788	100	5 412	100	15 299	100	5 011	100
Variable Message Sign	17 549	-1.4	5441	+0.5	14 765	-3.5	5 107	+1.9
Fixed speed limit of 80km/h	17 148	-3.6	5248	-3.1	15 098	-1.4	4 986	-0.5

An analysis of the volume distribution during the peak period also indicates that all scenarios show more or less the same efficiency. Figure 7.9 provides the volume distribution for the N2.

International literature also indicates that the effects of homogenising traffic flows, i.e. variable speed limits (VMS), on volumes is limited. The goals of VMS are to increase average headways and reduce variances in speed (Borrough, 1997; Ha et al., 2003; Pilli-Sivola, 2004). Less variability of speed leads to fewer, short headways and lower mean speeds according to Ha et al. (2003). This translates into fewer crashes (Smulders, 1990). A study in Finland by Rämä (1999) shows that Variable Speed Limits (VSL) lead to lower speeds and less variability. Borrough (1997) found the use of VSL and strong enforcement (video cameras) greatly reduced the number of crashes (28% over 18 months). The effect was attributed not only to a smoothing of traffic conditions through longer following distances, but also due to reducing the number of lane changes during congestion (Borrough, 1997).

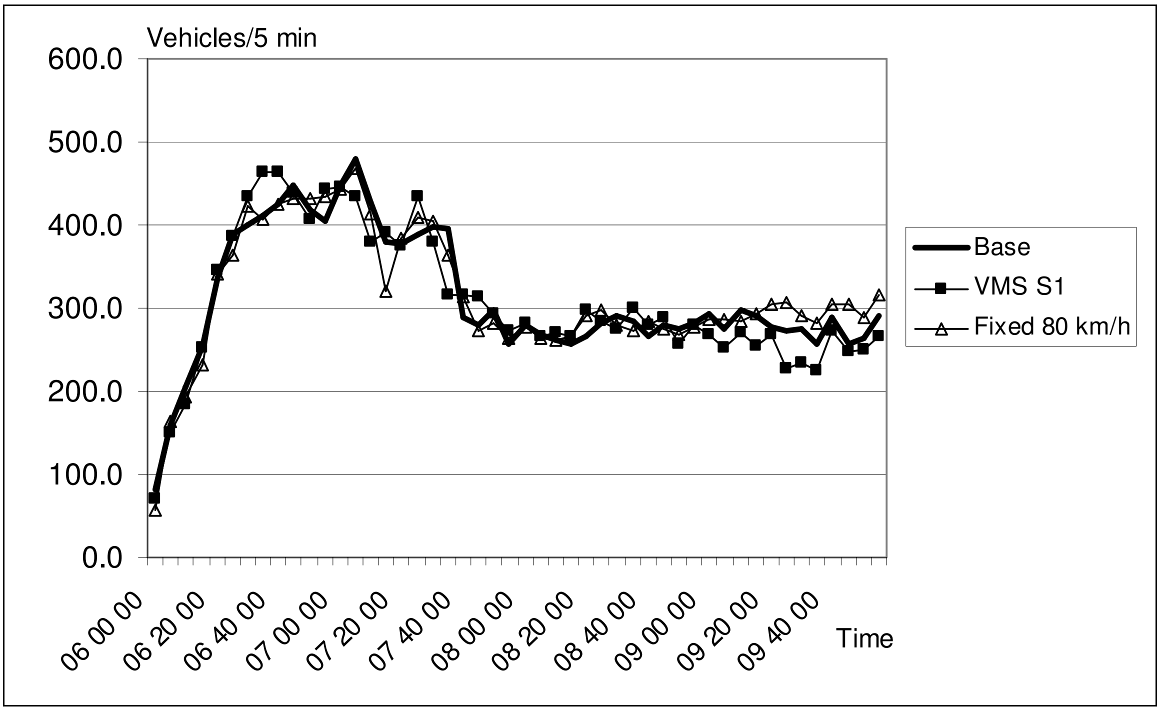

Figure 7.9 Volume distribution over time of homogenising scenarios for the N2

Although the focus of the homogenised traffic flow scenarios should be the analysis of speeds, headways and TTCs, it was decided to provide the lane distributions and travel time analysis as well.

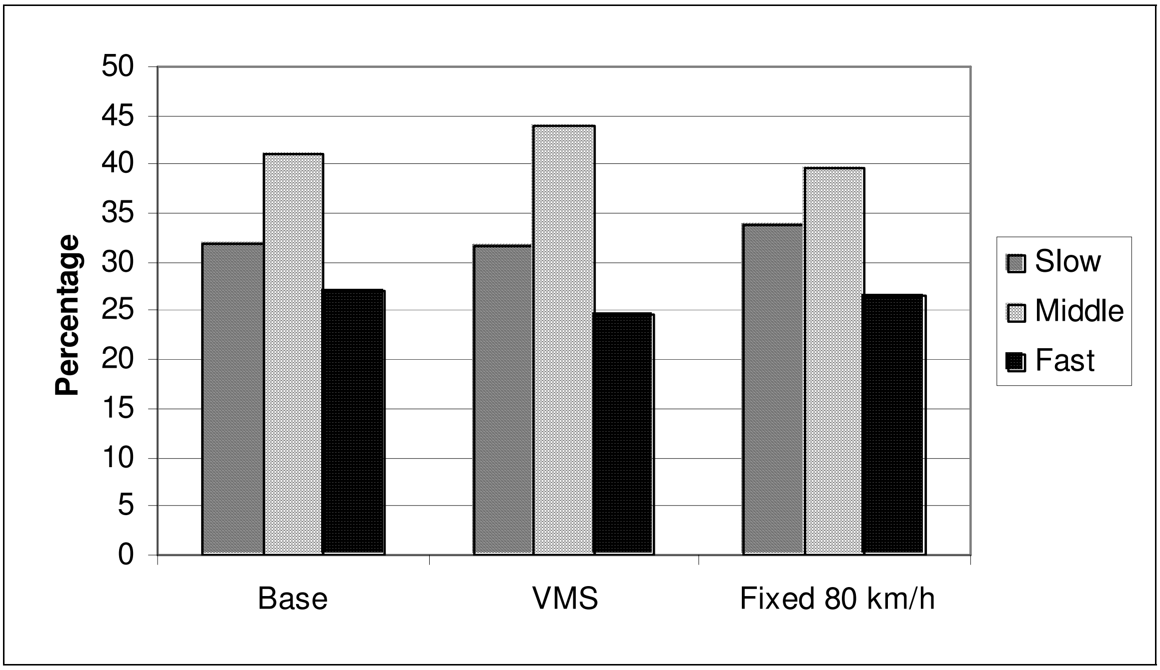

Figure 7.10 Lane distribution of homogenising scenarios for the N2

With regards to the lane distribution (the N2 is used as an example), it appears that the lane distribution for the scenario with fixed speed limits is slightly more efficient (see figure 7.10).

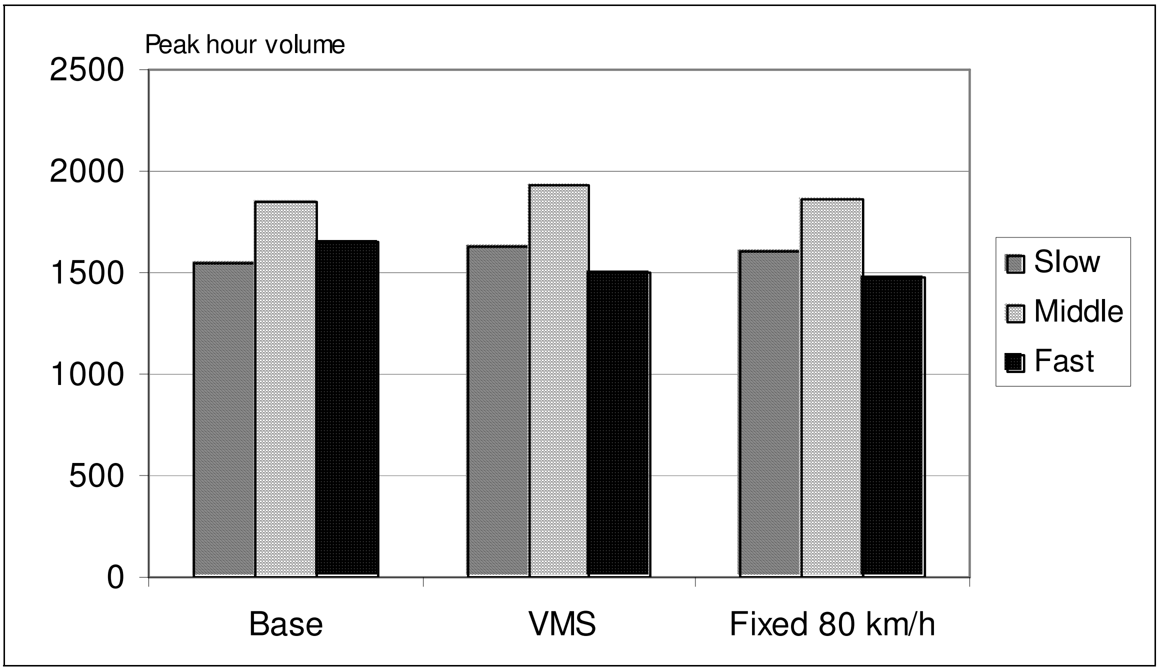

Figure 7.11 Peak hour volume of homogenising scenarios for the N2

During the peak hour (see figure 7.11), the volumes per lane for the scenarios do not show major differences. The small additional volume carried by the VMS scenario uses the middle lane. Moreover, other than the base case, both scenarios have a higher volume in the slow lane than the fast lane. This distribution is generally preferred by road managers.

7.2.2 Travel time comparison

Travel time analysis for both the BSH, as well as N2, show that the travel times for the homogenising scenarios are slightly longer than the base case. Other than the HOV scenarios, the trends are the same as for the base case. By the end of the peak period, travel times are almost identical to the base case (see figure 7.12).

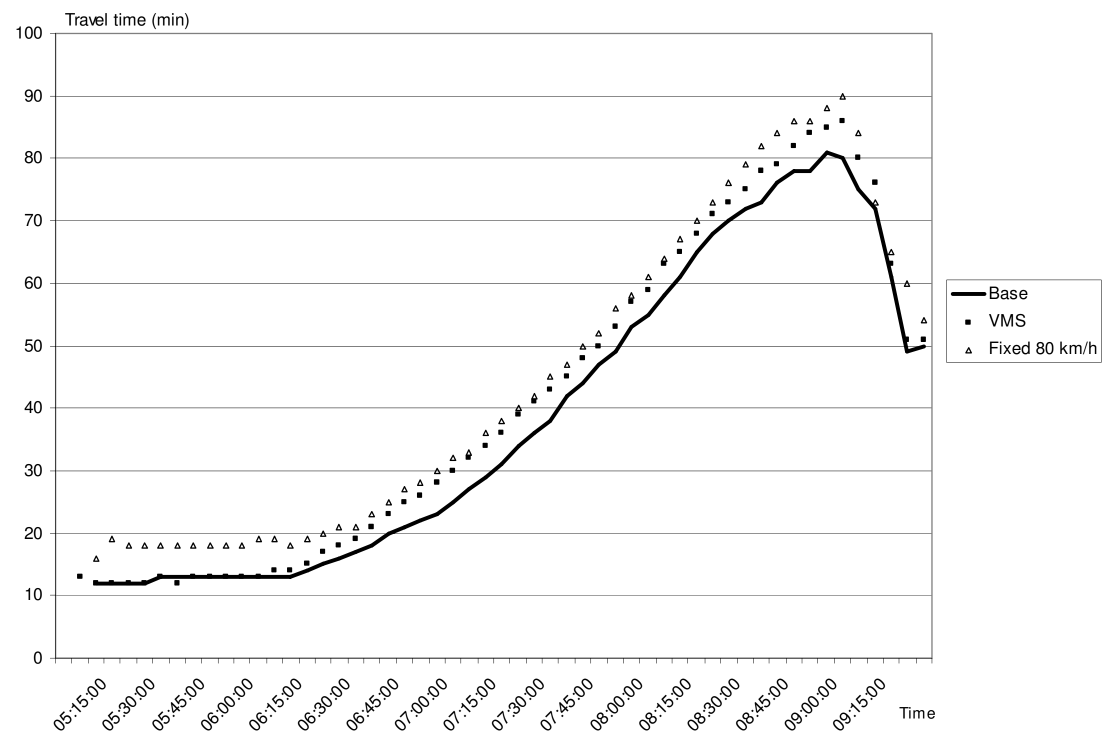

Figure 7.12 Travel time over time of homogenising scenarios for the BSH

7.2.3 Speed comparison

The speed analysis starts with an overview of the change in average speed (table 7.5).

Table 7.5 Average speed for the peak period of homogenising scenarios (km/h)

Scenario	BSH	N2
Base case	106	113
VMS	99	115
Fixed 80 km/h	77	79

On the BSH highway the homogenising scenarios reacted as expected - there is a drop in average speed. The N2, on the other hand, shows a slight increase in average speed for the VMS scenario.

Due to the higher gain in peak-hour flow for the N2 and the increase in speed for the VMS scenario, it was decided to focus the further speed analysis on the N2.

Table 7.6 Vehicles with a TTC of less than three seconds of the homogenising scenarios on the N2 (%)

	Base case	VMS	Fixed 80 km/h
TTC < 3 sec and ΔSpeed ≥ 20 km/h	3.7	10.7	5.2
TTC < 1 sec and ΔSpeed ≥ 20 km/h	0.2	1.2	1.0

The analysis of short TTCs and high speed differences shows that the homogenising scenarios have a higher accident risk than the base case (table 7.6). The fixed 80 km/h scenario appears to be safer than the VMS scenario. This is an unexpected result and a more detailed analysis of the individual vehicle data is needed.

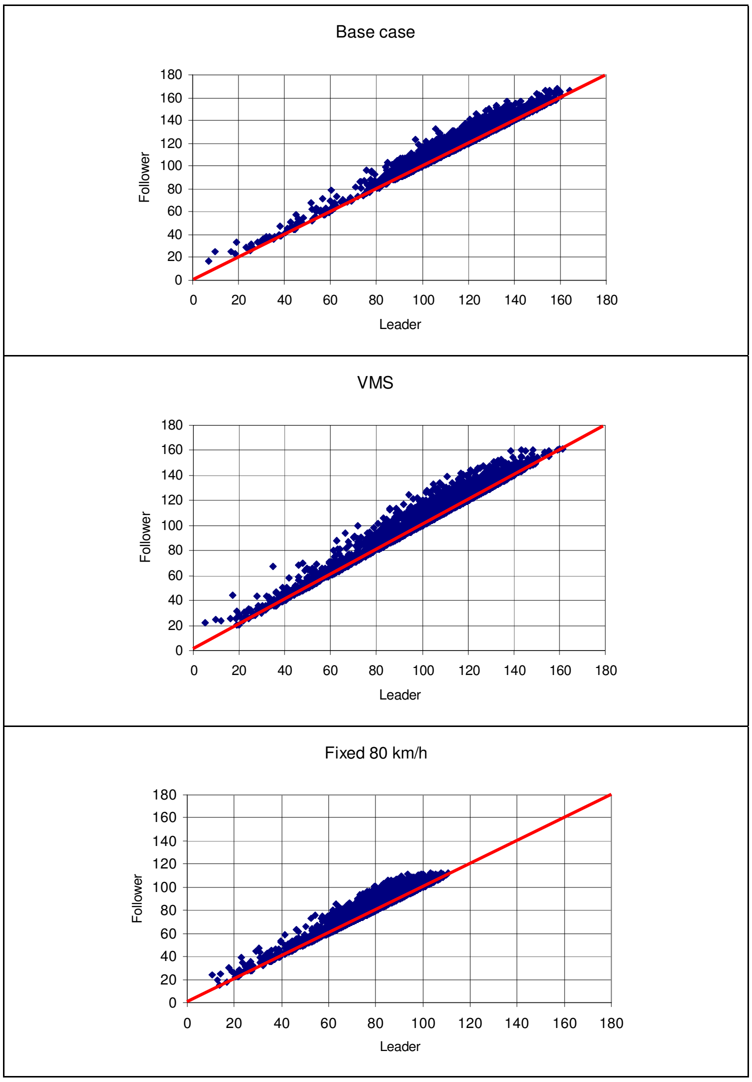

Figure 7.13 Comparison of leading/following vehicle speed with a TTC < one second of homogenising scenarios for the N2 ($\forall_{ij}$: $S_i(t) < S_j(t)$)

No headway measurements are available for the N2. Figure 7.13, therefore, only includes the base case and the two homogenising traffic flow scenarios.

The VMS scenario shows no significant difference compared to the base case scenario. Large speeds keep appearing, which indicates that the VMS is only partly active. Comparing the fixed 80 km/h scenario (which effectively is the same as a VSL scenario where the VMS is active 100% of the time), with the base case scenario for the N2, a substantial improvement is witnessed. The fixed 80 km/h scenario appears to be much safer than the other scenarios. All speeds of followers with a TTC of less than one second are less than 120 km/h, compared to 160 km/h for the base case and the VMS scenario.

7.2.4 Headway analysis

The peak of the homogenising scenarios is equal to the peak for the base case. Nevertheless, the headways between one and three seconds for the fixed 80 km/h scenario are significantly lower than the base case, as well as the VMS scenarios (figure 7.14).

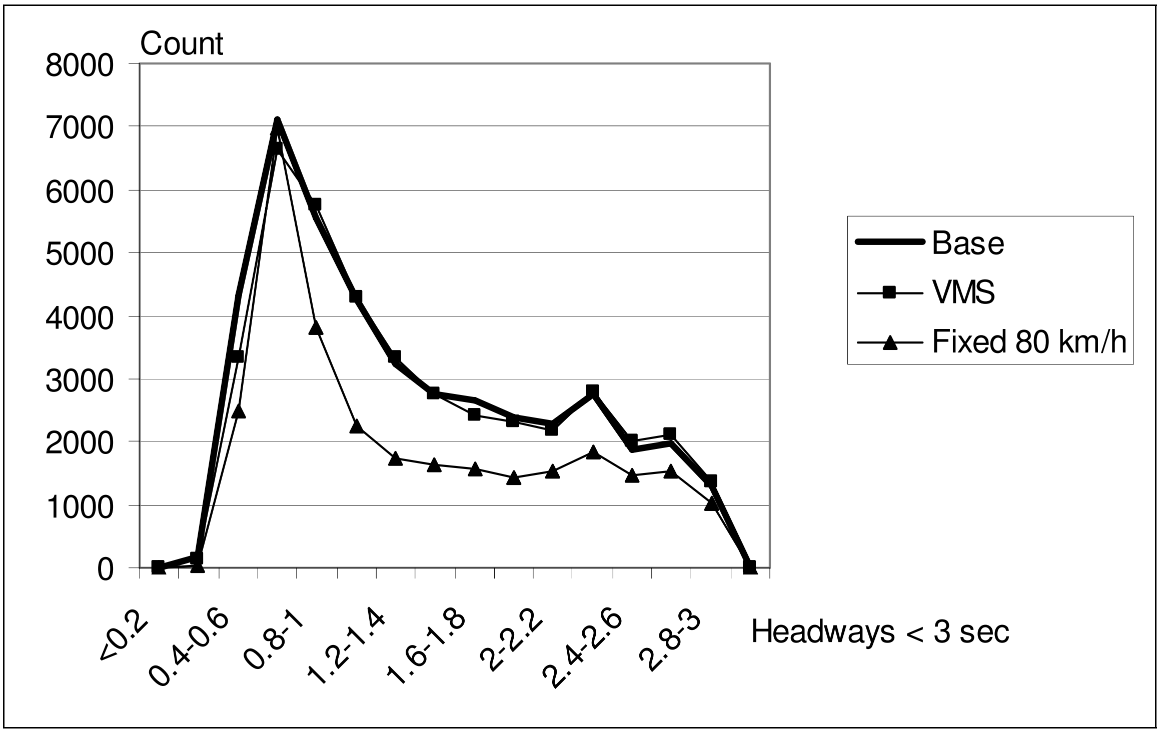

Figure 7.14 Headway distribution of homogenising scenarios for the BSH

7.2.5 Overall results

The modelling of homogenising scenarios for the BSH and N2 estimate changes in throughput of between +1.9% and -3.5%. The literature provides slightly better estimates of between +2.9% and +5.7% (Bonsall et al, 2005).

Other than the HOV scenarios, travel time trends for the homogenising scenarios are similar to the base case. Nevertheless, travel times for both scenarios are slightly higher than for the base case.

Travel times and headways indicate that the VMS scenario shows similar patterns to the base case, whereas results for the fixed 80 km/h scenario are significantly better. Moreover, analysis of individual vehicles also indicates that the fixed 80 km/h is a much safer option. As the maximum speed for dangerous followers (see table 7.6) drops from 160 km/h to 120 km/h, it is not unlikely that the number of accidents will also drop. A significant (20%) reduction in the accident rate has been estimated in the Netherlands (www.swov.nl) and measured in the USA, where accident reductions of between -20%

to -29% were recorded (www.benefitcost.its.dot.gov). Obviously, there is a need for enforcement before these benefits are materialised.

7.3 Ramp metering

Ramp metering is an ITS measure that aims to improve traffic flows on highways. A traffic controller is placed on the on ramp to avoid the merging of too many cars on the highway at once. The green time of the traffic controller is decreases proportionally to the increasing volume on the highway. If the traffic flow on the highway is above a certain threshold, the traffic controller will let the merging cars through one by one. In many cases, the level of service for the merging traffic decreases.

The results of ramp metering in literature have been positive. The throughput increases by between zero and eight percent (see section 3.4.2). Ramp metering has produced both positive and negative impacts on the travel time. The overall changes in travel time varied between decreases of up to 48% and an increase of two percent. In the US, a reduction of accidents by between 15% and 50% has been witnessed due to ramp metering. The public appears to support ramp metering (www.benefitcost.its.dot.gov); between 79% and 86% of interviewed people are positive.

The measuring of traffic flows on the highway can be conducted by loops before or after the merging on ramp. In the case of the BSH and N2, loops before the on ramp are simulated. The ramp metering settings used in this dissertation is based on the suggestions of the model developers, and appears to be quite conservative. If the loops on the highway are occupied for 25% of the time or more, the traffic light on the ramp will show red for seven percent of the time. Moreover, ramp metering has been introduced on all on ramps in the corridors.

7.3.1 Comparison of the volumes

The first aspect that is analysed for the ramp metering scenario is volumes.

Table 7.7 Traffic volumes of ramp metering scenarios

Scenario	Ben Schoeman Highway				N2 near Cape Town			
	Peak period (05:00 – 09:30)		Peak hour (06:20-07:20)		Peak period (06:00 – 10:00)		Peak hour (06:30-07:30)	
	Abs	%	Abs	%	Abs	%	Abs	%
Measured traffic volume	17 437		6 200		15 190		5 048	
Base case	17 788	100	5 412	100	15 299	100	5 011	100
Ramp metering	18 185	+2.2	5 874	+8.5	14 543	-5	4 573	-8.8

The introduction of ramp metering provides better utilisation of road capacity on the BSH (see table 7.7). During the peak period, the throughput increases by 2.2% whereas the increase during the peak hour is 8.5%.

The results for the N2 show that the throughput decreases by five percent and 8.8% respectively. Attempts to increase the throughput by reducing the red time and/or eliminating traffic controllers on some of the ramps, has not sufficiently improved the throughput; the peak period throughput decreases by 2.5% and the peak period throughput by 8.5%. The scenario analysed in the remaining part of this section is, therefore, the originally selected settings on all ramps.

In effect, the reduced throughput means this traffic is not able to join the highway and will queue in the suburbs. As there is already congestion in the suburbs in the current situation, this scenario is not seen as a sustainable option.

For both the BSH, as well as N2, it appears that the fast lane is better utilised if ramp metering is introduced (see figure 7.15).

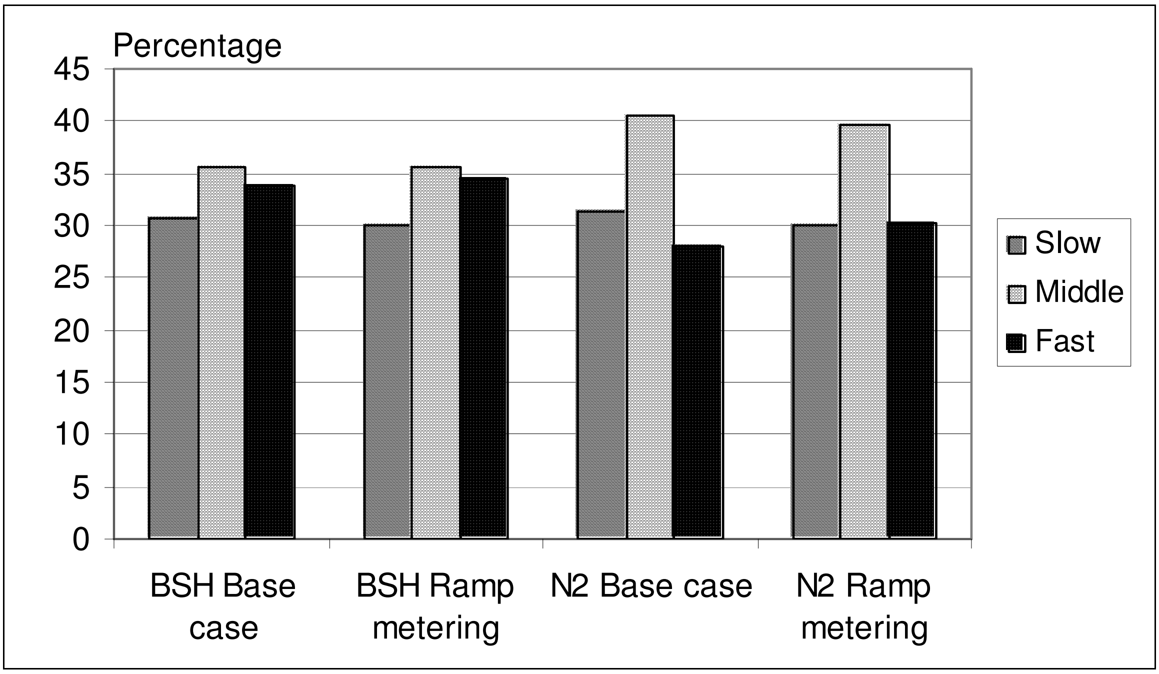

Figure 7.15 Lane distribution of ramp metering scenarios for the BSH and the N2

7.3.2 Travel time comparison

The BSH calculations resulted in an increase in throughput, while the N2 experiences a reduction in throughput if ramp metering is introduced. It was decided to analyse the travel times for the BSH (see figure 7.16). All previous travel time comparisons have focussed on trips from Tshwane to Johannesburg. Analysing the same trip combination, it appears that the travel times for the base case and the ramp metering scenario are almost identical. Further analyses of the trip relation from Midrand to Johannesburg (with a traffic controller on the ramp), indicate that the travel times are also very similar. It can be concluded that ramp metering on BSH on ramps does not have a significant positive or negative effect on travel times.

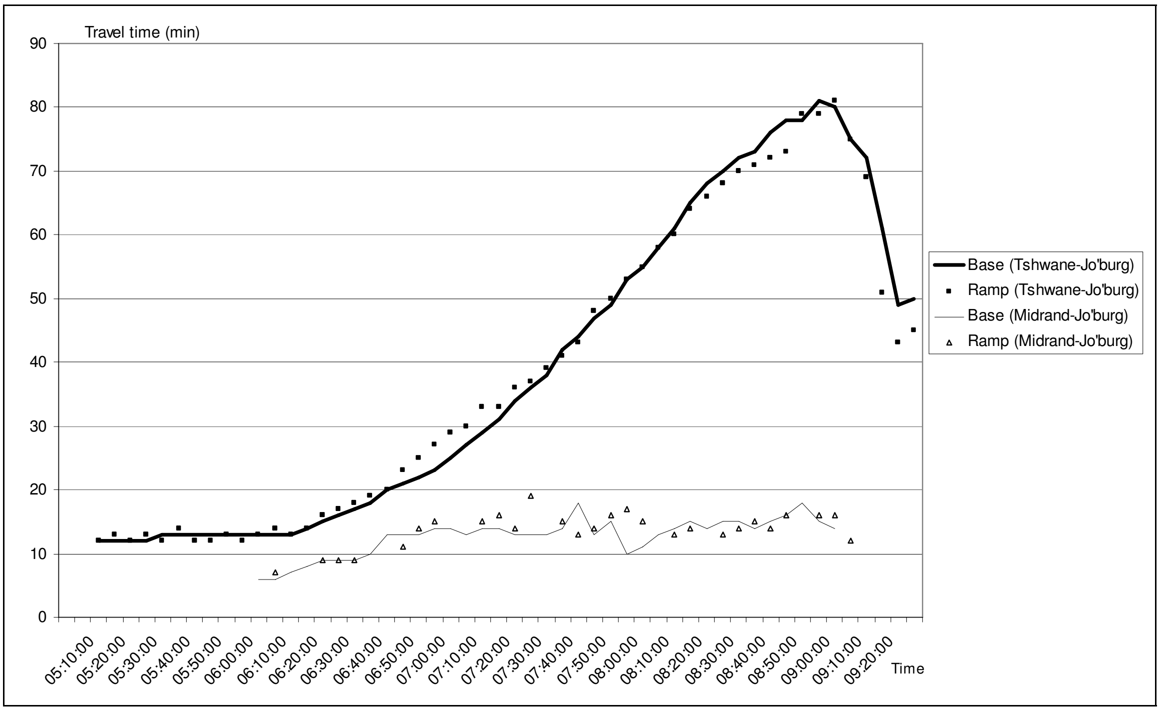

Figure 7.16 Travel time over time of ramp metering scenarios for the BSH from Tshwane as well as Midrand to Johannesburg

It needs to be mentioned that the same OD-matrix has been assigned in both cases (the base case and ramp metering scenario). Only a slight change in the profile might have taken place (due to the assignment process Paramics uses). As the travel times show no significant difference, a change in the profile is unlikely.

7.3.3 Speed comparison

With regards to safety indicators it is interesting to analyse the BSH, as well as the N2. The first step is to analyse the average speeds (see table 7.8).

Table 7.8 Average speed for the peak period for ramp metering (km/h)

Scenario	BSH	N2
Base case	106	113
Ramp metering	112	103

It appears that the overall average speed on the BSH increases, while the overall average speed on the N2 drops. As mentioned, throughput on the N2 decreases. It is, therefore, striking to see a decrease in speeds.

The traffic flows on the BSH seem to have stabilised, which allows for higher average speeds. Obviously, this might be negative from a safety point of view. A further analysis of speed and headways is needed.

The next step is to analyse the percentage of vehicles with a short TTC and high speed difference (table 7.9).

Table 7.9 Vehicles with a TTC of less than three seconds of ramp metering scenario (Percentage)

	BSH		N2	
	Base case	Ramp metering	Base case	Ramp metering
TTC < 3 sec and ΔSpeed ≥ 20 km/h	9.3	4.6	3.7	8.5
TTC < 1 sec and ΔSpeed ≥ 20 km/h	2.8	0.7	0.2	1.0

The effect, due to ramp metering, with regards to a TTC of less than three and one seconds, with a speed difference of 20 km/h or more, is different for the two corridors.

Risky behaviour on the BSH appears to be reduced, while there seems to be an increase in risky behaviour on the N2 (see table 7.9). A further graphical analysis verifies this finding (see figure 7.17).

Figure 7.17 shows a significant improvement with regards to the BSH. It appears that ramp metering stabilises the traffic flows. Although a speed increase is found, other safety indicators show an improvement.

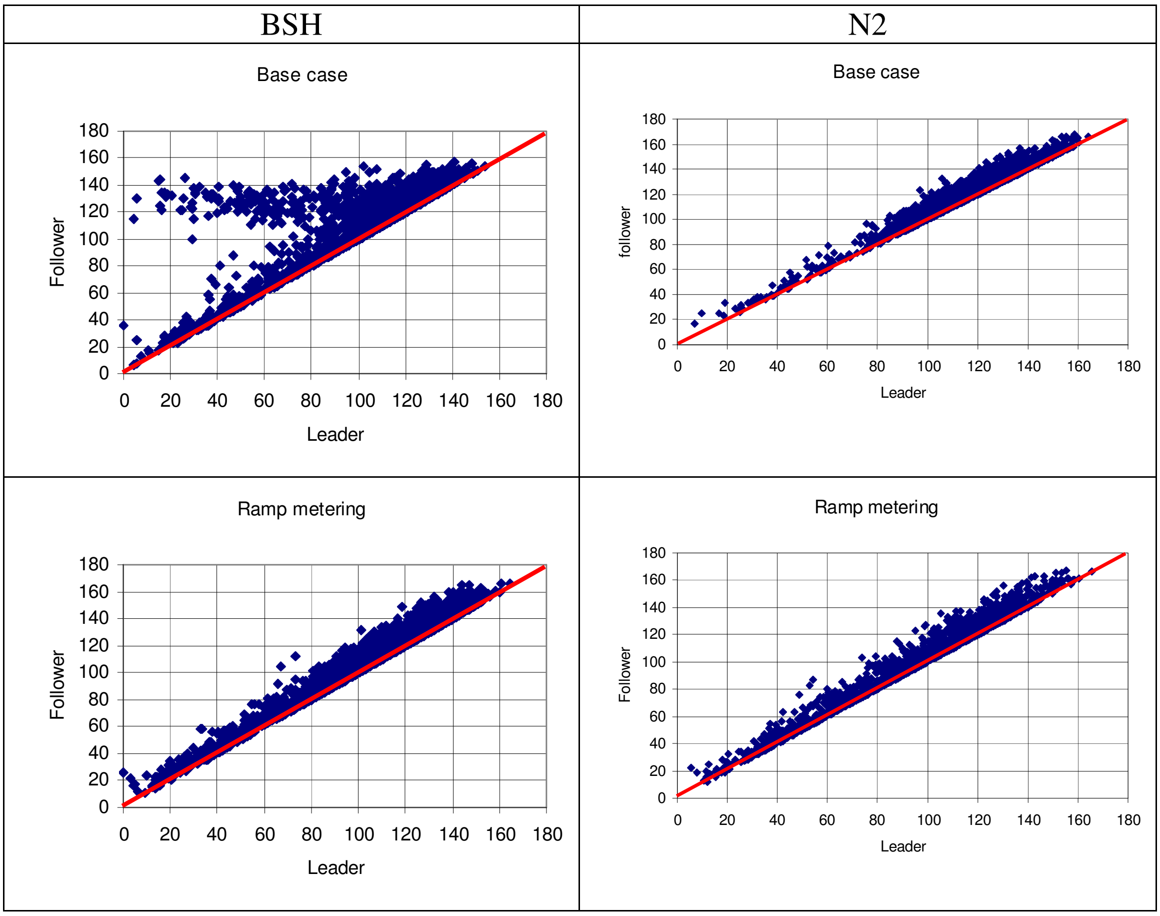

Figure 7.17 Comparison of leading/following vehicle speed with a TTC < one second of ramp metering scenarios for the BSH, as well as the N2 ($\forall_{ij}$: $S_i(t) < S_j(t)$)

The leader/follower analysis for the N2 does not indicate a significant difference, although the width of the band of data points seems slightly wider. Moreover, table 7.8 indicates an increase in the safety risk.

7.3.4 Headway analysis

For the N2, it was found that both, the throughput and speed decrease. It is, therefore, highly unlikely that the headways decrease as well. It was decided to concentrate on the headway analysis with regards to ramp metering on the BSH.

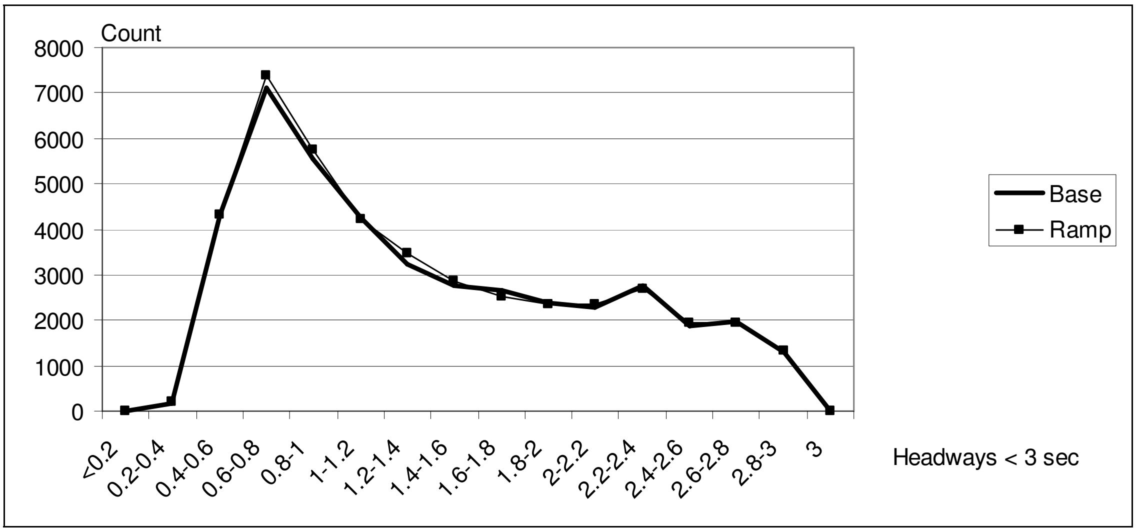

Figure 7.18 Headway distribution of ramp metering scenario for the BSH

It appears (see figure 7.18) that the headway distribution for the ramp metering scenario is virtually identical to the base case scenario.

7.3.5 Overall results

Internationally, ramp metering has been an ITS measure with positive effects. Throughputs show increases of between 0% and 8%, while accidents have been reduced by between 15% and 50%.

The results of the ramp metering scenarios for the BSH and N2 provide very different effects. For the N2 the throughput is reduced while the safety risk increases. The fact that the majority of the traffic comes via the on ramps, and is not present on the highway from the start, as well as the fact that the on ramps are short and do not have a big holding capacity, results in a frequent overwrite of the traffic controller settings. The traffic controls appear to contribute to the disturbance of the traffic flow without improving the utilisation of the road, which was not anticipated beforehand. Ramp metering might be more beneficial on other highways in the Cape region as the amount of through traffic is higher.

The introduction of ramp metering on the BSH provides very positive results. Volumes during the peak period have increased by 2.2% while the increase during the peak hour is 8.5%. The effect on travel times for the main traffic stream (from Tshwane to

Johannesburg), as well as the flows affected by the ramp metering traffic controller (from Midrand to Johannesburg), is minor. Moreover, the safety risk decreases while the headway distribution is virtually identical to the headway distribution for the base case.

It can be concluded that ramp metering is not an option if the majority of traffic arrives on the highway via the on ramps. Only if the majority of traffic travels long distances and is on the highway before ramp metering is introduced, then the measure had a positive effect.

7.4 Résumé

Although a drop in speed and headways is witnessed for bus/HOV lane scenarios, due to the severe drop in throughput and increase in travel time, it is not recommended to implement a bus/HOV lane on the BSH or the N2. Nevertheless, if one of the scenarios needs to be implemented, it is recommended that an HOV lane be implemented that allows vehicles with two or more occupants. Due to the current lack of public transport services, it is unlikely that a five percent shift, as calculated, will materialise.

Homogenising scenarios generally improve traffic flows. VMS slightly increases the throughput during the peak hour, while the fixed 80 km/h scenario shows a significant decrease in the safety risk. As mentioned before, the US has measured accident reductions of between 20% and 29% (www.benefitcost.its.dot.gov). With a significant drop in the speed of followers with a TTC of only one second or less, similar drops in accidents are likely.

Ramp metering appears to have a positive effect if the majority of traffic is on the highway, as is the case on the BSH. If the majority of traffic joins the traffic flow via the on ramps, as is the case on the N2, ramp metering is not recommended. Different controller settings, as well as ramp metering on a selection of the ramps, did not improve the results. On the BSH the volumes increase by up to 8.5%, which is similar to international findings. The safety risk decreases significantly, while there is no negative impact on travel times.

Chapter 8

Conclusions and recommendations

8.1 Conclusions

The traditional approach to transport planning includes the following steps: the estimation of (future) demand, the identification of bottlenecks in transport networks and the provision of desired road or public transport infrastructure. In the developed world it has been concluded that this Predict-and-Provide method is not sustainable. A paradigm shift has taken place, aiming to create more liveable cities. With regards to road transport, a better utilisation of the infrastructure in a safe manner, minimising noise, fuel consumption and pollution, is the focus.

The introduction of Intelligent Transport Systems is one of the measures to improve the performance of the transport system, without the provision of additional infrastructure. Although results vary, international studies show benefits with regards to safety, mobility, efficiency, productivity, energy, environment and customer services, due to the introduction of Intelligent Transport Systems.

Although the interest is growing, ex ante and ex post studies regarding the impacts of Intelligent Transport Systems in South Africa have still hardly been conducted. As a consequence, knowledge on the effects of the introduction of Intelligent Transport Systems is lacking.

The objective of this dissertation was to investigate whether Intelligent Transport System measures are beneficial in South Africa. Several questions were asked and investigated. This chapter provides a summary of the findings with regards to each question.

Is South Africa's transport system, as well as related problems, similar to those of the developed world?

South Africa is a two tier society. On the one hand, many services have a developed world standard, such as the road infrastructure. On the other hand, a large portion of the population lives in poor conditions. In many cases, they live on the outskirts of the city and, if they can afford to travel, they depend on informal minibus taxis that have a low service level (uncomfortable, unsafe and unreliable).

Land-use planning, mainly realised during the apartheid era, has initiated some of the problems described. Previously disadvantaged individuals were relocated to far away areas. These relocation areas were often 35 to 50 km away from the Central Business Districts. The current government has tried to improve the situation for the urban poor by creating corridors; providing public transport services and non-motorised transport infrastructure. Moreover, economic development is promoted.

The urban wealthy's demand for transport is similar to the developed world, particularly the United States. They make use of private vehicles, as they can afford to own a private car. Infrastructure is available and for them public transport is not considered an option, due to the lack of safe, secure and comfortable systems. Moreover, walking and cycling are not perceived as a convenient transport mode, due to a lack of dedicated infrastructure. Similar to the developed world, the rapidly growing use of private vehicles is accompanied by problems, such as congestion and pollution.

Many transport related problems, such as congestion and air pollution, are similar to those of the developed world. Nevertheless, with regards to road safety, the South African situation is very different. Due to higher pedestrian volumes and vehicle-pedestrian conflicts, road safety in South Africa is much worse than the developed world.

As indicated, with regards to road safety, South Africa does not compare to the developed world. The combination of high motorisation rates by the urban wealthy and the unaffordability of motorised transport by the urban poor, leads to a high rate of vehicle-pedestrian conflicts. Moreover, unsustainable land-use patterns often lead to pedestrians crossing the highways. As mentioned in chapter two, jaywalking and speeding are the two main human factors that cause road fatalities. Undoubtedly, the unsustainable layout of South African cities contributes to a higher road fatality rate than is found in developed countries.

It can be concluded that the road supply in South Africa's urban areas is very similar to the developed world, particularly for the primary road system. The geometry is based on guidelines imported from the United States. Differences are only apparent in poor, local areas where the availability of infrastructure may be lacking in some instances. Moreover, maintenance of the road system is frequently lacking. It needs to be mentioned that the adoption of standards from the United States has meant that secondary and tertiary roads do not cater for non-motorised transport, which is different to many cities in Europe.

Studies, mostly conducted in the developed world, show potential benefits due to the implementation of ITS measures, with regards to some of the road transport problems witnessed in South Africa. The introduction of Intelligent Transport Systems has proven to improve road safety and reduce congestion and pollution. Before analysing the potential benefits of Intelligent Transport Systems in South Africa, it needs to be investigated whether these types of technologies would be accepted by society.

Would South African society accept new technological solutions?

South Africa has an extremely sophisticated banking system with high levels of infrastructure. South African banks are world leaders in technology, including full-service internet banking. Automated Teller Machines (ATM) are widely used and largely replace the need to enter banking halls. The network of ATM is extensive, located adjacent to banks, in shopping malls and petrol service stations. One of the reasons for the technology push by the banking industry is the provision of banking facilities in rural areas. Due to the topography of South Africa and the low population densities in rural areas, it is not financially viable to open face-to-face banking facilities in these areas. In addition, high crime levels urge for the elimination of cash transactions.

Another technological advancement that has been introduced in South Africa over the past decade is the cell phone. By June 2005, 18.7 million people were using cell phone technology, of which 80% were active users.

Due to the demographic profile of cell phone users (it cuts across all economic and social groupings), banks are now using cell phones to offer their services. For the first time in South Africa, anyone can bank at anytime. This means that services are now more accessible to the urban poor and people in rural areas.

Within the transportation field, Tracker Systems and Fleet Management Systems have been introduced. These systems have proven to be beneficial to the operators. Besides initial acceptance problems by the drivers, these systems are a success.

With regards to the acceptance of new technologies it was concluded that South Africans are generally open minded.

Which benefits of Intelligent Transport Systems have been established in the developed world?

Ex ante studies mainly report the safety criteria speed, the mobility criteria travel time and the efficiency criteria throughput. It appears that some in-vehicle systems, such as Autonomous Cruise Control and Intelligent Speed Adaptation, are most promising. It needs to be mentioned that this dissertation focuses on infrastructure measures, as these can be influenced by government. Moreover, the motor industry in South Africa has already researched in-vehicle systems for which there might be a market.

Ex ante studies of infrastructural systems that show promising results on safety and mobility, as well as efficiency criteria, are homogenising speed limits systems, dedicated lanes and ramp metering.

Ex post infrastructural studies mostly focus on integrated systems, such as Highway Management Systems, Arterial Management Systems and Incident Management. Some studies have looked at ramp metering in isolation. The reported benefits are an increase in capacity, an increase in speed, a reduction in accidents and a reduction in pollution.

Which ITS measures are potentially beneficial to South Africa?

Based on the existing ITS systems in South Africa and research already carried out, it was concluded that there is a lack of knowledge with regards to Intelligent Transport Systems for highways.

During ex ante studies, it is more informative to analyse the effects of measures independently, although in practice, implementing a range of measures might be more effective.

Measures that have been most promising in other countries are homogenising speed limits, dedicated lanes and ramp metering. Although not enforced, a bus lane is available on the N2. Moreover, the existing bus lane is even extended at the moment. Enforcement of the bus lane might have unacceptable negative impacts on private vehicles. Extremely high travel times and unacceptable congestion levels in the suburbs are anticipated. Based on the international experiences and the interest in bus lane scenarios by the Cape municipality, as well as the anticipated problems, it was decided to include bus lane scenarios in this dissertation. Moreover, related High Occupancy Vehicle scenarios are included as well.

South Africa has extremely high road fatality levels. There were 9 918 fatal road accidents in South Africa during 2002 (www.arrivealive.co.za). The main contributory factors to fatal accidents in December 2002 were categorised as follows: human factors 78%, road factors 12% and vehicle factors 10% (UNIARC, 2003). A recently conducted investigation with regards to road safety in South Africa has found that jaywalking, speeding, alcohol abuse and unroadworthy vehicles are the main causes of fatal accidents (Ojungu-Omara, 2006). Knowing that results with variable speed limits using Variable Message Signs are positive in other counties, it was decided to include this scenario in this dissertation.

Deciding on a third and last set of scenarios, it was contemplated that several municipalities have been considering pilots with ramp metering. As these pilot studies have not materialised yet and no results with regards to ex ante studies have been published, it is especially interesting to get an impression of the effects. Moreover, foreign studies generate positive expectations.

Based on national and international information, including modelling exercises as well as practical implementation, it appeared that High Occupancy Vehicle lanes, speed limitation via Variable Message Sign systems and ramp metering are the most promising measures. Scenarios with regards to these measures have been modelled.

Is it possible to use developed world models to investigate ITS measures in South Africa?

Based on an analysis of modelling requirements for Intelligent Transport System measures, it became clear that macroscopic transport models are not an appropriate tool for Intelligent Transport System scenarios. Mesoscopic, microscopic or nanoscopic models need to be used. Macroscopic transport models have a long history. The development of mesoscopic, microscopic and nanoscopic models is much younger. Moreover, the aims of different models often vary substantially, which results in huge differences with regards to input requirements, possible measures that can be calculated and the outputs generated.

The original aim was to use two models for this dissertation. To investigate a wider range of models, it was decided to use a mesoscopic and a microscopic transport model. The focus area of investigated nanoscopic transport models appeared to be too narrow.

After a broad investigation of models, taking modelling as well as financial restrictions into account, it was decided to purchase the mesoscopic transport model DynaMIT from MIT in Boston (United States) and Paramics from Quadstone in Edinburgh (United Kingdom). The added advantage of selecting these two models is the fact that one is based on US principles and the other on European principles.

Unfortunately, it was impossible to get DynaMIT running. After 10 months the idea to include this model was abandoned. All modelling results in this dissertation are, therefore, based on Paramics.

Paramics has proven to be a model able to run scenarios for the South African situation. Although challenging, it was possible to calibrate the model.

What data needs to be available to use developed world models in the South African context?

Microscopic simulation models are data hungry. In the developed world there is a large emphasis on data collection. Most countries collect information based on trip diaries on an annual basis. Moreover, traffic management systems that are available in all major cities and on the highway systems provide volume and speed data.

In South Africa, no travel demand trends, based on trip diaries, are available. In the eighties and early nineties, panel data was collected. With 1994 being the last year for which data is available, this was not useful for this dissertation (information is based on an interview with Dr. R. Behrens, 2006).

The first National Household Travel Survey was held in 2003. The technical report based on this survey was published in August 2005 (NDoT, 2005). The raw data became available about six months later. The National Household Travel Survey provides a wealth of information. The government aims to repeat this kind of survey every four to five years. This will provide many possibilities for transportation research. Unfortunately, this data was not available during the course of this dissertation.

Safety statistics in South Africa are summarised in the annual transport statistics document. The last available document provides statistics for 2002 (NDoT, 2002). Studies have revealed (Ojungu-Omara, 2006) that the capturing and recording of data is problematic in South Africa. Moreover, data is often 'too summarised' to be useful for research and raw data is not available.

South Africa's major municipalities use transport planning models, and they are willing to share their information with academics. The information in the model of the City of Cape Town was dated. The municipality was busy with a review of the data while this dissertation was underway. If accurate, the data in planning models can be used for the estimation of the Origin-Destination matrix. Nevertheless, data with regards to the time element in microscopic simulation models is not available in planning models.

MIKROS, a South African traffic count specialist, collects loop data on behalf of the South African Road Agency Pty Ltd (SANRAL). Loop data for all urban agglomerations is stored. MIKROS then sells this loop data for a nominal fee. The stored data includes information about the date, time of the day, lanes and the vehicle type for every 15-minute interval. Unfortunately, microscopic simulation models require more detailed information. Preferably one-minute or five-minute information should be available. MIKROS appears to have stored ad-hoc five-minute data collected for the N2 near Cape Town. This data was purchased for this dissertation.

Innovative Traffic Solutions Pty Ltd, a South African consultancy firm, conducted a once-off study of the Ben Schoeman Highway. This was one of the few ex ante studies carried out in South Africa with regards to Intelligent Transport Systems. Innovative Traffic Solutions made the collected data available for this study.

In many cases, the reliability of data is also a problem. Low education levels jeopardise data collection and capturing. This problem also occurred during the capturing of data on the N2. Although thorough instructions were provided before capturing started, which should have avoided this problem, some data had to be discarded.

Although recent developments indicate that data collection is improving in South Africa, it can be concluded that data reliability and availability is problematic. The lack of raw data poses severe challenges in academic research. Moreover, as microscopic simulation models have, so far, not been used often in South Africa, it can be concluded that the available data does not cater for these types of studies.

Based on the available data and financial resources, it was concluded to investigate two highway corridors, the Ben Schoeman Highway and the N2 near Cape Town.

Is South African driving behaviour different from the driving behaviour in developed countries?

Microscopic simulation models include driving behaviour aspects. It was found that no parameter settings have been developed in South Africa. Within this dissertation a search for literature was carried out that could assist establishing these parameters.

In a study conducted in 2005 (Sukhai, 2006), a comparison of ten countries, including South Africa, was carried out. South Africa appeared to have the highest aggression levels. Due to the recent publishing of this study, the results could not be used in this dissertation. Furthermore, no other literature with regards to South African driving behaviour is available. It was, therefore, necessary to analyse general behaviour literature and translate it into driving behaviour.

Hofstede (1991) comes to the conclusion that different cultures/countries score differently on the following four criteria: power distance, individualism, masculine/feminine attitude and uncertainty avoidance.

The international comparison carried out by Hofstede (1991) shows that South Africa scores, on average, higher for masculinism and individualism. With regards to uncertainty avoidance, the average score for South Africa is slightly below average. A translation of Hofstede’s scores provides a first indication that South Africans are quite aggressive drivers.

Trompenaars (Trompenaars and Hampden-Turner, 1998) indicates, South Africa has a triple heritage; from African, Europe and Asia society. It is, therefore, ‘tricky’ to compare the South African average score with other countries. South Africa is culturally diverse, not simply among blacks and whites, but also among the various language groups within the black community, as well as between the rural and urban black communities.

Trompenaars identified eight cultural groups within South Africa. Based on economical achievement, he made sure the respondents came from an urban background. On average it can be concluded that South African societies score high on all the indicators Trompenaars uses. Analysing the scores in more detail, it can be concluded that there are large differences between the different cultural groups in South Africa. The standard deviation, especially for universalism and individualism, is very high.

Based on the work done by Hofstede (1991) and Trompenaars (Trompenaars and Hampden-Turner, 1998), it was concluded that South African behaviour is different to developed world behaviour. Moreover, within South Africa different cultures show very different behaviour.

How can differences in driving behaviour be included in transport models?

Traditionally, driving behaviour was researched measuring speeds and headways on the road. During the past 10 years or so, a new field of research using self-reported driving behaviour via questionnaires has emerged. The original driver anger scale (DAS) was developed in the United States by Deffenbacher (Deffenbacher et al, 1994). Strangely enough, it appears that integration of this part of the literature into microscopic simulation modelling has hardly been researched, even in the developed world. Within microscopic simulation models, an attempt is made to include driving behaviour via driver classes. No research is available with regards to the reliability of this approach, as well as whether the error included using this approach is acceptable.

Some authors have translated general behavioural information into driving behaviour information and parameter settings for models. Lajunen and Summala (1995) undertook research into driver experience, personality, skills and safety motivation. Within the model this informs the settings of parameters such as aggression and alertness.

In a DAS based study (Sukhai, 2006) comparing 10 countries, it appeared that South African drivers were most aggressive. Based on the knowledge gathered from the literature, it was concluded that the Paramics parameters of aggression and awareness need to be tested. Many settings were investigated. Based on Trompenaars (Trompenaars and Hampden-Turner, 1998), who found severe differences in South African cultural groups, an argument was made to test a squared distribution (large variance in driver behaviour/experience).

With regards to the Mean Target Headway and Mean Reaction Time it was found that the parameter settings are much lower than the default setting, which is based on driving behaviour in the United Kingdom.

Although the changed parameters Mean Target Headway and Mean Reaction Time appear to be the same for both investigated corridors, aggression and awareness show different settings for the two corridors. For the Ben Schoeman Highway, a normal distribution for aggression and a squared distribution for awareness appeared to represent the measurements best. For the N2, a squared distribution for both aggression and awareness provides the closest fit to the data.

What is the magnitude of potential ITS measures in the South African context?

Although the expectations with regards to Intelligent Transport Systems are generally positive, large variations have been found. Specific local aspects have a large influence on the magnitude of Intelligent Transport Systems.

Severe drops in throughputs and an increase in overall travel time were found for all **High Occupancy Vehicle lane** scenarios investigated. Introducing a High Occupancy Vehicle lane on the Ben Schoeman Highway as well as the N2 will, therefore, lead to congestion in the suburbs as vehicles are not able to enter the highway. Moreover, on the Ben Schoeman Highway further congestion will occur due to the bottleneck created by the High Occupancy Vehicle lane. Nevertheless, the travel time for buses and High Occupancy Vehicles is, in all scenarios lower than the base case scenario. In addition, the speed and safety risk decreases for all scenarios, while the number of short headways also decreases. All in all it can be concluded that High Occupancy Vehicle lanes will decrease the service level of the road but increase road safety.

Homogenising speeds by introducing Variable Message Sign systems has a small influence on the throughput. Mostly, there is a small decrease in throughput, whereas a slight increase in throughput is experienced during the peak hour. The magnitude of the effect on throughput for the two investigated corridors appears to be equal. Homogenising speeds (and, therefore, traffic flows) will lead to a slight increase in travel time and decrease in speed. It was found that the safety benefit is large if a fixed 80 km/h scenario is introduced.

The third investigated scenario was the implementation of **ramp metering**. It appears that the effects on the Ben Schoeman Highway and the N2 are very different. On the Ben Schoeman Highway an increase in throughput of between 2.2% and 8.5% is realised, while travel times for all traffic is virtually unchanged. Moreover, the safety risk on the Ben Schoeman Highway decreases. The N2, on the other hand, shows a decrease in throughput of between five percent and 8.8%, while the safety risk increases. An analysis of the functioning of ramp metering on the N2 indicates that the system is often over-ruled due to the high number of vehicles entering the highway via the on ramps. In addition, runs changing ramp metering settings, as well as altering the number of on ramps that use ramp metering, did not improve the results.

Is the magnitude of ITS measures in South Africa different to international experiences?

To be able to compare the estimated effects of Intelligent Transport System measures in South Africa to other countries, a comparison table was drawn up. As mentioned in chapter three, it is not entirely correct to compare the results of different modelling studies, often carried out with different models. Moreover, local situations vary severely. Nevertheless, the percentage change is a tool that makes comparisons possible (see table 8.1).

Unfortunately, international High Occupancy Vehicle lane studies do not provide any information with regards to traffic volumes. Compared to earlier studies in South Africa, it is clear that the results for the Ben Schoeman Highway and the N2 are similar. Internationally, a wide range of changes in travel time have been estimated. This is also the case in the scenario calculations for the Ben Schoeman Highway and the N2. The findings with regards to the changes in speed for the Ben Schoeman Highway and the N2 are different from the study previously conducted in South Africa. Nevertheless, the results for the Ben Schoeman Highway and the N2 are similar.

Table 8.1 Comparison of the magnitude of different ITS measures (%)

	International	National	Ben Schoeman Highway	N2
HOV lanes				
• Volume		-40	-47 to -19	-26 to +0.4
• Travel time	-8 to +200	-76	+266 to +333	-50 to +722
• Speed		+319	-24 to -13	-20 to -8
Homogenising speeds				
• Volume	-24.2 to +5.7		-3.6 to +0.5	-3.5 to +1.9
• Travel time			+12	+10
• Speed			-27.4 to -6.6	-30.1 to +1.8
• Safety (accidents)	-20 to -29			
• Safety risk			-270 to -10	-300 to -40
Ramp metering				
• Volume	-1 to +8	0 to+24	+2.2 to + 8.5	-8.8 to -5
• Travel time	-48to +22	-28	0	+10
• Speed	-5.2 to +8.2	+13	+5.7	-8.8
• Shockwaves	+0.6			
• Safety risk			+50 to +75	-400 to -129

Internationally, a wider range of changes in traffic volume have been experienced. The calculations for the Ben Schoeman Highway and the N2 fall within that range. The magnitude of the effects on safety is different for the various studies. Nevertheless, a reduction in actual accidents or a reduction in the safety risk both point in the same direction.

With regards to ramp metering, the calculated changes for the Ben Schoeman Highway and the N2 fall within the ranges estimated (inter)nationally relating to volumes, travel time and speed. No comparative material was available with regards to safety.

Should ITS measures be implemented in the South African context?

South African cities are unsustainable with regards to land-use patterns, and the provision of affordable, comfortable, convenient and safe transport services. Moreover, negative environmental impacts, such as congestion, emissions and noise pollution, have been significant.

Based on the calculations carried out, it can be concluded that Intelligent Transport System measures can be beneficial to South Africa and can contribute to the improvement of sustainability.

The ways in which the measures are implemented, as well as local specifics, influence the efficiency of the measure. In some cases specific legislation influences the implementation and enforcement possibilities of Intelligent Transport Systems (i.e. a High Occupancy Vehicle lane).

The lessons learned with regards to High Occupancy Vehicle lanes are that an additional lane needs to be created to ensure the measure is successful. If an existing lane changes into a High Occupancy Vehicle lane at a given point, a bottleneck will be created. Moreover, in congested situations it is not advisable to decrease the capacity and, therefore, block private cars. The reader needs to keep in mind that additional blocking of private vehicles will put an environmental strain on the corridor as pollution increases. The overall conclusion with regards to High Occupancy Vehicle lanes is that the service level of public transport needs to sufficiently improve before this Intelligent Transport System measure is considered. Unfortunately, it was not possible to include ITS measures that improve public transport.

Homogenising speeds provides a substantial safety improvement. Having a fixed speed limit of 80 km/h during the peak period decreases the safety risk, while the effect on throughput and travel time is minor. As indicated in chapter two, road safety is a severe problem in South Africa. Homogenising speeds is, therefore, recommended.

With regards to ramp metering, it can be concluded that the effect of this measure depends on the corridor. On the BSH the effect on throughput and safety is positive, while speed and travel times are not affected. On the N2, on the other hand, the measure is not positive at all. Due to the characteristics of the traffic flows (the majority of traffic enters the highway via the on ramps), the controllers on the ramp add a further disturbance to the traffic without any gains.

8.2 Recommendations

About 75% of all South Africans are dependent on public transport. One of the urgent needs in the country is, therefore, the provision of reliable, safe and comfortable public transport. An investigation into Intelligent Transport measures that can improve the current service level of public transport is recommended. The service level of public transport in South Africa is not considered high. Due to security problems, only captives (people who can not afford any other mode) will use public transport. Moreover, time-table information is often lacking and real-time information for passengers about delays is unavailable. It is recommended that a smart card system be introduced, including a wallet and personal details to overcome the security problems. Passengers will not have to carry cash and the operators will be able to eliminate unwanted travellers easily. A challenge with regards to these kinds of smart cards is the security of personal information and making sure that it can not be abused. Implementing vehicle tracking systems will generate data to provide real-time information to users. Estimated arrival times could not only be displayed at the stops. In addition, with the wide spread of cell-phone technology, Short Message Service (SMS) technology could be used to provide user specific information.

Analysis of existing transport models and their advantages and disadvantages has shown that microscopic models are useful for ex ante studies with regards to Intelligent Transport Systems. Applying one of the available microscopic models in South Africa, it became clear that the standard calibration procedure (changing Mean Target Headway and Mean Reaction Time and loading an Origin-Destination matrix of more than 100%) is not sufficient. During the calibration it became apparent that insight into the calculations method (detailed equations) and the option to adapt behavioural assumptions is not available. In the literature, many more parameters are discussed than are available to the user. In the view of the author, this limits calibration possibilities. A thorough sensitivity analysis will most probably provide additional insight to the model, as well as the transferability of it to the South African situation.

Expert opinion indicates that driver behaviour in South Africa is different to the developed world. A large proportion of vehicles are unroadworthy, slow due to overloading, and drivers are less aware of risky situations due to a lack of proper driver education. On the other hand, speeding and aggression is a problem. Driving education and alcohol abuse play a role. Moreover, the 'new middle class', who used to use minibus taxis when they were younger, copy aggressive driving behaviour of the minibus taxi drivers, as they think this is the norm.

A recent study confirms the speeding and aggression aspect of South African driving behaviour. It was found that South Africans were the most aggressive of the 10 countries included in the study (Sukhai, 2006). Moreover, literature confirms the widespread in behaviour in general. It was revealed that behavioural differences between South African groups are large (Trompenaars and Hampden-Turner, 1998). Further research is, therefore, recommended.

Although some literature is available, it is suggested that further information be collected on (driving) behavioural differences in South Africa. Moreover, a way to translate the findings of this kind of research into microscopic simulation models needs to be explored. Findings of a sensitivity analysis should indicate which behaviour aspects need to be investigated first. In addition, the research carried out by Lajunen and Summala (1995) into driver experience, personality, skills and safety-motivation provides an indication on how to 'kick-start' this research.

The findings in literature, with regards to cultural differences within South Africa, appear in the different regions as well. The parameter findings in the calibration process appear to differ. Although these differences can most probably be explained by the concentration of different cultural groups in varying regions, it is recommended to collect region-specific information and develop regional-specific parameter settings.

As mentioned, research into driver behaviour is limited in South Africa. Expert opinions indicate that lane changing happens more frequently in South Africa. Moreover, minibus taxis abuse the on and off ramps to overtake. Unfortunately, a bug in the software made it impossible to analyse differences in lane changing. During the calibration process, it was impossible to fit the lane distribution. It appeared to be necessary to settle for slightly different distributions. Further research is recommended into the actual lane change and ramp abuse behaviour on South African roads, as well as finding a way to calibrate the model in such a way that this lane distribution and lane change behaviour is reflected.

Considerable differences have been found between the two corridors included in this dissertation. Besides behavioural differences, it appeared that the characteristics of traffic flows, geometric design, the Origin-Destination matrix, as well as the profiles, influence the findings with regards to the effects of Intelligent Transport Systems. Further research into the effects of the local situation with regards to Intelligent Transport measures is required.

Although chapter two argues that a major increase in private vehicle trips is expected, this research did not attempt to estimate future traffic flows on the Ben Schoeman Highway or the N2. It is likely that findings with regards to the implementation of Intelligent Transport Systems will change. Before any investments are finalised, it is recommended that future traffic flows and the impact of planned measures for these flows be estimated.

The Ben Schoeman Highway, most probably the busiest highway on the African continent, shows severe congestion which, especially during the peak period, leads to considerable inefficiencies. Ramp metering appears to be very promising for this corridor; the capacity of the road increases, safety improves and there are no negative impacts on travel times. Taking the previous recommendation into account, it is suggested that a further analysis of ramp metering for the Ben Schoeman Highway be conducted. In addition, a holistic network investigation of a wider corridor might provide insight into more efficient measures.

The ramp metering scenarios use the following settings: if the loops on the highway are occupied for 25% of the time or more, the traffic light on the ramp will show red for seven percent of the time. This is the scenario recommended by the developers. In the Netherlands, the ALINEA algorithm in practice uses 18% occupancy (and 16% if reliability of the traffic flow needs to be guaranteed). The occupancy rates are influenced by the local situation as well as the length of the loops. A comparison of local differences and testing of various algorithms for the South African situation is recommended.

Some Intelligent Transport measures on the N2 decrease the safety risk. Nevertheless, expected throughput problems are so severe that the implementation of these measures is not recommended. The short distances between on ramps might call for the closure of some ramps during the peak. Closing the road to heavy vehicles, as is done in other countries, is not expected to have a significant benefit as the percentage of heavy vehicles on the N2 is low. A holistic network analysis is recommended in order to find more optimal Intelligent Transport Systems to improve the transport system. It can be concluded that more analyses are needed before any investments are made in this corridor.

It has become clear during this dissertation that microscopic models are data hungry. Data availability and reliability is a challenge in South Africa; data collection is clearly less structured than in developed countries. Even though the National Household Travel Survey (NDoT, 2005) has become available and loop data were collected, many gaps were identified. A thorough analysis of the traffic data needs of the country is required. As a start, it is recommended that loop data be collected on a five-minute basis. If smart card technology is introduced, a wealth of origin-destination data will be generated with regards to the use of public transport. For private vehicles, floating car data could be generated using cell phone technology, which is widely spread in South Africa. Internationally, much research is carried out with regards to the use of new technologies in data collection. South Africa should explore the findings. Moreover, procedures for structural and more permanent data collection should be put in place.

The remaining question is how to encourage the urban wealthy to use public transport, as this will potentially increase the shift from Single Occupancy Vehicles to High

Occupancy Vehicles and public transport. Although the High Occupancy Vehicle scenarios on the Ben Schoeman Highway and the N2 do not promote the use of dedicated lanes, the reduced traffic volumes, due to a change in behaviour, will most probably improve the efficiency of these lanes. Further research is required with regards to this question.

In this dissertation, the most promising Intelligent Transport Systems, based on the literature review, were investigated. Information with regards to other Intelligent Transport measures is available in the literature. It is recommended that these measures be analysed. Moreover, including other corridors in the research will increase the insight into the expected effects of Intelligent Transport Systems in the South African context.

The research period in this dissertation is the morning peak. This is due to the fact that this period shows the most severe transport related problems, such as congestion and pollution. Nevertheless, Intelligent Transport Systems are likely to be beneficial during the off-peak period as well. Further research into the effect of Intelligent Transport Systems during the off-peak period is recommended.

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Summary

Mobility and transportation are the engine to economic growth of a country. Unfortunately, this engine also depicts the signs of the times (i.e. congestion, accessibility and road safety problems). It has been proven that the supply of infrastructure cannot keep up with population and mobility growth of countries, especially in the developing world, this is due to financial and human resource constraints.

At the moment, in nearly all urban areas in South Africa, the common signs of an ineffective traffic and transport (management) system are experienced: traffic jams during peak hours, little or no use of public transport by the urban wealthy, unreliable and unsafe trains and taxis, and unsatisfied customers.

Previous land-use planning has resulted in unsustainable cities. It is, therefore, a major challenge for the new South African government to combat land-use and transport problems. One of the possibilities under investigation is the introduction of new technologies, i.e. Intelligent Transport Systems.

Currently, systems such as advanced traffic control and Variable Message Signs (VMS) are available. Moreover, an incident management system is planned. Finally, the rising interest in Intelligent Transport Systems has lead to the establishment of the South African Society for Intelligent Transport Systems (SASITS).

The raising interest and investment in the field warrants a closer look at the potential benefits for South Africa. The main objective of this dissertation is to investigate whether ITS measures are beneficial to South Africa. Several questions need to be answered before this main question can be investigated.

The methodology followed to answer the identified questions includes an analysis of the specific characteristics of South Africa, a broad investigation of Intelligent Transport Systems, including a scan of the expected and/or measured benefits of different systems, an analysis of the modelling requirements and a scan of existing data. Based on existing and additional data, which was feasible to collect, two cases, the Ben

Schoeman Highway between Tshwane and Johannesburg and the N2 near Cape Town, were selected and data was adapted to suit the modelling requirements. The two cases were calibrated for the current situation, after which the three Intelligent Transport Systems (High Occupancy Vehicle (HOV) lanes, homogenising traffic flows via speed limits using Variable Message Signs and ramp metering) were modelled. Analysis of the information has provided answers to the questions and generated recommendations. The questions asked and answers provided are summarised hereafter.

Is South Africa's transport system, as well as related problems, similar to those of the developed world?

The road supply in South Africa is similar to the developed world. Expected mobility growth is higher than in the developed world, partly due to the fact that the previously disadvantaged communities are catching up. The urban wealthy's demand for transport is similar to the developed world, particularly the Unites States. Many problems are, therefore, also similar, such as congestion and air pollution. With regards to road safety, the South African situation is different from the developed world. Due to much higher pedestrian volumes and vehicle-pedestrian conflicts, road safety in South Africa is worse than the developed world. Moreover, the transport burden for the urban poor is higher than in developed world countries as public transport has lower quality standards.

Would South African society accept new technological solutions?

South Africa has an extremely sophisticated banking system with high levels of infrastructure. Moreover, cell phone technology is available in all parts of society. This technology is even used by the banks to provide banking access in rural areas. Problems with the acceptance of new technologies are, therefore, not expected.

Which benefits of Intelligent Transport Systems have been established in the developed world?

Ex ante studies mainly report the safety criteria speed, mobility criteria travel time and efficiency criteria throughput. It appears that some in-vehicle systems, such as Autonomous Cruise Control and Intelligent Speed Adaptation, are the most promising. This dissertation focuses on infrastructural systems. Ex ante studies of infrastructural systems that show promising results on safety and mobility, as well as efficiency criteria, are homogenising speed limit systems, special lanes and ramp metering.

Which ITS measures are potentially beneficial to South Africa?

As indicated, measures that have been most promising in other countries are homogenising speed limits, special lanes and ramp metering. Although not enforced, a bus lane is available on the N2. It was decided to investigate a bus and HOV lane scenario for the N2, as well as the second corridor, the Ben Schoeman Highway.

South Africa has extremely high road fatality levels. As speeding is one of the main causes of road fatalities and knowing that results with variable speed limits using Variable Message Signs are positive in other counties, it was decided to include this scenario in this dissertation.

Deciding on a third and last set of scenarios, it was contemplated that several municipalities have been considering pilots with ramp metering. As these pilot studies have not as yet materialised and no results with regards to ex ante studies have been published, it is especially interesting to get an impression of the effects. Moreover, foreign studies generate positive expectations.

Is it possible to use developed world models to investigate ITS measures in South Africa?

Based on an analysis of modelling requirements for ITS measures, it became clear that macroscopic transport models are not an appropriate tool for ITS scenarios. After a broad investigation of models, taking modelling as well as financial restrictions into account, it was decided to purchase the microscopic transport model, Paramics. Paramics has proven to be a model that is able to run scenarios for the South African situation. Although difficult, it was possible to calibrate the model for the South African situation.

What data needs to be available to use developed world models in the South African context?

In the modelling part of this dissertation, the focus was on highway corridors. To model a highway system in Paramics, an Origin-Destination matrix, profiles (distribution of vehicles over time), as well as the behaviour parameters with regards to driving behaviour, are required. In this study, primary as well as secondary data was used to generate the model input required.

Is South African driving behaviour different from the driving behaviour in developed countries?

Unfortunately, no research with regards to driving behaviour has been conducted in South Africa. It was, therefore, necessary to make a side step to general human behaviour information. A literature review provided insight into the differences between general behaviour in South Africa and the rest of the world. Moreover, major differences between South African cultural groups were found. The insight into general behaviour was translated into driving behaviour parameters for the microscopic model used in this dissertation.

How can differences in driving behaviour be included in transport models?

In this study it was concluded that the Mean Target Headway, Mean Reaction Time, aggression and awareness are the parameters that have to be carefully tuned, with regards to the average value and the distribution, to simulate actual behaviour in South Africa. Moreover, the final setting for the Ben Schoeman Highway and N2 appeared to be different.

What is the magnitude of potential ITS measures in the South African context?

Although the expectations with regards to Intelligent Transport Systems are generally positive, large variations have been found. Specific local aspects have a large influence on the magnitude of Intelligent Transport Systems. Severe drops in throughputs and an increase in overall travel time were found for all **High Occupancy Vehicle lane** scenarios investigated. Introducing a High Occupancy Vehicle lane on the Ben Schoeman Highway as well as the N2 will, therefore, lead to congestion in the suburbs as vehicles are not able to enter the highway.

Homogenising speeds by introducing Variable Message Sign systems has a small influence on the throughput. Homogenising speeds (and, therefore, traffic flows) will lead to a slight increase in travel time and decrease in speed. It was found that the safety benefit is large if a fixed 80 km/h scenario is introduced.

It appears that the effects of **ramp metering** on the two corridors are different. On the Ben Schoeman Highway an increase in throughput of between 2.2% and 8.5% is realised, while travel times for all traffic is virtually unchanged. Moreover, the safety risk on the Ben Schoeman Highway decreases. The N2, on the other hand, shows a decrease in throughput of between five percent and 8.8%, while the safety risk increases.

Is the magnitude of ITS measures in South Africa different to international experiences?

A comparison of the values for ITS measures in the (inter)national literature and the estimated results of the modelling exercise, have indicated that the magnitude of the effects are similar (see table S1). It needs to be mentioned that the range of some of the (inter)national results is wide. It is, therefore, impossible to draw final conclusions with regards to the magnitude of measures. Moreover, it was found that the local situation has a considerable influence on the results. Nevertheless, based on the analysis, there is no reason to assume that the effects of ITS measures in South Africa are different from other countries, even though driving behaviour is significantly different.

Table S.1 Comparison of the magnitude of different ITS measures (%)

	International	National	Ben Schoeman Highway	N2
HOV lanes				
• Volume		-40	-47 to -19	-26 to +0.4
• Travel time	-8 to +200	-76	+266 to +333	-50 to +722
• Speed		+319	-24 to -13	-20 to -8
Homogenising speeds				
• Volume	-24.2 to +5.7		-3.6 to +0.5	-3.5 to +1.9
• Travel time			+12	+10
• Speed			-27.4 to -6.6	-30.1 to +1.8
• Safety (accidents)	-20 to -29			
• Safety risk			-270 to -10	-300 to -40
Ramp metering				
• Volume	-1 to +8	0 to+24	+2.2 to + 8.5	-8.8 to -5
• Travel time	-48to +22	-28	0	+10
• Speed	-5.2 to +8.2	+13	+5.7	-8.8
• Shockwaves	+0.6			
• Safety risk			+50 to +75	-400 to -129

Should ITS measures be implemented in the South African context?

Based on the calculations carried out, it can be concluded that Intelligent Transport System measures can be beneficial to South Africa and can contribute to the improvement of sustainability. The way in which the measures are implemented, as well as the type of corridor that they are implemented in, influence the efficiency of the measure. The lessons learned with regards to High Occupancy Vehicle lanes are that an additional lane needs to be created to ensure the measure is successful. Moreover, the service level of public transport needs to improve sufficiently before this Intelligent Transport System measure is considered. Homogenising speeds provides a substantial safety improvement. Having a fixed speed limit of 80 km/h during the peak period decreases the safety risk, while the effect on throughput and travel time is minor. The analysis of ramp metering indicates that the results depend on the type of corridor. Nevertheless, for one corridor, this was the most effective measure.

The overall conclusion is that Intelligent Transport Systems have potential for South Africa.

Several recommendations were made based on this dissertation. This summary includes the most important ones.

Due to the fact that about 75% of all South Africans are dependent on public transport, it is recommended that the potential benefits of Intelligent Transport Systems in public transport be investigated.

A lack of driving behavioural theory and understanding has been identified in South Africa. Further research is urgently needed. The hypothesis is that regional differences will be found.

Considerable differences have been found between the two corridors included in this dissertation. Further research into the effects of the local situation with regards to Intelligent Transport System measures is required.

It is expected that vehicle ownership and use in South Africa will increase substantially in the coming years. This dissertation did not include the mobility growth. Further research into the potential benefits of Intelligent Transport Systems in the future, taking mobility growth into account, is recommended.

This dissertation includes an analysis of two, single-route corridors. A holistic network analysis is recommended in order to find more optimal Intelligent Transport Systems that will improve the transport system. It can be concluded that more analyses are needed before any investments are made in this corridor.

The research period in this dissertation is the morning peak. This is due to the fact that this period shows the most severe transport related problems, such as congestion and pollution. Nevertheless, Intelligent Transport Systems are likely to be beneficial during the off-peak period as well. Further research into the effect of Intelligent Transport Systems during the off-peak period is recommended.

Samenvatting

Mobiliteit en transport zijn de motor van de economische groei in een land. Helaas hapert deze motor door huidige problemen als congestie, een slechte bereikbaarheid en verkeersonveiligheid. Het aanbod van additionele infrastructuur blijkt niet voldoende te zijn om aan de groei van bevolking en mobiliteit tegemoet te komen. Dit vanwege de beperkte financiële middelen en een gebrek aan menskracht.

Momenteel zijn in bijna alle bebouwde gebieden in Zuid-Afrika inefficiënte verkeers- en vervoers(management) systemen gangbaar. Dit leidt tot files gedurende de piek, zeer beperkt gebruik van openbaar vervoer door groepen met een middelhoog en hoog inkomen, onbetrouwbare frequenties, onveilige treinen en minibustaxi's (een informeel systeem dat gebruik maakt van voertuigen die 16 personen kunnen vervoeren) en ontevreden reizigers.

De ruimtelijke ordening gedurende de jaren van apartheid heeft geleid tot niet-duurzame steden. De nieuwe Zuid-Afrikaanse regering heeft daarom een immense taak aan het oplossen van stedenbouwkundige- en verkeerskundige problemen. In deze dissertatie worden technologische oplossingen (Intelligente Transport Systemen) onder de loep genomen die duurzaamheid kunnen bevorderen.

Momenteel zijn in Zuid-Afrika geavanceerde verkeersregelinstallaties en flexibele bebording (Variable Message Signs) in gebruik. Bovendien wordt momenteel een proef gepland met een Incident Management Systeem. De interesse in Intelligente Transport Systemen (ITS) blijkt te groeien, en dat heeft geleid tot de oprichting van de South African Society for Intelligent Transport Systems (SASITS).

Deze groeiende interesse en de eveneens groeiende investeringen rechtvaardigen de bestudering van de potentiële baten voor Zuid-Afrika. Het hoofddoel van deze studie is het berekenen van de potentiële baten van Intelligente Transport Systemen. Maar voordat hierop een antwoord kan worden gevonden, moeten diverse vragen worden beantwoord.

De methode die is gevolgd om de gestelde vragen te beantwoorden, is het scannen van de specifieke karakteristieken van Zuid-Afrika, een brede scan van Intelligente Transport Systemen, inclusief een analyse van de berekende en gemeten effecten van verschillende systemen, een analyse van de eisen waaraan modellen moeten voldoen en een analyse van bestaande data. Op basis van bestaande data en de mogelijkheden tot het verzamelen van data, zijn twee studiegebieden geselecteerd: de Ben Schoeman Highway tussen Tswane en Johannesburg en de N2 nabij Kaapstad. De data zijn bewerkt zodat ze gebruikt kunnen worden als input voor het geselecteerde microscopische simulatiemodel. Nadat een grondige calibratie is uitgevoerd, zijn drie ITS maatregelen getoetst, te weten: een strook voor bus c.q. High Occupancy Vehicle (HOV), variabele snelheden met behulp van VMS en toeritdosering. De analyse van de resultaten heeft de gestelde vragen beantwoord en verdere aanbevelingen opgeleverd. Hieronder een samenvatting van de antwoorden op de gestelde vragen.

Zijn het Zuid-Afrikaanse vervoerssysteem en de gerelateerde problemen vergelijkbaar met de problemen in de westerse wereld?

Het verkeersnetwerk in Zuid-Afrika is vergelijkbaar met dat in de westerse wereld. De verwachte mobiliteitsgroei is hoger, deels vanwege een inhaalslag door delen van de bevolking die onder het voormalige regime werden onderdrukt. De vervoersvraag van de midden- en hogere inkomensklassen is ook vergelijkbaar met die in de westerse wereld, met name de Verenigde Staten. Veel problemen, zoals congestie en emissies, zijn daardoor ook vergelijkbaar. Toch is de situatie op het gebied van verkeersveiligheid heel anders. Vanwege het grote aantal voetgangers en voetganger-voertuig-conflicten is het aantal slachtoffers vele malen hoger. Bovendien zijn de relatieve kosten voor vervoer voor het arme deel van de bevolking vele malen hoger dan in de westerse wereld, terwijl de kwaliteit van het openbaar vervoerssysteem veel te wensen overlaat.

Zal de Zuid-Afrikaanse samenleving nieuwe technologieën aanvaarden?

Zuid-Afrika heeft een banksysteem van hoge kwaliteit met een hoogwaardige infrastructuur. Mobiele telefoons worden door alle lagen van de bevolking gebruikt. Op het platteland worden mobiele telefoon zelfs gebruikt voor de afhandeling van bankzaken. Acceptatieproblemen worden daarom niet verwacht.

Welke baten hebben Intelligente Transport Systemen opgeleverd in de westerse wereld?

Ex ante studies berekenen met name baten ten aanzien van het verkeersveiligheidscriterium snelheid, het mobiliteitscriterium reistijd en het efficiëntiecriterium intensiteit. Systemen die in het voertuig worden geplaatst, zoals Autonomous Cruise Control en Intelligente Snelheids Adaptie (ISA), laten de grootste baten zien. Aangezien deze systemen al door autofabrikanten worden onderzocht, focust deze dissertatie op infrastructurele maatregelen. Ex ante studies over infrastructurele maatregelen rapporteren baten op het gebied van veiligheid, mobiliteit en efficiëntie. Met name het homogeniseren van snelheden, het toepassen van specifieke stroken en toeritdosering hebben effect.

Welke Intelligente Transport Systemen bieden potentiële baten voor Zuid-Afrika?

Succesvolle maatregelen elders, zijn het homogeniseren van snelheden, het toepassen van specifieke stroken en toeritdosering. Hoewel misbruik nog niet word bestraft, is er momenteel al een busstrook op de N2. Daarom is besloten om het effect van een bus/HOV-strook te bestuderen voor de Ben Schoeman Highway en de N2.

Te hard rijden is een van de oorzaken voor het hoge aantal ongevallen op Zuid-Afrikaanse wegen. Gegeven het voorgaande en mede vanwege de positieve ervaringen in andere landen, is besloten om variabele snelheidslimieten via VMS te onderzoeken.
Tijdens de zoektocht naar een derde en laatste maatregel die in deze dissertatie onderzocht kan worden, bleken diverse gemeenten plannen te hebben om toeritdosering in pilot-studies toe te passen. Omdat geen ex ante studies zijn uitgevoerd ter onderbouwing van deze pilots, is besloten in deze dissertatie toeritdosering ook te onderzoeken.

Is het mogelijk om modellen die in de westerse wereld zijn ontwikkeld te gebruiken om Intelligente Transport Systemen in Zuid-Afrika te onderzoeken?

Een analyse van de modelleerbehoeften van Intelligente Transport Systemen wees uit dat macroscopische modellen onbruikbaar zijn. Na een degelijke scan van beschikbare modellen en het maken van een financiële afweging, is besloten om het microscopische simulatiemodel Paramics aan te schaffen. Ofschoon de calibratie niet eenvoudig was, is gebleken dat Paramics toepasbaar is in de Zuid-Afrikaanse situatie.

Welke data zijn nodig om modellen die in de westerse wereld zijn ontwikkeld te gebruiken in de Zuid-Afrikaanse context?

De focus in het modelleerdeel van deze studie was autosnelwegcorridors. Om een dergelijke corridor in Paramics te modelleren, zijn een Herkomst-Bestemmingsmatrix (HB-matrix), profielen (die de distributie van de HB-matrix in de tijd vastleggen) en parameters ten aanzien van rijgedrag nodig. In deze studie zijn data van derden en eigen metingen gebruikt om de benodigde input te genereren.

Is het Zuid-Afrikaanse rijgedrag anders dan het rijgedrag in de westerse wereld?

Jammer genoeg is er geen literatuur beschikbaar over rijgedrag in Zuid-Afrika. Het was daarom nodig een zijstap te maken naar literatuur ten aanzien van gedrag en cultuur in algemene zin. Dit deel van het literatuuronderzoek bracht aan het licht dat gedrag in Zuid-Afrika anders is dan in de westerse wereld. Bovendien bleek dat de verschillen tussen de vele culturele groepen in Zuid-Afrika groot zijn. De informatie over gedrag in algemene zin is vertaald in rijgedragparameters voor het microscopische model dat in deze dissertatie is gebruikt.

Hoe kunnen verschillen in rijgedrag worden opgenomen in transportmodellen?

In deze studie is de conclusie getrokken dat de rijgedragparameters (de gemiddelde waarden en de verdelingsfuncties), gemiddelde gewenste volgafstand, gemiddelde reactietijd, agressiviteit en alertheid dienen te worden aangepast om het Zuid-Afrikaanse rijgedrag te kunnen weergeven. Tijdens de calibratie is gebleken dat er enig verschil is tussen de Ben Schoeman Highway en de N2.

Hoe groot zijn de potentiële baten van ITS-maatregelen in Zuid-Afrika?

Hoewel de berekende potentiële baten positief zijn ten aanzien van ITS-maatregelen, blijken de variaties groot te zijn. Lokale aspecten blijken de resultaten in grote mate te beïnvloeden.
Een behoorlijke reductie in intensiteiten en een toename in reistijd zijn geconstateerd bij de toepassing van **bus/HOV-stroken**. Introductie van HOV-stroken op de Ben Schoeman Highway en de N2 zal leiden tot congestie in de voorsteden, aangezien het verkeer niet voldoende toegang tot de autosnelweg heeft.

Homogeniseren van snelheden via de toepassing van Variable Message Signs heeft een minimale invloed op de intensiteiten. Het homogeniseren van snelheden (en daarmee de verkeersstroom) resulteert in een geringe toename in reistijd en afname van de snelheden. De positieve effecten ten aanzien van verkeersveiligheid blijken groot te zijn indien een gefixeerde maximumsnelheid van 80 km/u wordt toegepast.
De effecten van **toeritdosering** blijken zeer verschillend te zijn voor de beide corridors. Op de Ben Schoeman Highway wordt een toename in de intensiteit geconstateerd van tussen de 2,2% en de 8,5%, terwijl de reistijd voor al het verkeer nagenoeg gelijk blijft. Bovendien neemt het verkeersveiligheidsrisico af op de Ben Schoeman Highway. De N2 daarentegen laat een reductie in intensiteiten zien van tussen de 5% en 8.8% en een toename van het verkeersveiligheidsrisico.

Verschillen de potentiële baten van ITS-maatregelen in Zuid-Afrika van die in de westerse wereld?

Een vergelijking van de procentuele baten van ITS-maatregelen in de (inter)nationale literatuur en de modelleerresultaten in deze studie laat zien dat de omvang en richting gelijk zijn (zie tabel S.a). Wel moet worden opgemerkt dat de marges van vele resultaten breed zijn en dat het daarom moeilijk is om definitieve conclusies te trekken over de omvang van deze baten. Bovendien is gebleken dat de lokale situatie een behoorlijk grote invloed heeft. Toch geven de resultaten geen aanleiding om te veronderstellen dat het effect van ITS-maatregelen in Zuid-Afrika anders is dan in de westerse wereld, ook al zijn er verschillen in rijgedrag.

Tabel S.a Vergelijking van de omvang van verschillende ITS-maatregelen (%)

	Internationaal	Nationaal	Ben Schoeman Highway	N2
Bus/HOV stroken				
• Volume		-40	-47 à -19	-26 à +0.4
• Reistijd	-8 à +200	-76	+266 à +333	-50 à +722
• Snelheid		+319	-24 à -13	-20 à -8
Homogeniseren van snelheden				
• Volume	-24.2 à +5.7		-3.6 à +0.5	-3.5 à +1.9
• Reistijd			+12	+10
• Snelheid			-27.4 à -6.6	-30.1 à +1.8
• Veiligheid (ongevallen)	-20 à -29			
• Veiligheidsrisico			-270 à -10	-300 à -40
Toeritdoseering				
• Volume	-1 à +8	0 à+24	+2.2 à + 8.5	-8.8 à -5
• Reistijd	-48 à +22	-28	0	+10
• Snelheid	-5.2 à +8.2	+13	+5.7	-8.8
• Schokgolven	+0.6			
• Veiligheidsrisico			+50 à +75	-400 à -129

Is het wenselijk om ITS-maatregelen in Zuid-Afrika toe te passen?

Gebaseerd op de berekeningen in deze dissertatie is de conclusie getrokken dat ITS-maatregelen een positief effect hebben in Zuid-Afrika en een bijdrage leveren aan het verbeteren van de duurzaamheid van het verkeerssysteem. De wijze waarop maatregelen worden geïmplementeerd en het soort corridor waar de maatregelen worden gerealiseerd, beïnvloeden de effectiviteit. De les die is getrokken op basis van deze studie ten aanzien van bus/HOV-stroken, is dat de realisatie van een extra strook nodig is om ervoor te zorgen dat deze maatregel een positief effect heeft. Bovendien dient het serviceniveau van het openbaar vervoer te worden verbeterd voordat een bus/HOV-strook in overweging wordt genomen. De introductie van een gefixeerde snelheidslimiet van 80 km/u gedurende de piek laat een reductie van het verkeersveiligheidrisico zien, terwijl de intensiteit en reistijd nauwelijks worden beïnvloed. De resultaten ten aanzien van toeritdosering blijken zeer afhankelijk te zijn van de lokale situatie. Toch waren voor één corridor de resultaten zeer positief.

Al met al kan worden geconcludeerd dat Intelligente Transport Systemen potentie bieden in Zuid-Afrika.

Verschillende aanbevelingen zijn gemaakt in deze dissertatie. De belangrijkste zijn:

Aangezien zo'n 75% van alle Zuid-Afrikanen afhankelijk is van het openbaar vervoer, wordt aanbevolen om de potentiële baten van ITS-maatregelen in het openbaar vervoer te onderzoeken.

In deze studie is géén literatuur over rijgedrag in Zuid-Afrika aangetroffen. Indien betrouwbaar onderzoek naar ITS maatregelen gewenst is, is vervolgonderzoek dringend nodig. De hypothese is dat regionaal verschillen zullen worden geconstateerd.

Er zijn behoorlijke verschillen geconstateerd tussen de twee corridors die zijn onderzocht in deze dissertatie. Daarom dient verder onderzoek te worden gedaan naar de invloed van lokale karakteristieken op de resultaten.

De komende jaren wordt in Zuid-Afrika een substantiële groei van autobezit en –gebruik verwacht. In deze dissertatie is geen rekening gehouden met de verwachte mobiliteitsgroei. Analyse van de potentiële baten van Intelligente Transport Systemen, rekening houdend met de verwachte mobiliteitsgroei, wordt aanbevolen.

In deze studie zijn twee corridors onderzocht met één alternatieve route. Een holistische netwerk analyse wordt voorgesteld om optimale ITS-maatregelen te identificeren. Geconcludeerd kan worden dat verdere analyses nodig zijn voordat investeringen plaatsvinden.

In deze dissertatie is de ochtendspits onderzocht, omdat problemen zoals congestie en emissies in Zuid-Afrika dan het grootst zijn. De verwachting is echter dat ITS-maatregelen ook een positief effect hebben gedurende andere dagdelen. Verder onderzoek ten aanzien van de verwachte baten gedurende de daluren wordt daarom aanbevolen.

Glossary

AACC	Autonomous Adaptive Cruise Control
ACC	Adaptive Cruise Control
AMS	Arterial Management System
ATM	Automatic Teller Machine
ATSC	Adaptive Traffic Signal Control
AVI	Automated Vehicle Identification
BBS	Black Box System
B/C	Benefit/Cost
BSH	Ben Schoeman Highway
CC	Cruise Control
CCTV	Closed Circuit TeleVision
CST	Centre for Sustainable Transportation
EMS	Emergency Management System
EPS	Electronic Payment System
ET	Electronic Ticketing
ETC	Electronic Toll Collection
FHWA	Federal HighWay Administration
FM	Fleet Management
FMS	Fleet Management System
HOV	High Occupancy Vehicle
IMS	Incident Management System
ITP	Integrated Transport Plan
IM	Incident Management
IMS	Incident Management System
ISA	Intelligent Speed Adaptation
ITS	Intelligent Transport System
LCD	Liquid Crystal Display
LOS	Level Of Service
ME	Managing Executive
MIT	Massachusetts Institute of Technology
NDoT	National Department of Transport
NEPAD	New Partnership for Africa's Development
NHS	National Highway System

NLTTA	National Land Transport Transition Act
NMC	National Management Centre
NPV	Net Present Value
NS	Navigation System
NTS	National Travel Survey
OD	Origin-Destination
OHS	October Household Survey
PTP	Public Transport Priority
RTIS	Real Time Information System
SACO	South African Commuter Organisation
SANRAL	South African Road Agency pty Ltd
SARCC	South African Rail Commuter Corporation
SASITS	South African Society for Intelligent Transport Systems
SCOOT	Split Cycle and Offset Optimizer Technique
SD	Standard Deviation
SMS	Short Message Service
TA	Transport Authority
TDM	Travel Demand Management
TMS	Transit Management System
TRB	Transport Research Board
TS	Tracker System
UCT	University of Cape Town
UEPS	Universal Electronic Payment System
VMS	Variable Message Sign
VSL	Variable Speed Limits
WRI	World Resources Institute

Appendices

Appendix A: Simulated efficiency of different ITS measures outside South Africa

Appendix B: Simulated efficiency of different ITS measures inside South Africa

Appendix C: Developers/suppliers of micro simulation models

Table A ***Simulated effects of different ITS measures outside South Africa***

Measure	Speed	Travel time	Throughput	Shock waves[*]	Software
Adaptive Cruise Control (Ludmann er al, 1999)	-13% to +6%	N/A	+12% to +14%	N/A	N/A
Autonomous Adaptive Cruise Control (Vanderschuren et al, 2000)					
▪ 50%	0%	-1.5%	0%	-80%	MIXIC
▪ 50% and special lane (SL)	-3%	+1%	+1%	-73%	
▪ 50%, SL and short headways	-1%	0%	+1%	-71%	
▪ 60%, SL and short headways	-1%	-1.5%	+1%	-84%	
Autonomous Adaptive Cruise Control (VanderWerf et al, 2002)					
▪ 40%	N/A	N/A	+7%	N/A	N/A
▪ 100%	N/A	N/A	+2%	N/A	
Autonomous Adaptive Cruise Control (Marsden et al, 2000)					
▪ 10% and 1.5s	+10%	N/A	N/A	N/A	FLOWSIM
▪ 20% and 1.5s	+8%	N/A	N/A	N/A	
▪ 40% and 1.5s	-10%	N/A	N/A	N/A	
▪ 70% and 1.5s	-50%	N/A	N/A	N/A	
Cooperative Adaptive Cruise Control (VanderWerf et al, 2002)					
▪ 40%	N/A	N/A	+18%	N/A	N/A
▪ 100%	N/A	N/A	+100%	N/A	
Dynamic Road Profile (Tampère, 1999)	-30%	N/A	30%	N/A	MIXIC
Dynamic Road Profile (Stemerding et al, 1999)	-5.9% to +43.9%	N/A	-1.6% to 17.7%	-4%	INTEGRATION
Dynamic Road Profile (Goudappel Coffeng, 1998)	N/A	–41% to +16%	N/A	N/A	INTEGRATION
Dynamic Route Information Panel (Straaten van, 2001)	N/A	–42% to 0%[**]	N/A	N/A	PARAMICS
Freeway Management System (Thomas, 2001)	+16% to +62%	-48% to -13%	+8% to +25%	N/A	N/A
High Occupancy Vehicle lane (Johnston, 1996)	N/A	-8%	N/A	N/A	N/A
High Occupancy Vehicle lane (Dahlgren, 1998)	N/A	-1% to +200%	N/A	N/A	N/A
Homogenise via Speed Limits (VMS)[***] (Stemerding et al, 1999)	-9.8% to +1.5%	N/A	-6.6% to +1.6%	+4.8%	INTEGRATION
Intelligent Speed Adaptation (Lui et al, 2000)	-10%[11]	+1%[11]	N/A	N/A	DRACULA

Pay Lanes (Stemerding et al, 1999)	-15.7% to +3.1%		-1.9% to +2.4%	N/A	INTEGRATION
• Paying drivers		-56% to -42%			
• Non-paying drivers		+15.2% to +25.3%			
Pay Lanes (Schoemakers, et al, 2000)	N/A	-33%	0%	N/A	INTEGRATION
Peak Lane (Stemerding et al, 1999)	-5.6% to +50.7%	N/A	-1.5% to +18.1%	-4%	INTEGRATION
Peak Lane (Westra et al, 2002a)	N/A	-21%	N/A	N/A	INTEGRATION
Peak Lane (Bosch et al, 2003)	N/A	-9% to +50%	-5% to +6%	N/A	INTEGRATION
Ramp Metering (Stemerding et al, 1999)	-5.2% to +8.2%	N/A	-1% to +0.8%	+0.6%	INTEGRATION
Ramp Metering (Westra et al, 2002b)					INTEGRATION
Morning peak	N/A	-21% to +45%[****]	N/A	N/A	
• Evening peak	N/A	-23% to +22%	N/A	N/A	
Ramp Metering (Goudappel Coffeng, 1997b)	N/A	-6%	N/A	N/A	INTEGRATION
Ramp Metering (Goudappel Coffeng, 1998)	N/A	-48% to -14%	+8%	N/A	INTEGRATION
Road Trains (Hoogvelt et al, 1996)	0%	0%	More freight	0%	MIXIC
Road Trains (Ludmann et al, 1999)	N/A	N/A	+10% to +14%	N/A	N/A
Speed limit compliance (from 80% to 100%)					
(Bonsall et al, 2005)					
Peak					
• Current speed limit	N/A	N/A	+5.6%	N/A	DRACULA
• Speed limit minus 10 km/h	N/A	N/A	+5.7%	N/A	
Off peak					
• Current speed limit	N/A	N/A	+2.9%	N/A	
• Speed limit minus 10 km/h	N/A	N/A	-24.2%	N/A	

N/A Not Available

* Number of Shock waves is indication for the road safety situation; some studies use number of stops

** Estimated; based on different graphs

*** The speed is reduced from 120 km/h to 90 km/h

**** There is a positive impact on the travel time on the highway and a negative impact on the secondary road network.

Table B *Simulated effects of different ITS measures inside South Africa*

Measure	Speed	Travel time	Throughput	Shock waves*	Software
e-Mobility (Mkhize and Thomas, 2005)	-44% to -45%	-27% to -32%	N/A	N/A	AIMSUN2
High Occupancy Vehicle lane (Roux and Bester, 2002)	+319%	-76%	-40%	N/A	N/A
Interchange Control (De Jongh-Schreuder and Venter, 2005)					
• Manual improvement system	N/A	-17% to -46%	+3% to +54%	N/A	VISSIM
• ITS System	N/A	-19% to -1%	+ 2% to +37%	N/A	
Public Transport Priority (Beer de et al, 2005)					
• Signal upgrate only	N/A	+20% (PT) to +8% (Car)	N/A	N/A	DRACULA
• PT** priority network	N/A	-20% (car) to -29% (PT)	N/A	N/A	
• PT priority network + extra PT services	N/A	non significant	N/A	N/A	
Ramp Metering (Cloete, 2002)	+13%	-28%	0% to +24%	N/A	PARAMCS
Toll Roads (Oberholzer et al, 2001)	N/A	-31% to -23%	-16% to 0%	N/A	EMME/2
Toll Road (Venter et al, 2001)	N/A	N/A	-85% to 0%	N/A	AIMSUN2

N/A Not Available

* Number of Shock waves is indication for the road safety situation; some studies use number of stops.

** pt = public transport

Table C Suppliers of microscopic simulation models

Model	**Organisation**	**Country**
AIMSUN 2	Universitat Politècnica de Catalunya, Barcelona	Spain
ANATOLL	ISIS and Centre d'Etudes Techniques de l'Equipement	France
ARTEMIS	University of New Wales, School of Civil Engineering	Australia
ARTIST	Bosch	Germany
CASIMIR*	Institute National de Recherche sur les Transports et la Sécurité	France
CORSIM	Federal Highway Administration	USA
DRACULA	Institute for Transport Studies, University of Leeds	UK
FLEXSYT II	Ministry of Transport	The Netherlands
FREEVU	University of Waterloo, Department of Civil Engineering	Canada
FRESIM	Federal Highway Administration	USA
HUTSIM	Helsinki University of Technology	Finland
INTEGRATION	Queen's University, Transportation Research Group	Canada
MELROSE	Mitsubishi Electric Corporation	Japan
MICROSIM	Centre of parallel computing (ZPR), University of Cologne	Germany
MICSTRAN	National Research Institute of Police Science	Japan
MITSIM	Massachusetts Institute of Technology	USA
NEMIS	Mizar Automazione, Turin	Italy
PADSIM	Nottingham Trent University - NTU	UK
PARAMICS	The Edinburgh Parallel Computing Centre and Quadstone Ltd	UK
PHAROS	Institute for simulation and training	USA
PLANSIM-T	Centre of Parallel Computing (ZPR), University of Cologne	Germany
SATRUN	ITS, University of Leeds	UK
SHIVA	Robotics Institute - CMU	USA
SIGSIM	University of Newcastle	UK
SIMDAC	ONERA - Centre d'Etudes et de Recherche de Toulouse	France
SIMNET	Technical University Berlin	Germany
SISTM	Transport Research Laboratory, Crowthorne	UK
SITRA-B+	ONERA - Centre d'Etudes et de Recherche de Toulouse	France
SITRAS	University of New South Wales, School of Civil Engineering	Australia
THOREAU	The MITRE Corporation	USA
TRACKS	Transportation & Traffic Systems Ltd	New Zealand
TRANSIMS	Los Alamos National Laboratory	USA
TRAF-NETSIM	Federal Highway Administration	USA
VISSIM	PTV System Software and Consulting GMBH	Germany

* Note that this model is no longer maintained by INRETS.
Sources included: Smartest, 1997a and Koutsopoulos, 2004

About the Author

Marianne Vanderschuren was born in Kerkrade, the Netherlands, on the 6th of July 1966. After passing matric at the ‘Antonius doctor College’, in Kerkrade, she enrolled at the ‘Nationale Hogeschool voor Toerisme en Verkeer’ (National College for Tourism and Traffic) where she obtained her Bachelor's degree in Transportation Engineering in 1989. Between 1996 and 1999 she studied for a Masters degree in Systems Engineering, Policy Analysis and Management at the University of Delft, the Netherlands.

Marianne started her professional career at the University of Delft, where she worked as a researcher at the Department of ‘Bouwkunde’ (Architecture and Planning) and at the Department of Civil Engineering in 1989/2000. Between 1990 and 2000, she was a researcher at TNO Inro (Institute for Infrastructure, Transport and Regional Development) of the Netherlands Organisation for Applied Scientific Research. She was involved in a wide range of topics including transport models, dynamic traffic management and a wide range of (economic) evaluation studies, policy analysis, the impact of new technologies and tourism. She was the project leader of various large national (Dutch) and international (European Union) projects from 1995.

Marianne was appointed a Senior Lecturer, with responsibility for developing the teaching of transport studies, in the Department of Civil Engineering at UCT in 2000. She teaches transport planning and engineering on an undergraduate level. She was one of the core staff members that planned and developed the Postgraduate Programme in Transport Studies. Between 2001 and July 2004 she was programme convenor. She is part of the teaching staff of all courses offered and convenes the course on Transport Analysis, Modelling and Assessment. Moreover, she has supervised several students on a Bachelors, as well as a Masters level.

At the University of Cape Town, Marianne has taken part in several research projects, focussing on microscopic simulation modelling, ITS, environmental and sustainability issues, road safety, pedestrian and bicycle planning, as well as the development of sketch planning tools for transport and housing modelling.

Marianne has been an external examiner for the University of Natal (Masters thesis). Moreover, she is a reviewer of papers and proposals for the South African Institution of Civil Engineering Journal, Transport Reviews (journal) and the National Research Foundation.

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