The copyright of this thesis vests in the author. No quotation from it or information derived from it is to be published without full acknowledgement of the source. The thesis is to be used for private study or non-commercial research purposes only.

Published by the University of Cape Town (UCT) in terms of the non-exclusive license granted to UCT by the author.

University of Cape Town

Operational Upgrades to improve traffic flow in Small Middleweight Cities: Windhoek, Namibia

By: Henock Mankavu Ntinda (NTNMAN002)
Supervisor: Associate Professor Marianne Vanderschuren

Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Engineering

In the Department of Civil Engineering
Centre for Transport Studies

University of Cape Town

August 2012

Plagiarism Declaration

I know the meaning of plagiarism and declare that all work in this dissertation, save for which is properly acknowledged, is my own.

Signed by candidate

Signature Removed

17 – 11 - 2012

……………………………… …………………………

Signed Date

University of Cape Town

Executive Summary

The study of the improvements to transport controlling facilities, defined in this dissertation as operational transport upgrades, aims to ascertain its influence on a growing urban traffic demand. This dissertation assesses the influence that the conversion of Werner List Street into a one-way street has on the performance of traffic accommodation. Werner List Street links traffic commuting from the south to the north of Windhoek's Central Business District (CBD). The CBD traffic demand is estimated to breach network capacity by 2015, a scenario prevalent in many small middleweight cities.

The research conducted a literature review on aspects related to the development and implementation of operational upgrades; thereby gaining an understanding on the relevance that such improvements have on small middleweight cities. Studied literature suggests that with the reduction in the allocation of funds to develop transport systems, transport authorities resort to innovative methods of improving transport network utilising minimal capital expenditure. The limited funding is prevalent in small middleweight cities due to the current lack of major traffic impediment.

The research studied aspects of Windhoek's activity system, as presented in the city's Household Survey of 2004 that primarily focused on the income status, transport mode use and transport mode preference. The origin of trips would assist in determining the direction, in relation to Windhoek's CBD, peak traffic commutes.

The City of Windhoek embarked on establishing a base CBD traffic scenario, from which future improvements could be measured. The assessment of the network demarcated for the base study formed part of the input information used to establish the Strategic Transport Master Plan (STMP). The STMP aims to address the promotion of access to land-use areas (Phase 1), the modal composition distortion (Phase 2) and CBD traffic circulation improvement (Phase 3). The assessment of Windhoek's transport network has primarily consisted of visual inspections, with the one-way conversion of Werner List Street being the only upgrade completed.

The conversion of Werner List Street into a one-way street is an implemented improvement borne from the development of the STMP. The analysis of performance measures along the upgraded street entailed the micro simulation of peak traffic during morning and evening periods. Visual inspections, using the manual traffic count method, were conducted to validate turning movements and queue length build-up at the three major streets intersecting Werner List Street; Fidel Castro Street, Dr Frans Indongo Street and John Meinert Street.

Research questions were developed to investigate the influence that operational upgrades had on traffic network performance. The questions catered to:

- The incorporation of operational upgrades in the STMP's methodology,
- Operational upgrades as a traffic network improvement measure, and
- The future use of output data.

University of Cape Town

The research concluded that the STMP, fundamentally, aims to develop Windhoek's transport network. The proposed techniques, primarily, focus on operational improvements with limited infrastructure expansion required during the implementation phase. The operational upgrade improves the traffic network's accommodation transport demand, however, the wholesome implementation of the STMP's proposed operational upgrades could provide a better measure of improvement. The output data, obtained from the micro simulation of Werner List Street, was used to identify areas needing further attention. It was, therefore, concluded that output data formed a critical role in providing a platform to continually update the CBD traffic network's performance.

Through the assessment of Windhoek's activity system, it was noted that a significant percentage (40%) of residents have no access to private vehicle ownership use creating a potential market for public transport utilisation. Public transport occupancy per trip far outmatches that attained through public transport.

The analysis results, obtained from the micro simulation of the upgraded network and substantiated through results obtained from the conducted visual inspections, depict a slight improvement in the network performance. The John Meinert-Werner List intersection experienced significantly lower queue length levels than the levels established in the base study.

The results, further, depict areas of concern along Werner List Street. The queue length measurements for the eastern and western approaches of the Fidel Castro-Werner List intersection and the western approach of the Dr Frans Indongo-Werner List intersection depict relatively high levels of queue length build-up. Further, the analysis of the traffic commuting between the Fidel Castro-Werner List intersection and the Dr Frans Indongo-Werner List intersection depicts a low average speed, as compared with the average speeds measured for the other links. The implementation of additional upgrades, preferably operational upgrades, should, therefore, aim to reduce the impact at the assessed areas of concern whilst reducing overall traffic volumes within the CBD.

The research recommends a pragmatic implementation of the STMP, specifically the network continuity and ring route formations. These methods of network upgrading aim to reduce vehicle volumes within the CBD by providing alternate route choices for traffic that commutes across the CBD to reach the destinations outside the CBD.

Additionally, the incorporation of modern technology would provide updated count data and monitors the network's performance. Modern technology, such as the lane occupancy detectors and tolltag transponders, provides continually updated quantitative data at traffic intersection.

This dissertation primarily focuses on the operational aspects of the transport network. The possibility of attending to pedestrian movement and public transport regulation within the CBD would, further, improve the academic understanding of Windhoek's transport system and promote a holistic approach to improving the network's capacity.

University of Cape Town

Abbreviations

CBD – Central Business District

CoW – City of Windhoek Municipality

NICHES – New and Innovative Concepts for Helping European Sustainability

SACN – Southern African Cities' Network

STMP – Strategic Transport Master Plan

WHO – World Health Organisation

UN – United Nations

University of Cape Town

Acknowledgements

I would like to take this opportunity to show gratitude to the people and institutions that have guided and encouraged me through this academic chapter; presented in this research. The tough and demanding effort required to reach this point would not have counted without the mentioned support.

I thank my research supervisor, Associate Professor Marianne Vanderschuren, for allowing me the freedom to express my views whilst providing great guidance in attending to detailed aspects of my research. My gratitude extends, further, to Rahul Jobanputra for assisting me with the use of the Quadstone Paramics Suite.

I thank the Centre for Transport Studies administrative team. Rowen Geswindt, Isabel Ncube and Ayesha Dalwai; the availing of office space during the periods I attended to full-time research is greatly appreciated.

I thank the City of Windhoek, specifically the Transport Department, for availing invaluable information and data. Additionally, the students that assisted with the data collection process, my gratitude extends you.

Most importantly, to my family and friends, the patience you've afforded me is greatly appreciated. I sincerely thank you all for the support and encouragement shown throughout this academic journey.

Your support is greatly appreciated.

University of Cape Town

TABLE OF CONTENTS

University of Cape Town

University of Cape Town

List of Tables

List of Figures

University of Cape Town

University of Cape Town

Chapter 1. Introduction

1.1 Background

Assessed literature suggests that a general trend of insufficient funding for transport system improvements has created a platform for innovative development methods. Urban transport development has, therefore, moved to optimise the utilisation of existing infrastructure. For metropolises and large cities, the move to implement integrated transport mobility has developed considerably, with cities, such as Bogota and Cape Town incorporating mass transit systems into the public transport make up.

Small middleweight cities, as defined by McKinsey Global Institute (2011), experience low levels of traffic congestion. The growth estimated for these cities will breach current network capacity by 2025, with Central Business District (CBD) traffic circulation being of significant concern (SACN, 2011). Developing nations have struggled to meet the funding required for network development associated with mass transit systems (McKinsey Global Institute, 2011). The focus has, therefore, shifted to upgrading the operational features of the transport network.

Areas such as signal optimisation, one-way coupling and modal prioritisation have become critical to creating a transport system that is aimed at meeting future traffic demand. The assessment of operational upgrades, as a form of Windhoek's transport network development, however, has received limited attention in transport literature. The scientific assessment of operational upgrades for Windhoek's transport network, as proposed by the City of Windhoek (City of Windhoek, 2006c), forms the basis of this dissertation.

With a population of 332 300 people (NPC, 2012), Windhoek classifies as a small middleweight city (McKinsey Global Institute, 2011). The city's status as Namibia's major economic hub (Dierks, 2005), translates the need for its transport management and planning to form a critical support function in the country's economic development.

The city authorities, in partnership with Africon Consulting Engineers, introduced a Strategic Transport Master Plan (STMP) in 2006 with the aim of addressing access to developing land-use areas, the modal composition distortion and CBD traffic circulation improvement (City of Windhoek, 2006c).

1.2 Project Scope

The city's authorities developed a Strategic Transport Master Plan (STMP), reviewed every five years through Transportation Land-Use studies. The STMP addresses current and future transport needs, based on varying transport growth scenarios (City of Windhoek, 2006a).

The current transport infrastructure caters predominantly for private motor vehicle use, with peak traffic lasting 45 minutes during AM and PM peak periods.

University of Cape Town

The city's population growth percentage stands at 6.1% (City of Windhoek, 2004) and the Central Business District's (CBD) transport network is estimated to reach capacity by 2015 (City of Windhoek, 2006a). Consideration into a more optimised transport solution is steadily becoming a priority.

Funding for capital project implementation regarding the city's transport infrastructure is minimal with no infrastructure project being implemented in the past five years (Lisse, 2011).

The city's land-use priority has focused on residential development to accommodate a growing middle income population (FNB Namibia, 2010). An optimised and cost efficient solution to the potential transport problem will, therefore, become critical for future city development.

To accommodate future traffic movement, the proposed STMP measures aimed to implement operational upgrades to the existing network (City of Windhoek, 2006a). The one-way conversion of Werner List Street aimed to improve Windhoek's CBD traffic circulation. The scientific assessment of the effects that the conversion has on traffic circulation will provide a basis to promote future operational improvements.

1.3 Significance of Study

The research primarily aims to ascertain the influence that operational upgrades have on transport policy implementation in Windhoek. The focus is on analysing the transport movement in CBD; particularly the one-way conversion of Werner List Street using micro simulation modelling. The analysed data will be used to attain relevant output information and link its significance or potential significance to transport policy implementation.

Key areas of research to be studied:

- Windhoek as an economic hub of Namibia and SADC at large.
- The analysis of the traffic movement in Windhoek's CBD through the traffic modelling of the completed operational upgrades within the CBD.
- A study of the City of Windhoek's Strategic Transport Master Plan in relation to the results attained from the analysed traffic and the goals set out by the STMP (City of Windhoek, 2006a).

Based on the aims identified for the research, research questions were proposed regarding Windhoek's transport system:

- Does the City of Windhoek's Strategic Transport Master Plan (City of Windhoek, 2006a) incorporate operational upgrades in its improvement methodology?
- Do operational upgrades, alone, improve traffic circulation within the Windhoek's CBD?
- Can assessment outputs, obtained from traffic modelling, provide a basis to direct and update the implementation of the STMP's (2006) methodology?

University of Cape Town

The development of the research questions is detailed in Chapter three and its analysis discussed in Chapter six.

The modelling of the upgraded network will form a basis for the assessment of the improved network with updated network projections providing scientific support to policy formulation and implementation.

It is aimed that the assessed upgrades will, additionally, provide supportive information to future transport development literature for small middleweight cities.

1.4 Limitations

Windhoek is considered a small-middleweight city (McKinsey Global Institute, 2011). The current transport network has yet to experience a breach in capacity, hence a limited prioritisation in terms of funding for the networks development. With that, a key limitation identified is the lack of proposed project implementation to ensure the transport network maintains the capacity to accommodate future transport demand.

The operational upgrades proposed in the STMP are based on data extracted from the VISUM meso simulation of Windhoek's regional network (City of Windhoek, 2006c). The data was then converted to the VISSIM format for micro simulation. Post operational upgrade scenarios have been assessed through a visual assessment process (Lisse, 2011); the use of visual assessment as an assessment tool limits the accuracy of the findings.

The difficulty in defining "operational upgrades" as a transport network improvement method is apparent when searching for the required literature. The various improvement measures that detail the upgrades have been researched on an individual basis, rarely grouped to assess the combined effect on transport networks. Accessing the relevant literature proved to be a challenging task, specifically for small middleweight cities in the Southern African Development Community (SADC).

To allow for the comparison of transport systems present in small middleweight cities representing the SADC region, operationally improved network measures required desktop assessment. The lack of implemented projects in Windhoek, as proposed in the STMP (2006), limited the network improvement possibilities that could be assessed. Studies have, however, been conducted on the potential economic gain that SADC cities could attain through the development of current transport networks in light of the increasing urbanisation of African cities.

1.5 Study Approach

An analysis of the city's Strategic Transport Master Plan (STMP) and its subsequent Land Use study, Public Transport provisions and Central Business District network setup will provide an understanding of Windhoek's planned urban change process (City of Windhoek, 2006a).

University of Cape Town

Windhoek's STMP (2006), through the one-way conversion of Werner List Street, proposed the implementation of an operational upgrade to sustain the functioning of the CBD transport system (City of Windhoek, 2006c). The absence of a scientific analysis for assessing the upgraded system limits the understanding of the effects that the improvement has on traffic circulation within the CBD.

A micro simulation model (Paramics) will analyse the efficiency of the network sections proposed in the CBD base study with the obtained output results used to assess the relation between the modelling outputs and the objectives set out in the city's STMP (City of Windhoek, 2006c).

Interviews with the City of Windhoek's Chief Engineer; Planning, Design and Traffic Flow will provide a background understanding of the strategy the city has taken to ensure an efficient and sustainable transport system.

Policy implementation shortfalls will be assessed through the analysis of the STMP (City of Windhoek, 2006c) and its accompanying studies. An analysis of Windhoek's industrial and population growth scenario will provide a comparative look at the city's development trends. Further, the modelling of an integral traffic section within the CBD will be conducted to formulate conclusions. The aim being to compare the output results with objectives of the CBD's base study (City of Windhoek, 2006c).

A review of literature relating to history of operational upgrades is conducted in Chapter two. The effects of operational upgrades on small middleweight cities from an international and a SADC perspective are further discussed highlighting key issues present during policy formulation and project implantation.

Chapter three: *One-way Upgrade of Werner List Street* chronicles the methodology used to assess the concept behind the need to improve Windhoek's transport network as envisioned by the city authorities as well as the assessment of the implemented one-way conversion of Werner List Street in Windhoek's CBD. The development of the proposed research questions is discussed in this chapter with conclusions summarised in Chapter six. The calibration of the model parameters, aimed at meeting the on-site driver characteristics and physical constraints, is detailed in the chapter.

The analysis of Werner List Street's improvements in Chapter four depicts the household activity statistics gathered from the City of Windhoek as well as the output data obtained from the micro simulation model of Werner List Street. Of particular interest was the assessment of:

- Traffic capacity,
- Queue lengths, and
- Average speed.

University of Cape Town

The discussion (Chapter five) of the analysed upgrades provides an understanding of the potential transport network improvements that the implementation of operational upgrades can offer.

Based on the discussed analysis of Chapter five and the shortcomings experienced during the assessment of Werner List Street, Chapter six provides conclusions and recommends ideas that will assist future research on operational upgrades, particularly for small middleweight cities that have limited development budget. The assessment of the proposed research questions, in relation to Chapter four's analysis, is discussed in detail.

University of Cape Town

Chapter 2. Transport Systems for Small Middleweight Cities

2.1 Introduction

The mobility of the world's urban population, within respective urban spaces, is highly dependent on transport infrastructure accessibility. Saxena (2001) defines the infrastructure in both its physical and social form; "the physical framework of facilities, utilities and support systems through which goods and services are provided to the public". Guckenheimer (1999) further suggests that urban transport infrastructure effectiveness, measured through travel time, is characterised by its ability to meet what Goldman and Gorham (2006) define as "escalated motorisation and mobility demands". Past urban transport trends depict increased travel times for cities experiencing high urban growth. With small middleweight cities poised to, significantly, contribute to the global economic growth within the next 15 years (McKinsey Global Institute, 2011); the transport dynamic of such cities will play a critical role in accommodating this growth.

In light of the mentioned trends, the prevention of traffic congestion forms a critical part of the planning required to implement sustainable transport development. Developing cities are thus shifting from a focus on physical infrastructure development to that of an increased utilisation of public transport (WHO, 2004), a shift aimed to implement sustainable transport development.

Sustainable transport development initiatives are best implemented through the cooperation of technical organisations and the implementing authorities (Wuppertal Institute, 2005). A sustained funding program adds the necessary support that allows for a committed development initiative from both parties.

The will to support sustainable transport development, from an institutional and financial perspective, is lacking for small middleweight cities that have yet to experience major transport system setbacks. Currently, the planning and implementation of operational upgrades for small middleweight cities have received limited attention as compared to development support assigned to infrastructure expansion.

Operational upgrading of transport networks entails the reorganising of network circulation systems (Calthorpe, 2002). The upgrading aims to prioritise transport mode movement within a study area, such that the land density usage is efficiently proportioned to allow for free flow transit. This new paradigm limits the need for physical infrastructure expansion as urban infill and revitalisation development are seen as priorities. Further, signal sequence optimisation plays a significant role in controlling competing traffic movement specifically in urban areas that are characterised by a grid setup (Koukoumidis et al., 2011). Such measures should form part of an inclusive operational upgrade framework.

Windhoek has a population of 332 300 people (NPC, 2012) and can, therefore, be classified as a small middleweight city (McKinsey Global Institute, 2011). Windhoek's municipality is yet to fully implement its proposed Strategic Master Plan, due to the lack of institutional and financial

University of Cape Town

support. With the city's population growth currently at 6.1%, the transport network is estimated to reach full capacity by 2015 (City of Windhoek, 2006b). To prevent future congestion within Windhoek's Central Business District (CBD), the City Council embarked on implementing operational upgrades to areas experiencing traffic stress. Werner List Street was converted into a one-way street to streamline the northbound traffic commuting from Tal Street to Banhoff Street (City of Windhoek, 2006c).

This chapter aims to provide an understanding of the research that has availed the evolution of small middleweight cities whilst identifying the transport development aspects needed to accommodate the estimated urban future demand. A review of Windhoek's urban transport setup will assist in providing an understanding of small middleweight city transport provisions from a Southern African perspective. The chapter will further study operational improvements as a solution to transport supply problems, present in most small middleweight cities, before discussing the effects that institutional influences have on urban transport development.

2.2 Small Middleweight Cities

Urbanisation is an essential part of a nation's development towards an economically stable state (UNCHS, 1996). The scale at which a nation's cities avail provisions for growing population demand significantly influences this development and the sustainability thereof. Wegner (2005) categorises a city's growth status by defining the level of urban change experienced within that city over a ten year period; eight levels of urban change are introduced with a medium level of urban change experienced for the studied small middleweight cities.

McKinsey Global Institute (2011) further defines a small middleweight city as one with a population size of between 150 000 and two million people, compared to the below one million population assessment of Brockerhoff and Brennan (1998).

The contribution that small middleweight cities provide to the world's economic growth potential is staged to take a significant role. McKinsey Global Institute (2011) placed the economic growth influence between 2007 and 2025 for small middleweight cities at 19% (see Figure 1).

University of Cape Town

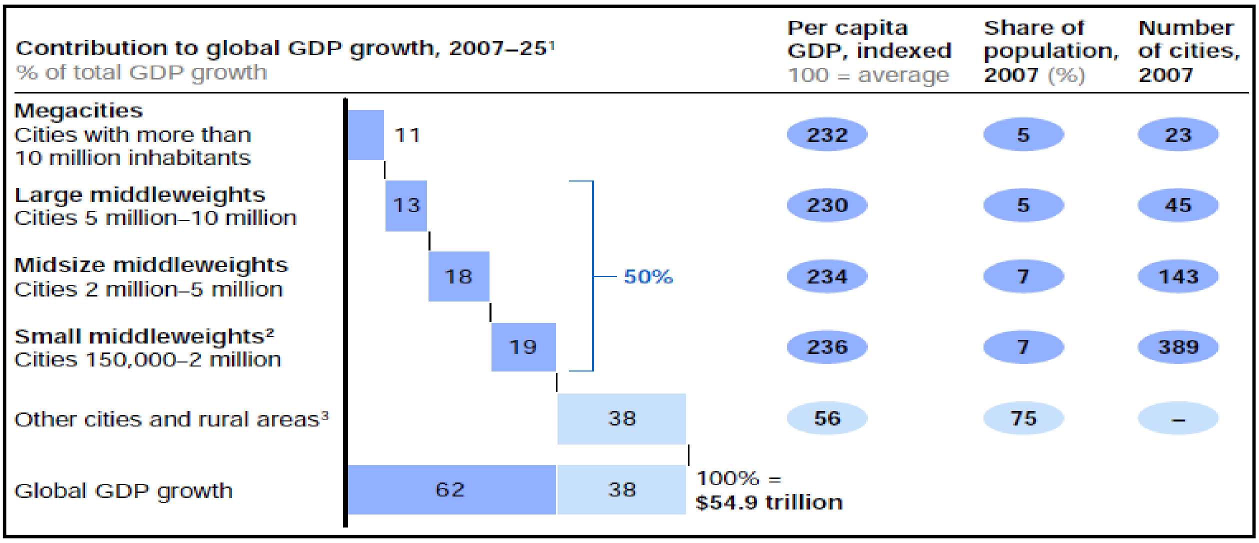


Figure 1: City contribution to GDP growth, *Source: McKinsey Global Institute, 2011*

Megacities, with population estimates of 10 million people or more (McKinsey Global Institute, 2011), are formed through the agglomeration of smaller surrounding cities (UN DESA, 2010). Figure 2 depicts statistics compiled between 1993 and 2010 that point to a slower economic growth for megacities as compared to their host countries (McKinsey Global Institute, 2011). Montgomery (2002) argues that modern literature has focused on megacity and rural health care provisions, in turn side-lining that of small middleweight cities.

Cape Town

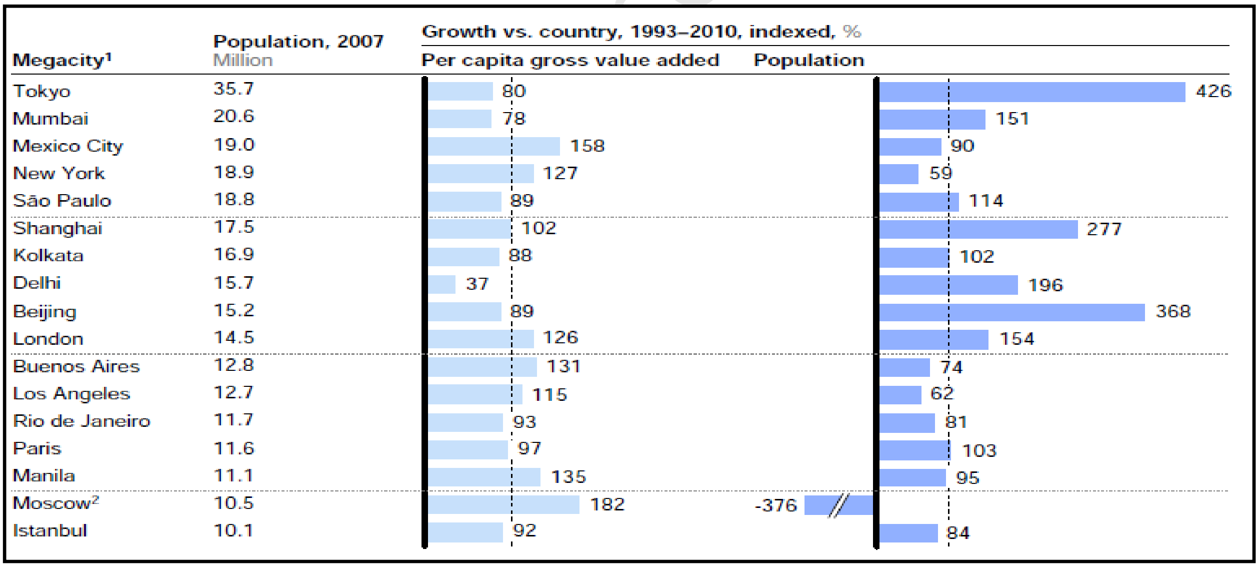


Figure 2: Country influence of megacities, *Source: McKinsey Global Institute, 2011*

The growth potential of small middleweight cities combined with the significant shortfalls experienced for megacities and rural areas provides a basis to place a greater focus than current on small middleweight city urban development.

From a Southern African perspective, the majority of cities outside of South Africa (see Figure 3) are classified as small middleweight cities (SACN, 2011). The economic importance of these cities, relative to the respective countries' economic status, is underpinned by the cities' housing of the countries' governmental, financial and legal headquarters (SACN, 2011). As recognised by the Southern African Development Community (SADC) member states in the SADC Protocol Agreement (2001), regional integration through the improvement of transport and communication networks promotes economic development.

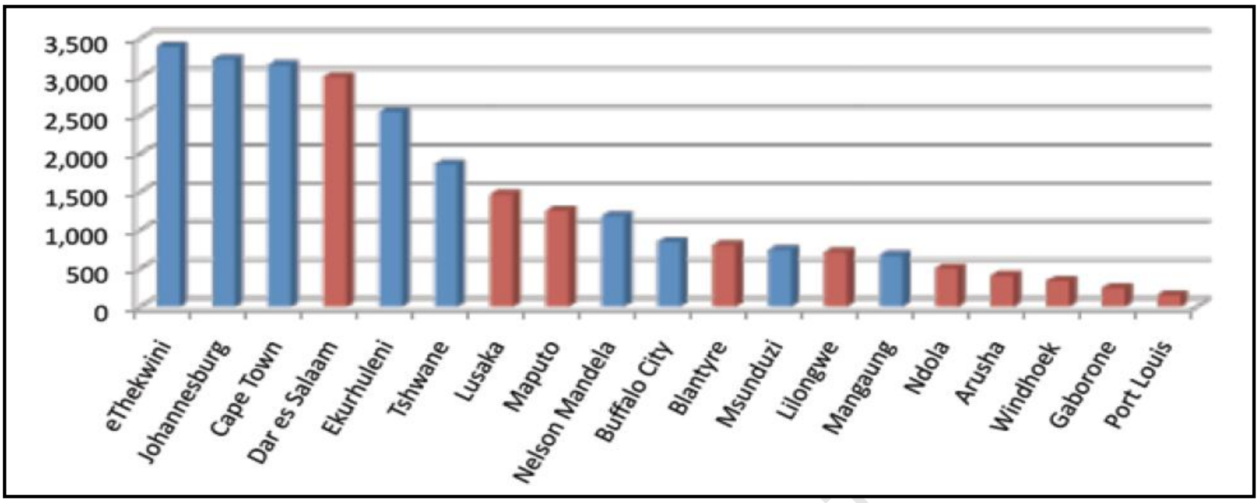


Figure 3: Southern African city population, *Source: SACN, 2011*

The spatial composition of SADC countries is such that cities or towns are geographically separated by considerable distances (SACN, 2011). This spatial composition added to the relatively small population size of the SADC countries, limits the possibility of megacity formation. Studies, however, show that small middleweight city population growth is estimated to double over the next 20 years (UN DESA, 2010), a clear development policy framework based on the local parameters is necessary to provide sustained urban development planning.

The underlying belief, among transport analysts, is that efficient and affordable transport provisions form a critical basis for urban development strategies. Banaster and Berechman (2000) favour the view that transport development provides a supportive role to urban growth and not the generating factor as perceived. For small middleweight cities, and compared to the factors influencing large city urban development, transport provisions form part of a limited support base for urban development (SACN, 2011). The limiting variance of small middleweight city development support, therefore, places considerable importance on transport development.

Transport network improvements are affected by institutional factors, discussed later in the chapter, both at a policy and organisational level (Mulley et al, 2005). The majority of small middleweight cities in Southern Africa have the advantage of being governed by a single authority or council (SACN, 2011); city development decisions are, therefore, handled under one governing policy directive. With future world population growth centred on urban growth (UN DESA, 2010), transport policy directives need to represent the aims of sustainable development in order to maintain an efficient commuting service to the growing population.

University of Cape Town

2.3 Sustainable Transport Development

Brundtland's (1987) view of meeting current human needs whilst preserving those of the future, when defining sustainable development, is commonly used in modern literature. Zegra (2006) relates Brundtland's view to the transport system dynamic by identifying measures that critique the effects of current transport development on future generations. The measured outputs provide an examination of the capability that current urban transport systems (transport supply efficiency) have in meeting the growing urban population travel demands.

Using a city's population and density increase as a measured urban characteristic, Litman (2012) examined the "discretionary rider" (people who have the option of driving) increase in public transit usage. Figure 4 depicts the observed commuter shift to public transport use for a growing city population. It was further observed that the quality of transit service played a critical role in the mode use change, a transport supply-demand relationship that Zuidgeest (2000) relates to Manheim's (1979) theory of transportation equilibrium.

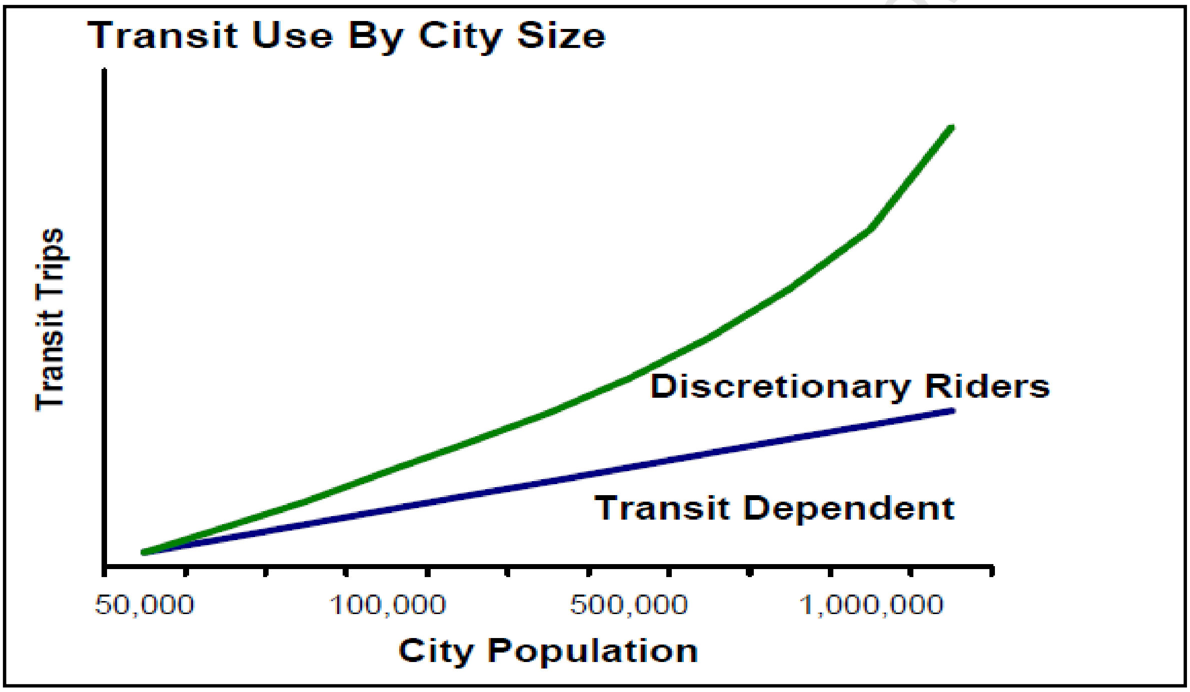


Figure 4: Transit use with increase in city size. *Source: Litman, 2012*

Constant in the sustainable transport development literature is its association with time. Litman (2006) quotes the United Kingdom Centre for Sustainability's definition, "the capacity for continuance into the long term future", as precedent for underpinning development along future demand considerations.

The practicality of relating present development with that of future needs is difficult to argue for developing nations combating poverty (Zegra, 2006). The United Nations Food and Agriculture Organisation (2010) estimated that 925 million people were living in undernourished conditions, the majority of which live in the developing rural world. With urban migration for the developing world estimated at 2% per annum (WHO, 2010) and annual urban expansion of 6% (World Bank, 2002), the sustenance of the future urban population heavily depends on the efficient planning of urban systems.

In light of the need to accommodate growing urban mobility demand, the Wuppertal Institute for Climate, Environment and Energy (2005) has partnered with various city authorities in formulating "social, financial and environmentally sound solutions" to urban mobility problems. Some of the solution proposed:

- Energy efficiency for mass transit vehicles; best engine/fuel combination for high capacity vehicles,
- Developing a methodology to monitor and measure urban transport emission status,
- Sustained financial support for the planning and implementation of Integrated Rapid Transit (IRT) systems, and
- Rezoning urban spaces to promote pedestrian circulation.

The solutions combine the idea of efficiently utilising urban space for a sustained period, while reducing the effects that energy usage has on the environmental. The concept of efficiently "using more with less" is the basis that dictates the idea of Operational Urban Transport Upgrades.

2.4 Operational Urban Transport Upgrade

The World Bank (2002) reported that the decentralisation of urban transport responsibilities from national to city governments has significantly contributed to the deterioration of urban transport networks. Giannopoulos (2005) further supports this view by assessing the lack of financial support and limited institutional capability required for urban development planning in South Eastern Europe. The financial and institutional constraints have provided an impetus to promote innovative urban development planning. Transport development is thus undergoing a shift, at planning level, from infrastructure expansion to that of utilising existing infrastructure in a more efficient manner (OECD, 2002). This view is particularly relevant to small middleweight city transport development where funding for current development proposals is limited.

Small middleweight city transport is signified by an averaged low traffic demand (SACN, 2011). With high traffic flow impediment visible for short (30 minutes) periods of the day, attention to the sustainable development of transit networks within these cities has received limited support. The implementation of operational upgrades has assisted various cities achieve significant mobility improvements (NICHES, 2012).

The city of Barcelona has introduced the concept of "space management for urban delivery" (Barcelona Municipality, 2011) whereby the use of computerised information availability assists in improving freight accessibility to highly trafficked areas. The use of multiuse lanes and demarcated delivery areas allows for improved circulation, fairer sharing of valuable transport space and an average reduction in operator travel time. Additionally, inner city (CBD) night time freight delivery was introduced to further improve freight transport mobility and transport safety

University of Cape Town

(NICHES, 2012). The freight delivery was consigned to night-time (22:00 – 06:00) activity considerably reducing day-time traffic congestion.

An important consideration when aiming to improve urban traffic circulation is signal timing. Traffic signalising aims to minimise average traffic and pedestrian delays at points of possible conflict (Federal Highway Administration, 2008). Jinyuan (2007) refers to research conducted by Webster (1958) and later Akcelik (1980) on the optimisation of signal controls as significant contributors to the development of Intelligent Transportation Systems (ITS). The research evaluated the effects that over-saturation had on signal sequencing to replicate real-time variations. Further, improved demand detection methods such as the Split Cycle Offset Optimisation Technique (SCOOT) have been developed to provide an accurate replication of real-time traffic variation (Robertson and Bretherton, 1991).

One-way coupling presents a move to improve traffic circulation within areas of relative confinement such as CBD's. A parallel grid-structure forms the basis for the one-way coupling system providing traffic circulation (City of Windhoek, 2006c). Calthorpe (2002) suggests that circulation patterns should complement adjacent land use. The conversion of a two-way street to that of a one-way presents the possibility of demarcating the converted lane to accommodate an alternate means of commuting; pedestrian passage, public transport prioritisation and multi-lane use.

The combination of these relatively inexpensive interventions, amongst others, to urban transport development creates a manageable network; a scenario that greatly appeals to the transport development needs of small middleweight cities.

2.5 Institutional Will

2.5.1 Definition of an Institution

Literature defining an institution provides varying views of responsibilities assigned to the governance of societal interaction. The relationship between human constraints and interaction structures, resulting from institutional regulations, is a constant theme.

Hodgson (2006) defines institutions as promoters of "ordered social interactions" through the creation of platforms that impose sustained "form and consistency" in human activity. Such platforms, from a transport point of view, connect spatially separated activities in a regulative manner. Morgan (1997) views this order-constraint relationship as a result of the institutional approach to governance. If a systematic approach is used then social interactions govern regulatory decisions, whereas, a political approach is aligned to a more controlling authority.

Either way, institutional regulations influence the link between urban transport availability and land-use patterns, which in turn significantly influences the cost of city mobility for commuters (Zegra, 2003). Well governed institutions, therefore, provide the necessary support required to develop integrated urban transport networks.

University of Cape Town

2.5.2 Institutional Challenges

Cohesive regulatory policies promote the coordination of governing agencies, in turn reducing the possibility of operational stagnation (Farah, 2010). Achieving institution coordination requires an understanding of effects that regulatory decisions have on the affected parties (European Transport Safety Council, 1999). Varying challenges are, consequentially, presented when enacting policy regulations.

Concerns raised in literature imply, for the majority, that policy coordination between interlinking institutions is lacking. In preparation for a post-apartheid South Africa, the World Bank assessed the country's transport regulatory authorities, an assessment that revealed a fragmented governing framework (Kane, 2001). Schalekamp (Schalekamp et al., 2010) further argues that the conflicting regulations are caused by a lack of communication between relevant stakeholders during the initial policy formulation stage.

Part of the communication process for policy formulation requires user participation. The World Bank's third transport assessment mission to South Africa in 1995 highlighted the lack of efficient response to user demands (Kane, 2001). Additionally, capacity shortage within institutions limited the institution's ability to fully implement and regulate enacted policies. Kane (2000) emphasises the need for institutes to implement what Bultynck (1998) refers to as staff "continual and systematic" training in order to meet the growing user demands.

With an ever changing urban society, Giannopoulos (2005) argues that future transport planning will require a greater spatial integration, a situation that emphasizes the need for regional coordination. Speaking on Namibia's road sector reform, Runji (2003) highlights the agreement signed by the Southern African Development Community (SADC) to enact the protocol for Transportation, Communication and Meteorology, which aimed at ensuring "an adequate transport network in support of socio-economic growth" within the region.

Litman (2012) argues that the combined effect of transport network upgrade and land use development has been undermined at policy level, especially for growing cities. The trends observed have pointed towards what is described as an encouragement of either "urban sprawl" or "smart growth" as depicted in Table 1.

A major theme is that of the significant cost consideration during policy formulation. The policies linked with urban sprawl encourage the expansion of infrastructure to accommodate the growing population; this in turn requires initial capital expenditure. The Smart growth proposition attends to matters relating to the operational functioning of transport facilities, hence reducing the need to adjust the transport infrastructure.

University of Cape Town

Table 1: Policies that encourage sprawl vs. smart growth

Policies that encourages Sprawl	Policies that encourages Smart growth
Maximum roadway capacity and speed.	Traffic calming and traffic speed reductions.
High public transit fares.	More affordable public transit fares.
Inferior public transit service.	Transit service improvements.
Poor walking and cycling conditions.	Pedestrian and cycling improvements
Low road user charges and fuel taxes.	Road and parking pricing.
Generous parking supply.	Reduced parking supply with parking management

Source: Litman, 2012

Lisse (2011) argues that budgetary constraints have limited the implementation of Windhoek's Strategic Master Plan for the past five years. Funding limitations, for the majority of SADC cities, have hampered project implementation and the required foresight to plan and develop the region's urban transport systems is lacking at institutional level (SACN, 2011).

2.5.3 Funding

In tandem with sound governance, a city's long-term development requires sustained funding (SACN, 2011). A constant theme for developing cities is the requirement to produce innovative projects at a minimal cost. This view, along with a paradigm shift from new construction to a maintenance-orientated upgrade of transport networks (Runji, 2003), depicts a notion that funding for transport improvement is limited. Revenue generating developments are, therefore, essential to urban setups. Purandare and Pandurangi (2008) table various conventional instruments for financing urban transportation (see Table 2).

Table 2: Conventional methods of financing urban transportation

Revenue Type	Target Customer	Funding Allocation
Fare-Box: Collection of fares for transport service	Commuters	Operational Costs
Advertisements: Fee for the right to advertise on transport furniture	Advertisement companies	Operational Cost
License Fee: Business activities rentals	Food stores, Book-stores, ATM services, etc	Operational Cost
Real Estate Development: Develop property at various points along transport corridor	Urban developers, Property Developers	Capital Expenditure

Source: Purandare, 2008.

University of Cape Town

The first three instruments proposed (Purandare, 2008) target the need to meet operational costs while the return on real estate development is aimed at funding capital expenditure. Sourcing private funding for urban transport development projects requires incentive driven proposals (Purandare and Pandurangi, 2008). The commercial opportunity prevalent with owning real estate rights along transport corridors creates the required incentive to attract private funding. Examples such as Northway Highway Project in New York where the added increment of land value was eleven times higher than the cost of constructing the section highway (Phu, 2003) demonstrates the type of return on investment that “land value” infrastructure development can generate.

Real estate development value, however, depends on rental demand, a characteristic not common in small middleweight cities. A sustained urban development strategy will, therefore, heavily rely on the support of availed project funding and support from governing institutions.

The City of Windhoek has identified a methodology that aims to promote the sustainable development of Windhoek’s transport network with a key focus on an efficient public transport utilisation (City of Windhoek, 2006b), as well as an improved CBD traffic circulation (City of Windhoek, 2006c) using the limited financial backing available (Lisse, 2011).

2.6 Windhoek

Windhoek is the capital city of the Republic of Namibia and has a population size of 332 300 (City of Windhoek, 2010). The United Nations’ Department of Economic and Social Affairs (2009) estimates a 30% increase in urban population for Namibia over the next 30 years, most of which is assigned to Windhoek’s population increase. The population size and growth estimates classify Windhoek as a small middleweight city. It’s status as the major economic hub of Namibia (Dierks, 2001), translates the need to plan and manage its urban development in a sustainable manner.

Surrounded by a rocky and mountainous topography, land development is costly leading to the city’s decision to conduct a combined radial and linear development model (City of Windhoek, 1996). The radial development is aimed at increasing the City Centre’s bulk zone area, thereby unlocking the large commercial potential of Windhoek. With an increase in commercial prioritising, it is aimed that smaller commercial sources would form part of the city’s decentralisation logic. Due to Windhoek’s topographic confinement, the city’s commercial decentralisation and further expansion would have to occur in a linear formation along the B1 route to Okahandja (see Figure 5).

University of Cape Town

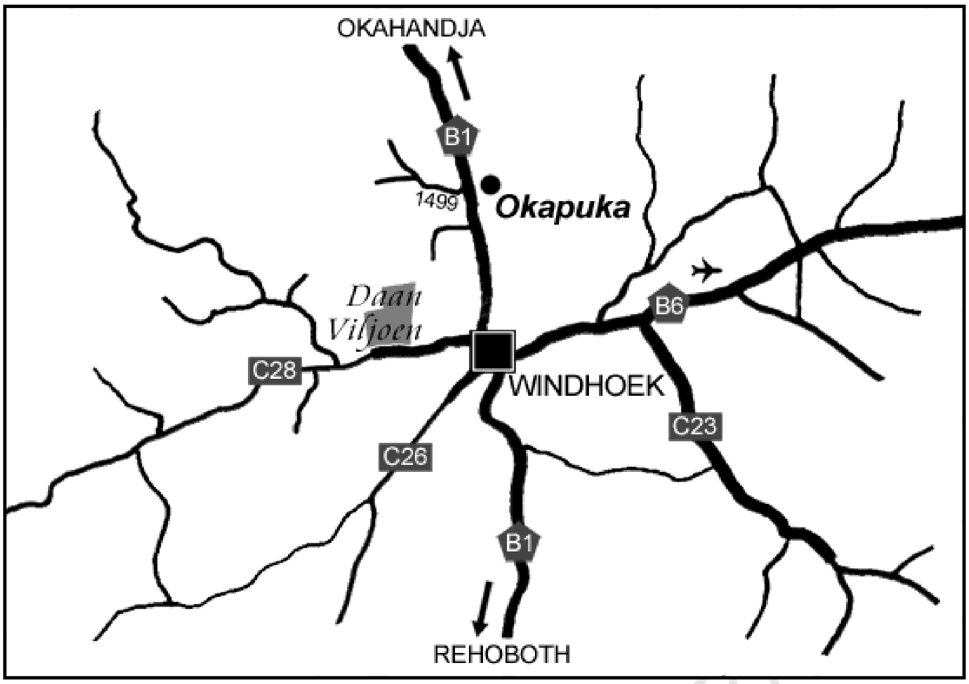


Figure 5: Windhoek surroundings. *Source: www.namibian.org*

2.6.1 Windhoek Travel Patterns

Based on data analysed from Windhoek's Household Survey of 2004, 20% of the population utilise public transport in the form of sedan taxis (City of Windhoek, 2006b). Peak traffic movement in the Central Business District (CBD) occurs during the morning and evening periods of the day. An aggregate inflow and outflow for the respective periods defines the CBD travel behaviour (Lisse, 2011), with traffic almost non-existent after 19:00.

Following Namibia's independence from South Africa in 1990, and the consequential removal of the restrictive urban settlement laws, Windhoek experienced a high level of urban migration (World Bank, 2002). For the majority, settlement occurred on the outer boundaries of the city creating a need for transport access to areas of employment. The City of Windhoek's (2006b) mode choice study revealed that 24.6% of commuters, mainly from the outer-city settlements, used public transport (see Table 3) to access areas of employment.

Table 3 depicts a majority private vehicle use; a scenario that Watson (1977) ascribes to the appealing nature of comfort that private vehicles provide as compared to the available public transport service. It is worth noting that private vehicle usage, in proportion to the area population, is considerably higher in the more affluent suburbs of Windhoek where households own on average between two and three vehicles (City of Windhoek, 2004).

University of Cape Town

Table 3: Mode of travel for morning peak travel

Transport Mode	Number of Trips	% of Trips	Sector
On foot	1053	26.6	
Bicycle	16	0.4	
Taxi	820	20.7	24.6% Public
Public bus	153	3.9	
Motorcycle	2	0.1	65.6% Private
Private car (driver)	953	30	
Private car (passenger)	659	16.6	
Employer's transport	223	5.6	
Rented/hired car	17	0.4	
Others	14	0.4	
Unknown	52	1.3	

Adapted from: City of Windhoek, 2006b

University of Cape Town

The public bus service failed to cater to the affluent areas due to the difficulties experienced in competing with the comfort and convenience of private vehicles (Namwandi, 2011). The feasibility of a bus service operation from a cost point of view and combined with the low target population density, relevant in most small middleweight cities, produced a lower return as compared to private vehicle use. The public bus service, therefore, focused on connecting commuters from low-income areas to areas of employment, such as the CBD.

The City of Windhoek sought to increase the 34.4% representing public transport trips by increasing the bus service's route allocation to commute in the more affluent areas and by increasing the vehicle occupancy levels of taxis (City of Windhoek, 2006b). The increased contribution of public transport aimed at transporting a larger volume of commuters, thereby reducing total vehicle trips (City of Windhoek, 2006b).

2.6.2 Windhoek Central Business District

The transport studies that have been conducted for the City of Windhoek refer to Enumeration Areas (EA's) that define population activity within various regions in Windhoek, one of which is the CBD. Located in the centre of the city (see Figure 6), the CBD houses the country's major financial institutions, government buildings, judicial house and diplomatic headquarters (City of Windhoek, 1996); the elements that determine a country's stability.

With the CBD being the economic centre of the city, development has radially expanded to cater for the population's residential and social needs (City of Windhoek, 1996). More recently, Windhoek has been characterised by a combination of what Vanderschuren (2006) defines as compact and fringe city development. The development of informal settlements has expanded the city's boundaries while the redevelopment of residential suburbs, to meet commercial demand, has decentralised the city's economic activity (City of Windhoek, 2004).

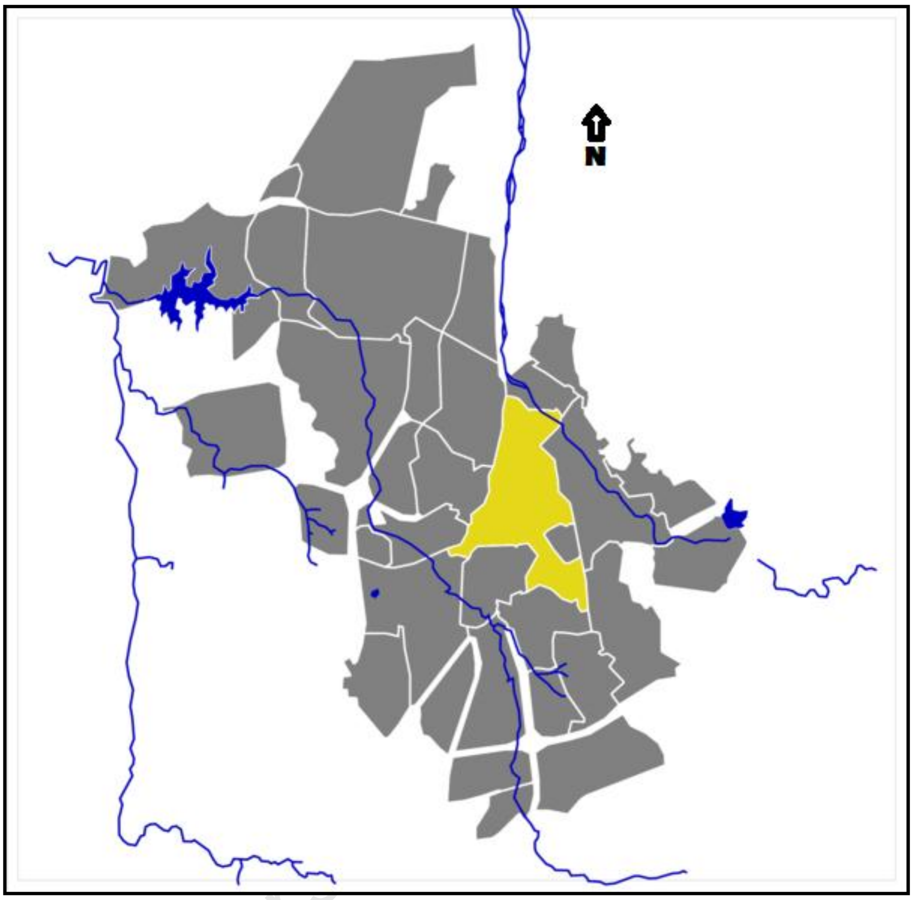


Figure 6: Windhoek Central District. *Source: Wikipedia, 2008*

Werner List Street traverses the heart of Windhoek's CBD, providing access to institutions that represent the mentioned elements of the city. The study of the street's traffic flow efficiency, therefore, forms a critical part in the overall assessment of the CBD's traffic network.

2.6.3 Werner List Street

Werner List Street traverses for 1100 meters in a northbound direction connecting Tal Street with Banhoff Street while crossing Fidel Castro Street, Dr Frans Indongo Street and John Meinert Street as depicted in Figure 7. Institutes that contribute, significantly, to the city's social and economic development namely; Namibian Defence Force Headquarters, First National Bank, Wernhill Shopping Mall, Namdeb Diamond Corporation Head Office, Roman Catholic Hospital, Embassy of the Federal Republic of Germany amongst others, are accessed using Werner List Street.

Formerly a set of connecting two-way streets, the City of Windhoek decided to convert the stretch between Fidel Castro and Banhoff Street to a one-way system with the aim of reorganising the street's traffic through flow such that future CBD traffic congestion would be prevented (City of Windhoek, 2006c).

The majority (60%) of vehicles traversing the one-way stretch are sedan taxis (City of Windhoek, 2006c). Peak traffic flow is experienced during morning (07:00 – 08:00) and evening (16:45 – 17:30) periods of the week day.

Figure 7: Werner List Street. *Source: www.map-of-namibia.com*

Chapter four: Traffic Data Assessment of Werner List Street, will provide a detailed assessment of the implemented one-way intervention along Werner List Street.

2.7 Résumé

Urban mobility is dependent on the efficiency of transport infrastructure provisions. The world's growing urban population has negatively impacted urban mobility characterised by the increase in urban congestion levels. The availing of transport provisions to accommodate the current and future increased demand formed the focus of small middleweight city transport system development.

Small middleweight cities, population range of between 150 000 and 2 million people, are estimated to contribute 19% of the world's economic growth by 2025. The implementation of strategies that promote efficient use of transport facilities will require greater attention.

Examples of the high returns that land value investments yield, proves that innovative and proactive governance can promote sustainable development.

Sustainable development accommodates current needs whilst preserving future needs. The process whereby private vehicle users convert to public transport usage, for a growing urban population, validates the theory of transportation equilibrium. The constraints posed by a particular mode encourage the promotion of an alternate mode to meet the aggregate supply. Transport planners are obliged to create platforms and systems that balance this aggregate supply such that future demand is not compromised, “the capacity for continuance”.

For small middleweight cities sustainable transport development initiatives have received limited support, due to the non-perceived impacts current traffic scenarios will cause in the future. Innovative and cost effective developments have been proposed with the aim of improving traffic circulation in densely trafficked city areas, as well as reducing operational delays amongst others. The developments focus on improving the operational functionality of transport infrastructure, minimising the need for infrastructure expansion. Operational upgrades require support at an institutional and regulatory level as these initiatives provide greater effect through combined implementation phases.

Operational upgrades further promote social interaction through interactive methods proposed as a means to inform commuters of the development; a “doing more with less” philosophy. The governing of social interactions, through policy development and implementation, should sort to maximise the benefits of current transport infrastructure. The notion of innovative and proactive governance appeals greatly to small middleweight cities.

Institutions, specifically those governing small middleweight cities, face concerning challenges that undermine policy implementation. The lack of cohesive planning between partner institutions during the policy formulation stage, added to the lack of relevant capacity, has placed many cities in the developing world at a disadvantage during implementation stage. Further, the lack of sustained funding for long term transport development initiatives reduces the impact that approved measures will have on the transport systems.

Windhoek is a small middleweight city by definition, and as the economic hub of Namibia it plays a critical role in national and regional (SADC) integration. The provision of efficient urban mobility within the city is of paramount importance to the country’s economic growth consideration. The current Central Business District transport network is estimated to reach full capacity by 2015; measures to preserve the current efficiency require the implementation of the proposed Strategic Transport Master Plan. Windhoek’s current transport scenario is common to many small middleweight cities; innovative development measures will, therefore, need to include future demand consideration.

University of Cape Town

Chapter 3. One-way Upgrade of Werner List Street

3.1 Conceptualisation

The conversion of Werner List Street into a one way street, from the Fidel Castro Street intersection to that of Banhoff Street, formed part of Windhoek's proposed Central Business District (CBD) traffic improvements. Assessing the impact of the conversion required an understanding of the city's proposed goals for the study area.

The one way operational upgrade aimed at improving traffic flow within the CBD. Inbound (morning) and outbound (evening) traffic circulations characterise Windhoek's CBD traffic movement; a result of the radial city development present in Windhoek. Traffic volume levels have yet to breach the city's transport infrastructure capacity (City of Windhoek, 2006b).

The City of Windhoek engineers conducted a visual assessment of Werner List Street (Lisse, 2011) after the implementation of the operational upgrade. The assessment entailed a study of various performance criteria:

- Queue lengths at intersections,
- Vehicle composition,
- Length of peak traffic period and
- General adherence to operational upgrades.

University of Cape Town

This study aims to assess the one-way upgrade of Werner List Street by utilising traffic modelling methodology. Aspects to be assessed entail the City of Windhoek's transport vision, the operational upgrade introduced to Werner List Street and the post-upgrade traffic assessment for Windhoek's CBD (see Figure 8).

To gain an understanding of the aims envisioned by the City of Windhoek, research on the Windhoek's Strategic Transport Master Plan (STMP, 2006a) was conducted. City development statistics such as economic and household growth indicators in relation to regional (SADC) benchmarks were studied additionally to assess the possible effects that these statistics would have on the traffic growth. Interviews held with the relevant city transport department were further aimed at understanding the detailed implementation of the STMP. The information gathered from the study formed part of the initial data collection process, used in the calibration of Werner List Street's traffic model.

Traffic counts were conducted over a five working day period to calibrate vehicle functionality and modelling parameters along Werner List Street. Turning movements at major intersections were assessed along with the modal split witnessed during the assessment period. Data received from the City of Windhoek, and further validated during the traffic count process, depicted the signal optimisation method used for the respective signalised intersection. CBD traffic circulation during the peak periods, as well as the adjusting of the signal timing was of particular interest.

The effects that the operational upgrade had on Werner List Street traffic movement were analysed using Quadstone Paramics traffic micro simulation software. The calibration of the modelling sourced the input variables from the manually collected data. The principles that govern the simulation of detailed traffic scenarios and the availability of the Paramics software, courtesy of the University of Cape Town's Centre for Transport Studies, influenced the choice to use the Paramics micro simulation module.

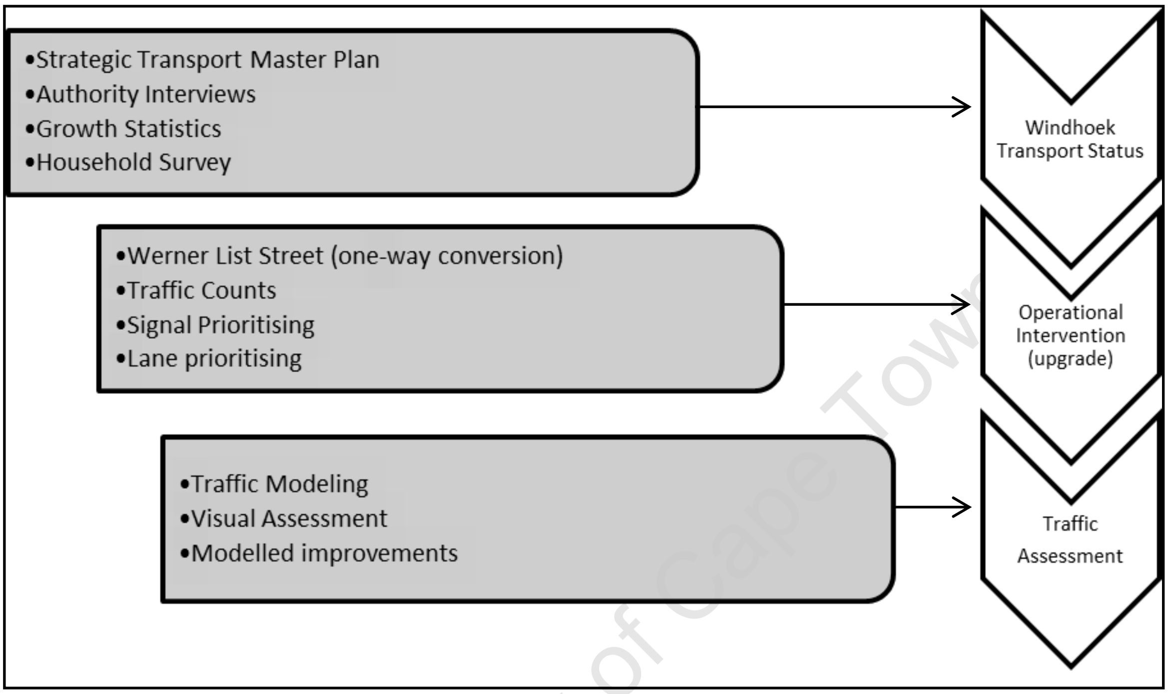


Figure 8: Conceptual method of assessing Windhoek's transport network

Chapter two reviewed the literature relating the use of operational upgrades as part of sustainable transport development. This chapter looks at the methodology used to assess the operational upgrades implemented in Windhoek, specifically the one-way conversion of Werner List Street.

3.2 Windhoek's Transport Vision

3.2.1 Strategic Master Plan

The Strategic Transport Master Plan (City of Windhoek, 2006a) comprises of three reports aimed at introducing measures that would promote efficient traffic circulation for Windhoek's transport network. The base year for the study is 2004 and the study scope caters for a traffic scenario beyond 2050. The reports are assigned to assess the following aspects of Windhoek's transport network:

- Phase 1: Transportation Land use study,
- Phase 2: Integrated Transport Master Plan, and
- Phase 3: Central Business District Transport Study.

University of Cape Town

3.2.1.1 The Transport Land-use Study

Phase 1 of the STMP aimed to develop a base year transportation model for Windhoek's city area (City of Windhoek, 2006a). The report detailed the use of household and workplace surveys to garner origin and destination data. The surveys detailed travel activity to and from the city's larger work areas; primarily the CBD.

Links contained within in the 225 designated zones (see Figure 9) defined road attributes such as number of lanes, speed and capacity. In line with the classification methods used in Southern Africa, Windhoek's road classification was defined using the following classes:

- Freeway,
- High order, Dual carriageway (Major Arterial),
- High order, Single carriageway (Minor Arterial),
- Medium order, Dual carriageway,
- Medium order, Single carriageway,
- CBD Roadway, and
- Local Street.

Town

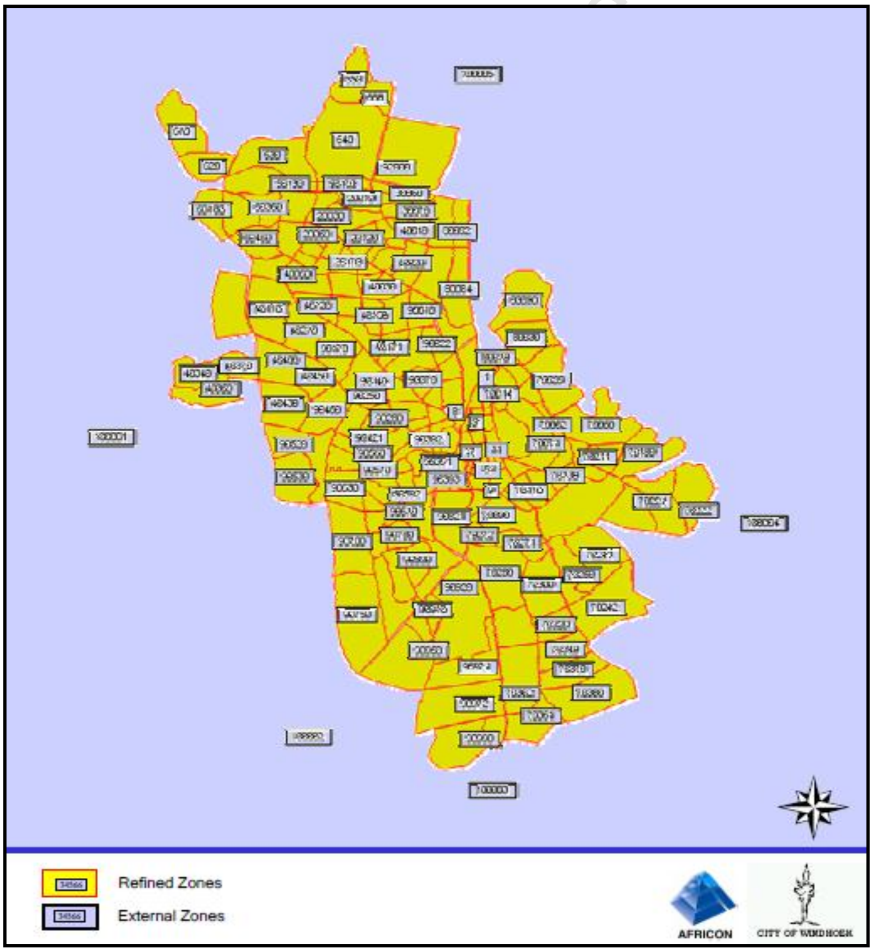


Figure 9: Windhoek Zoning. *Source: City of Windhoek, 2006a*

The network preparation incorporated the modelling of public transport facilities within the city is further discussed in Phase 2: Integrated Transport Master Plan (City of Windhoek, 2006a). The public transport consideration included the sedan taxi and municipal bus operations; with vehicle occupancy, route allocation and network penetration as the main focus.

The study made use of the Vision traffic modelling suite, to analyse the city's travel demand model, utilising visual inspection, traffic flow data and the mentioned surveys to calibrate the model parameters. The analysis, using the traditional four step model, incorporates the impact that transport policy has on the city's land-use development.

A key study focus was that of the influence that CBD activity had on city traffic movement. Aspects studied for this focus included:

- Traffic Assessment Zones (TAZ's) most affected by the CBD activity: population density and income levels,
- Time of day travel: AM-PM peak commuting,
- Highly trafficked routes linking the CBD with TAZ's: physical and operational characteristics,
- Modal split, and
- Public transport operating performance.

In the STMP (City of Windhoek, 2006a), future-year traffic scenario estimations were used to develop an implementation plan that would assist in formulating an integrated transport framework. The modelled traffic scenarios would ultimately determine the effects that proposed transport development would have on a saturated transport network at a time when land-use development was significantly slow.

The city's economic development, of which the CBD significantly influences, relies on the economic return of various land-use zones. The study, therefore, defined the value assigned to land-use development by providing market growth factors as input variables in calculating this return. The limited supply – growing demand relationship influenced the cost of land-use development; access to and within the land-use zones added to the total cost. The study, therefore, recommended a model that would:

- Allow for an update of the input characteristics (road hierarchy, population characteristics, etc),
- Redefine future traffic and land-use development scenarios as development policy directives changed, and
- Promote aspects defined in the City's Spatial Development Framework (integrated transport).

The results obtained from Phase 1 were aimed at providing input information for the future travel demand analysis assessed in Phase 2 and Phase 3.

University of Cape Town

3.2.1.2 Integrated Transport Master Plan

Phase 2 of the STMP aimed at developing a strategy that would incorporate Windhoek's various transport modes (City of Windhoek, 2006a). The analysis targeted the years 2010, 2015 and an ultimate year (2030 and beyond) as planning horizons. Various future transport scenarios were developed in conjunction with a future land-use development, proposed in Phase 1. The transport scenarios identified road network improvements that would alleviate future congestion levels while improving travel times. The improvements would assist the development of a detailed CBD traffic circulation model. The existing network was assessed using volume over capacity (v/c) ratios as indicators of saturation conditions (oversaturation: $0.75<v/c<1.0$).

Infrastructure network and public transport upgrade proposals formed the core development theme for three methods of implementation (City of Windhoek, 2006b):

- Ultimate Road Network Plan:
  - Physical infrastructure expansion, and
  - Consideration of modal shift towards public transport.
- Strategic Transport Plan:
  - Developing a road hierarchy, and
  - Reduced infrastructure upgrade requirement.
- Public Transport Plan:
  - Increased public transport operations; 5%, 10% and 20% modal shift towards Public Transport, and
  - Additional municipal bus route allocation and scheduling, 3% modal shift towards bus transport.

The Ultimate Road Network Plan (City of Windhoek, 2006b) aimed at improving transport provisions by expanding the physical infrastructure and improving transport aspects that created shortcomings in public transport operations. The assessment thereof was based on the effects that the expansion and improvements would have on the network's v/c levels. The proposed infrastructure expansions are depicted in Figure 10. The public transport improvements considered a 5% modal shift towards public transport from the previous split. The use of High Occupancy Vehicles (HOV) as opposed to sedan usage, for taxi services, was investigated.

The Strategic Transport Plan (City of Windhoek, 2006b) sought to define the functional role assigned to various routes within Windhoek's road network. The criteria used to distinguish the road hierarchy placed routes aimed to facilitate mobility as higher order roads (highway arterials) and those placed to facilitate access as lower order road (residential streets).

The Public Transport Plan (City of Windhoek, 2006b) proposed changes to Windhoek's transport policy such that commuters were encouraged to utilise public transport. The transporting of commuters using HOV's and an improved bus service formed the basis for redefining public transport within the city. Designated routes targeted movement to areas of high activity;

University of Cape Town

Industrial Zones (CBD included), Khomasdal (middle income residential) and Brackwater (Low income residential).

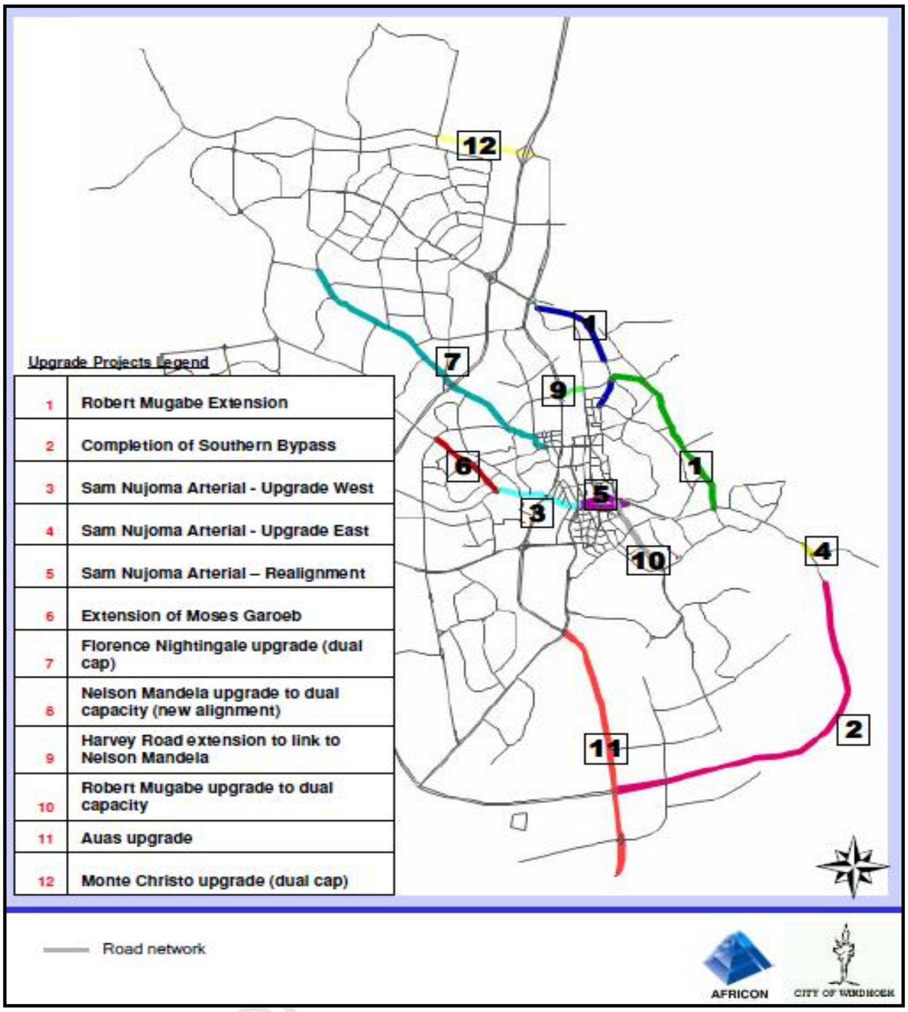


Figure 10: Proposed Infrastructure upgrade for Windhoek. *Source: City of Windhoek, 2006b*

3.2.1.3 Central Business District Transport Study

The CBD study aims to address existing network shortfalls whilst optimising future network capacity and circulation under forecasted traffic scenarios. The study focused on aspects related to traffic congestion, traffic flow, infrastructure capacity and parking; primarily within the CBD boundary. A regional traffic assessment, as developed in Phase 1 and 2, would form the basis for identifying the effect that Windhoek's traffic movement patterns had on the CBD network.

Traffic circulation principles governed the implementation strategy, the study proposed the following guiding principles (City of Windhoek, 2006c):
One-way pairs;

- The aim of pairing one-way routes within the CBD network aimed to create a grid structure. The grid structure would serve to minimise conflicting movement at intersections thereby allowing for the optimisation of traffic signal settings within the network. One-way pairs were proposed at Werner List (south-north), Dr Frans Indongo (east-west), Fidel Castro (west-east) and John Meinert (east-west) to coincide with the west-east upgrade of Sam Nujoma drive.

Clockwise/Anticlockwise ring routes;

- The directional ring route implementation primarily caters to higher travel speeds within the CBD network. The peripheral location (circulating the CBD boundary) of ring routes allows for a reduction of traffic volume within the CBD network the routes would look to serve through traffic movement.

Public Transport (PT) route prioritisation;

- PT optimisation entails the prioritisation of demarcated PT routes within the CBD. Signal setting prioritisation along with dedicated lane provisions improves PT movement. The city planners aimed to strategically select drop off/pick up zones to concentrate passenger volumes at locations earmarked for infrastructural development (e.g. Office complex, shopping malls, etc.). The dedicated PT routes and zones would, therefore, streamline PT movement within the CBD, effectively reducing passenger waiting time. The aspect, further, requires strict regulation in order to prevent illegal manoeuvring.

Improving the network's continuity;

- Network continuity aims to reduce the effects of traffic bottlenecks caused by a reduction in traffic lanes. The limited development space within the CBD has resulted in the reduction of lanes for high order routes passing through the CBD. Maintaining lane allocation reduces traffic congestion and queue lengths thereby improving through movement.

The ultimate capacity of the CBD network significantly influenced the effectiveness of the proposed principles. Transport policy scope and the CBD infrastructure potential were essential components of determining the ultimate capacity; defining the CBD boundary was, therefore, critical. The study identified Nelson Mandela Avenue, the city railway line; Hosea Kutako Drive and Robert Mugabe Avenue as the CBD boundary perimeter (see Figure 11).

University of Cape Town

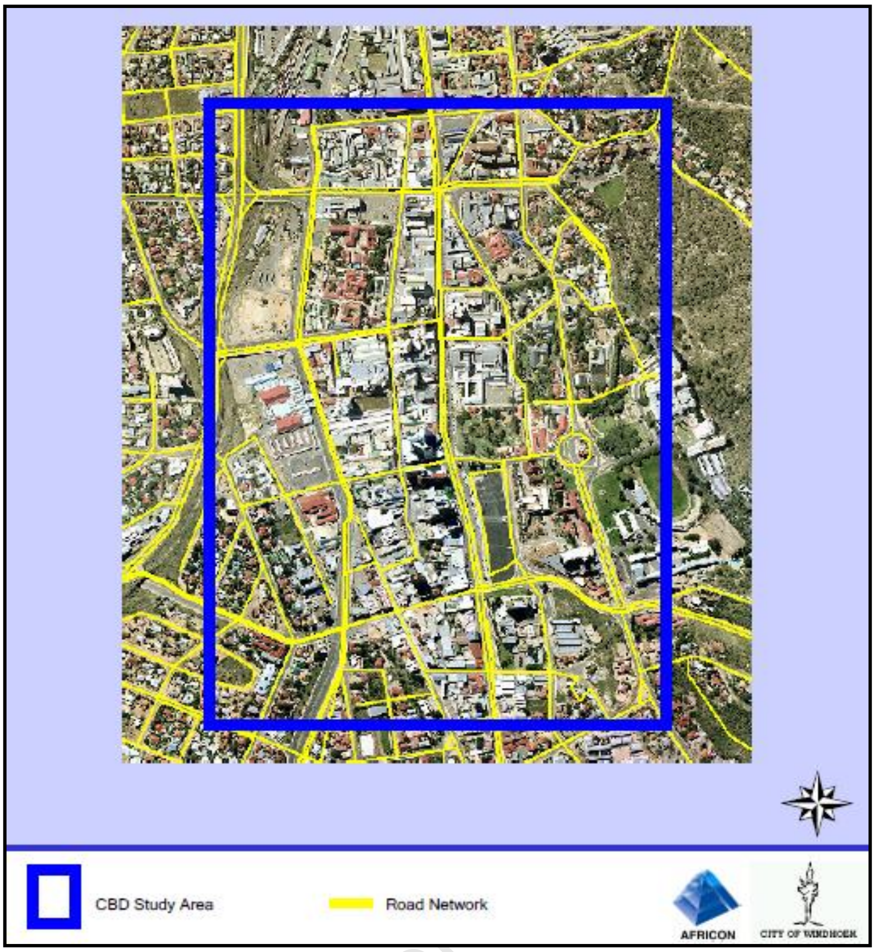


Figure 11: CBD Boundary. *Source: City of Windhoek, 2006c*

University of

The implemented circulation principles were assessed using meso-scale and micro simulation modelling techniques and software. The criteria used for assessment comprised of elements related to congestion and travel time measurement:

- Saturation levels (v/c ratios),
- Traffic volumes,
- Travel time,
- Queue lengths,
- Average speed, and
- Distance travel for various mode.

Currently, the one-way operational upgrade of Werner List is the only measure to have been implemented. Werner List Street lies in the centre of the CBD intersecting with Fidel Castro Street, Dr Frans Indongo Street and John Meinert Street. It connects the southern stream of traffic to that heading to the industrial areas in northern Windhoek. The one-way upgrade aimed to improve the travel speed and traffic circulation. A PT drop off/pick up zones was introduced along the route linking Dr Frans Indongo Street and John Meinert Street with the aim of serving commuters traveling to and from the north western and northern suburbs areas of Khomasdahl and Katutura respectively.

Werner List's upgrade depicts the aims envisioned by the City of Windhoek; the improvement of the CBD's traffic circulation scenario whilst prioritising PT usage.

3.2.2 Authority Interview

An interview was held with the City of Windhoek's Chief Engineer for Transport Planning, Design and Traffic Flow (Lisse, 2011). The interview aimed to gain a background understanding of Windhoek's transport network characteristics whilst trying to identify current concerns and future developments to the network.

Questions posed tackled concepts relating to:

- The City of Windhoek's Strategic Transport Master Plan,
- Public Transport prioritisation,
- CBD pedestrian movement,
- Transport policy framework,
- Council support – Institutional will,
- Budget allocation for transport improvements,
- Transport data records, and
- Traffic assessment methods.

The general theme during the discussion aimed at understanding the implementation of the mentioned interrelating concepts, with a key focus assigned to the aspect of Institutional will.

University of Cape Town

3.3 Development of Research Questions

The implementation of the one-way conversion of Werner List Street, the only transport upgrade implemented from those proposed in the STMP (2006), forms a basis for the assessment of the strategy undertaken by the City of Windhoek. This thesis developed research questions in relation to the upgrade's effect on the STMP's (2006) strategy objectives, CBD traffic circulation and the future implementation of the proposals presented in the STMP (2006).

Chapter six presents the discussion that aims to answer the proposed questions through the information gathered during the analysis of both the STMP (2006) and the micro simulation of Werner List Street.

3.3.1 Transport Strategy Objectives

Does the City of Windhoek's Strategic Transport Master Plan (City of Windhoek, 2006a) primarily cater to operational upgrades in its improvement methodology?

The low prioritisation assigned to Windhoek's transport network development, as discussed with the Chief Engineer: Planning, Design and Traffic Flow, depicts a scenario that does not cater for infrastructure expansion (Lisse, 2011). Reasons were, therefore, sought to identify the logic used to conduct the implementation of the network's development.

Windhoek's STMP (City of Windhoek, 2006) presents a development methodology that aims to improve land-use accessibility (City of Windhoek, 2006a), public transport efficiency (City of Windhoek, 2006b) and CBD traffic circulation (City of Windhoek, 2006c). The conversion of Werner List Street into a one-way street attends to the third aspect and is the only proposed upgrade implemented thus far (Lisse, 2011).

Aimed at improving the CBD traffic circulation by adjusting an operational aspect of the transport system, it was assumed that the City of Windhoek primarily focused on improvements of this kind. Further methods included the implementation of ring roads and maintaining lane width at the CBD boundary thereby promoting network continuity for traffic looking to bypass the CBD (City of Windhoek, 2006c). It was proposed that Sam Nujoma Drive, an arterial that links the east and west of Windhoek, maintain its lane structure (two lanes per direction) throughout its course from east to west. Currently, the lane reduction (one lane per direction) for the section passing through the CBD has created a bottle-neck scenario; its expansion aims to improve traffic flow.

In light of the mentioned improvements the study of the STMP (2006), therefore, aimed to assess whether the City of Windhoek prioritised operational improvements in accommodating future traffic demands.

3.3.2 Influence of operational upgrades on traffic circulation.

Do operational upgrades, alone, improve traffic circulation within the Windhoek's CBD?

Adding to the assessment of the one-way conversion, the main focus of this dissertation is the assessment of improvements to CBD traffic circulation. It was noted that the CBD experiences an aggregate traffic inflow during the morning period and an aggregate traffic outflow during the evening period (Lisse, 2011). Further, and because of the CBD's central geographic location, commuters travel through the CBD to reach travel destinations on opposite sides of their origin destinations.

With an increase in urban population, as discussed in Chapter two, the traffic demand is set to breach the supply threshold provided by the existing transport network by 2015 (Lisse, 2011). An improvement on the utilisation of the transport facilities' availability through innovative means was borne by the limited financial provisions made for infrastructure expansion. The proposed operational transport upgrades allowed for a means to accommodate future traffic demand at relatively low expenditure on the existing transport facilities (City of Windhoek, 2006c).

The impact that the one-way conversion has on traffic movement will ultimately be measured by assessing the level of stress experienced along Werner List Street due to traffic demand. Identifying the stress areas could be essential in determining further improvements, preferably of the operational type, to the network.

University of Cape Town

3.3.3 The effects of modelling outputs

Can assessment outputs, obtained from traffic modelling, provide a basis to direct and update the implementation of the STMP's (2006) methodology?

With the assigned operational upgrades in effect, the assessment technique should provide an analysis that will assist the continual development of transport networks. The modelling, at a micro, meso or macro level, of traffic realities provides foresight into the impact that various transport improvements have on networks. If successful, the upgrades could form part of an approval system to implement proceeding steps within development strategies.

The modelling process in itself would need to analyse improvements based on the assigned objectives of the strategy. The operational transport upgrades of Werner List Street aimed to improve CBD traffic circulation by reducing queue lengths and improving travel time along the street (City of Windhoek, 2006c). The micro simulation of the upgraded network aimed to determine the level and areas of stress along the route after the conversion.

The future development of the CBD network could incorporate the results obtained from the micro simulation of Werner List Street. The analysis of the stress areas would provide an indication as to where future CBD development priorities should lie in relation to the strategy in place. The modelling of the future development could, as a check, identify the improvement stress areas within Werner List Street.

3.4 Data Collection

3.4.1 Household Survey

Household survey studies provide an understanding of a transport network's activity system. The gathered data defines the generating capability of areas viewed as activity zones forming the first step of the Four Step Model (see Section 4.1).

The City of Windhoek, in partnership with Africon Consulting Engineers, conducted a household survey for the greater Windhoek area whereby 2474 households formed the study group. Three aspects were assessed, namely; household characteristics, trip making characteristics and attitudes towards varying transport modes.

3.4.1.1 Household Characteristics

The household characteristic aspect attended to the identification of social and economic activities of household members. The study of transport provisions, aimed to facilitate access to the activities was a constant feature.

- Household income: statistics provided a representation of the spatial distribution of income levels.
- Household structure and employment: detailed the population demographics and income generating capabilities.

University of Cape Town

- Vehicle ownership: focused on the number of households owning vehicles. The spatial distribution of vehicle owners aimed to provide insight on Public Transport reliance.

3.4.1.2 Trip-making Characteristics

Trip generation by zone for varying income groups was compared to the household characteristics. The gathered statistics looked at morning (AM) and evening (PM) peak trips for varying transport modes. Of particular interest was the number of trips generated by CBD activity.

3.4.1.3 Transport Attitudes

Attitude statistics assessed commuter preferences, reasoning and satisfaction. Transport expenditure, waiting time, mode availability and frequency of mode use provided a platform to assess the influence that transport functionality had on the commuter attitudes.

Zone and time availability of public transport assessed the areas critically stressed with transport inefficiency and consequentially needing attention.

3.4.2 Traffic Counts

Traffic counts form part of the calibration process providing a quantitative view of traffic volumes on the various routes of the assessed network. Both manual and technological counting procedures are used in modern traffic analysis:

- Manual – physical count of vehicles. Used to validate aspects such as turning movements at intersections, queue lengths and the modal split of a link.
- Technological – largely comprised of motion detecting sensors that record vehicle speeds, parking counts and intersection queue lengths.

The Werner List Street assessment utilised the manual method of counting. Counting stations were placed at the network's entry/exit points and at all intersections (see Figure 12). By placing the stations at the designated locations, the assessment aimed to gather count data for turning movement and vehicle volumes.

The basic CBD scenario utilised visual inspections, through photographic accounts, to assess queue length build-up at 36 intersections across the CBD. Vehicle spacing was assumed at five meters for the counts; in light of the dimension of the majority low occupancy sedan vehicles present in the CBD network. To maintain uniformity and in view of the dimensions set out in Paramics modeller, this research utilised the same five meter spacing.

The manual traffic count method was utilised to gather queue length data at the three major intersections along Werner List Street. Four students, for each approach, were assigned at each intersection. Problem relating to attaining accurate counts occurred due to the difficulty in assessing two-lane approaches. Counts were, therefore, measured by two students per approach.

University of Cape Town

Chapter six recommends the use of modern technology in acquiring and updating accurate data counts.

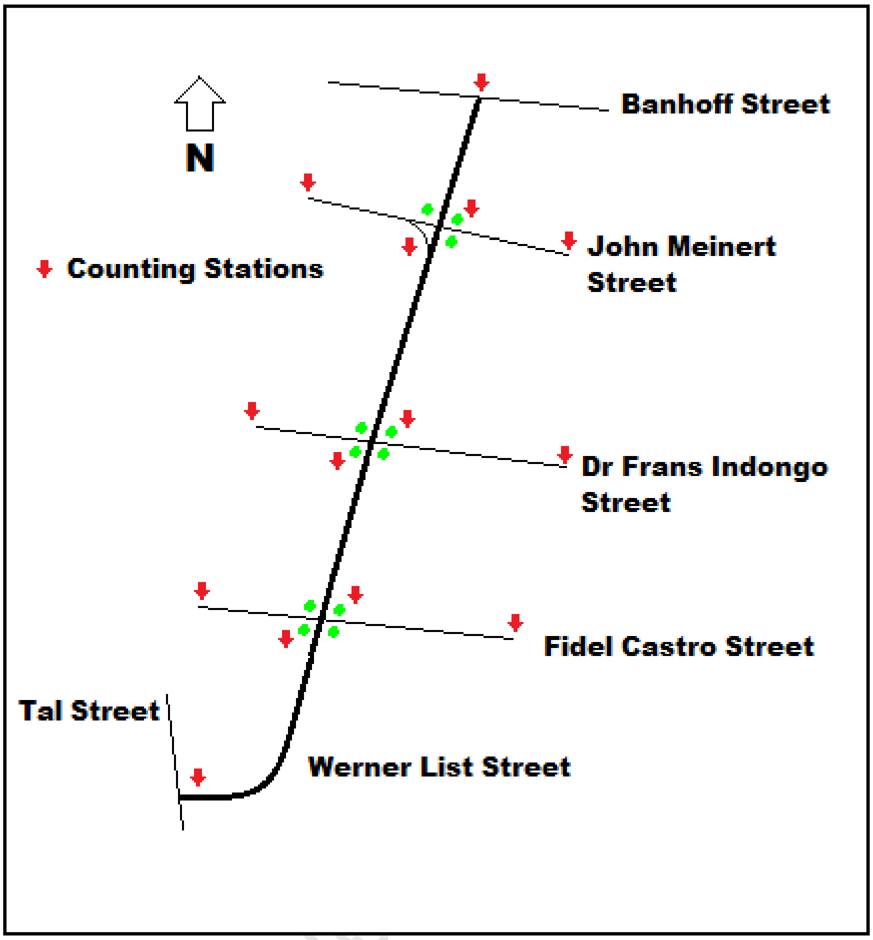


Figure 12: Werner List Street: Counting stations

3.4.3 Signal Optimisation

Werner List Street intersects three streets namely; Fidel Castro, Dr Frans Indongo and John Meinert Street; all of which are signalised using fixed pre-timed signal control (see Figure 13). The influence that each intersection's cycle time had on adjacent intersections (separated by one link) provided the basis for assessing the street's level of service.

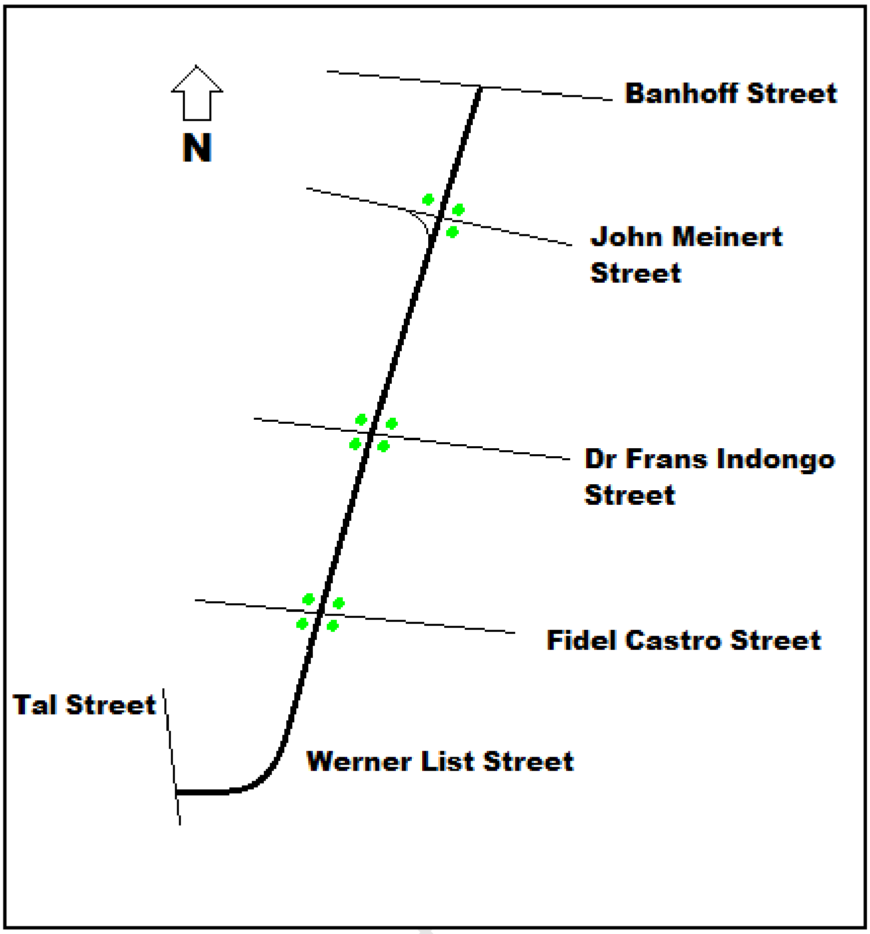


Figure 13: Werner List Street and intersecting streets

The City of Windhoek availed traffic signal sequence data for the three intersections (Appendix C). For each intersection the data included the cycle time for a specific time of day representing traffic peak conditions.

The signal settings provided calibration input for the assessment of the Werner List Street one-way upgrade. The cycle time, demarcated for peak traffic, focused on optimising the signal settings at areas seen to cause long delay and queue length (Lisse, 2011).

3.4.4 Visual Inspection

Visual inspections were conducted during peak morning and evening traffic periods at three intersections; Werner List – Fidel Castro, Werner List – Dr Frans Indongo and Werner List – John Meinert Street. The inspection sought to observe queue length build up and to validate the turning movement of vehicles travelling between assigned zones.

Figure 14: Morning Traffic at the Werner List - Fidel Castro Intersection

3.5 Traffic Modelling

3.5.1 Modelling Scope

Identifying the key objectives of traffic assessment dictates the type of network analysis to be conducted. For the Werner List Street assessment, the key performance measures studied are:

- Delay,
- Queue lengths, and
- Average speed.

The aim was to find a modelling tool that would provide results for the measures. An understanding of traffic modelling as a concept was studied by investigating the components of the traditional Four Step Model (FSM) and its link to transport and activity systems.

The assessment of urban mobility received considerable attention since the Detroit and Chicago Transport Studies of the 1950's provided analyses of transportation systems (Vanderschuren, 2006). Manheim's (1979) theory of Equilibration defined the effects that exogenous inputs, activity systems and transportation systems, had on traffic demand and network performance respectively. The developed theories describe the evolution of the FSM as a tool used to forecast future demand of transport systems (Hoogendoorn et al, 2007). Traffic modelling software assesses and forecasts transport network functionality in line with policy directives. The choice of software is dependent on the level of traffic demand detail required.

University of Cape

Perold and Anderson (2005) define the modelling process, for estimated travel demand characteristics, as an aim to assist decision makers during the planning of network development. The general distinction found in various modelling methods is that of activity and trip based models.

Activity based models analyse household activity travel patterns (Slinn et al, 2005). Extensive in-home and out-of-home surveys combine to provide a detailed understanding of society's travel pattern changes. Activity based models heavily assist in the formulation of policy measures. However, studies suggest that weak correlation results (below the 0.5 mark) have limited the accuracy of these models.

Trip based models facilitate travel demand characteristics by typically utilising the FSM method. Individual trips are the unit of analysis where both home based trips and non-home based trips are independently modelled. Multiple stops within these trips receive limited (if not, none) attention during the modelling process.

The FSM method, when used to analyse transport networks, incorporates both the activity and trip based systems (see Figure 15). The analysis allows for a continual flow data feedback, aimed at updating the trip distribution and modal split input before equilibrating the route assignment step.

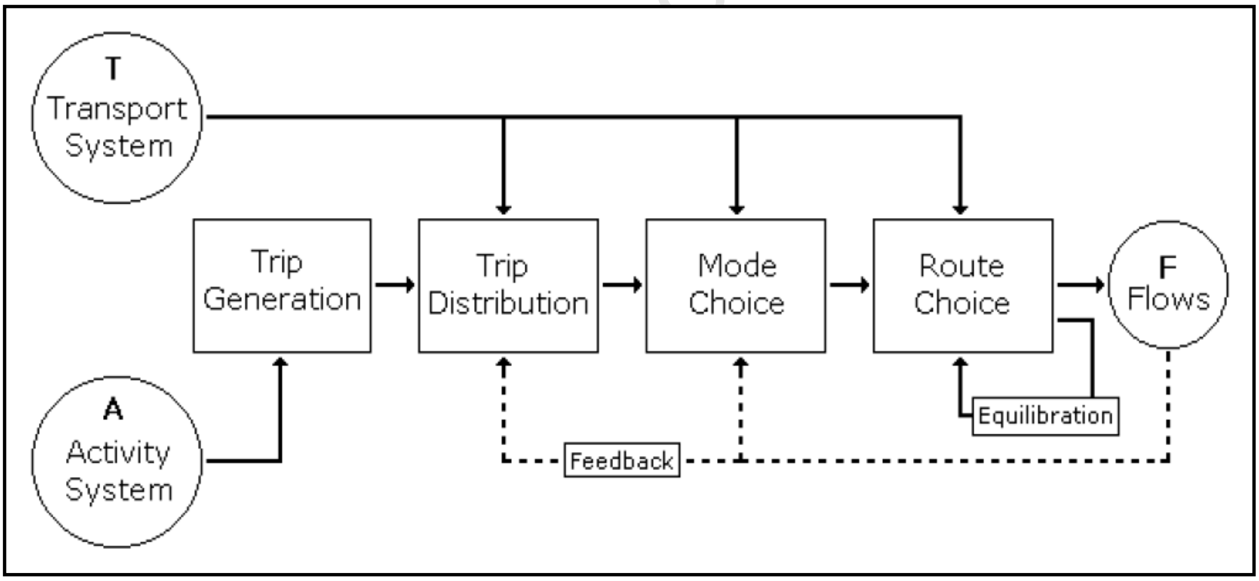


Figure 15: The Four Step Model. *Source: McNally, 2007*

For the Werner List study Activity System data was sourced from the mentioned Household Survey (see Section 3.1) with population growth provided by the National Planning Commission. Driver and infrastructure characteristics were sourced from household statistics and graphical geometric layouts as presented by the City of Windhoek; visual inspections assisted in validating of the information.

In view of the systems presented, it was aimed to pair the required level of detail with the availability of modelling packages.

3.5.2 Model Classification

Vanderschuren (2006) relates driver choice, as part of driver characteristics, to time dependant planning decisions when describing the level of detail different transport models represent. The driver's strategic, tactical and operational options represent decisions made before and during trip execution along transport networks that cater for planned traffic horizon.

Planners forecast this relationship by estimating, with the aid of mathematical formulae, perceived reaction to network upgrades. An assessment of the planning horizon in relation to changing driver characteristics allows for effective updating of transport policies.

The detailed nature of operational upgrades dictates the need to assess the dynamic activity of affected vehicles within the study area. Figure 16 depicts the relationship evident between driver characteristics and that of the decision maker when tasked to assess a transport network. The relationship can, therefore, be utilised as a basis to classify the level of detail required for traffic assessment.

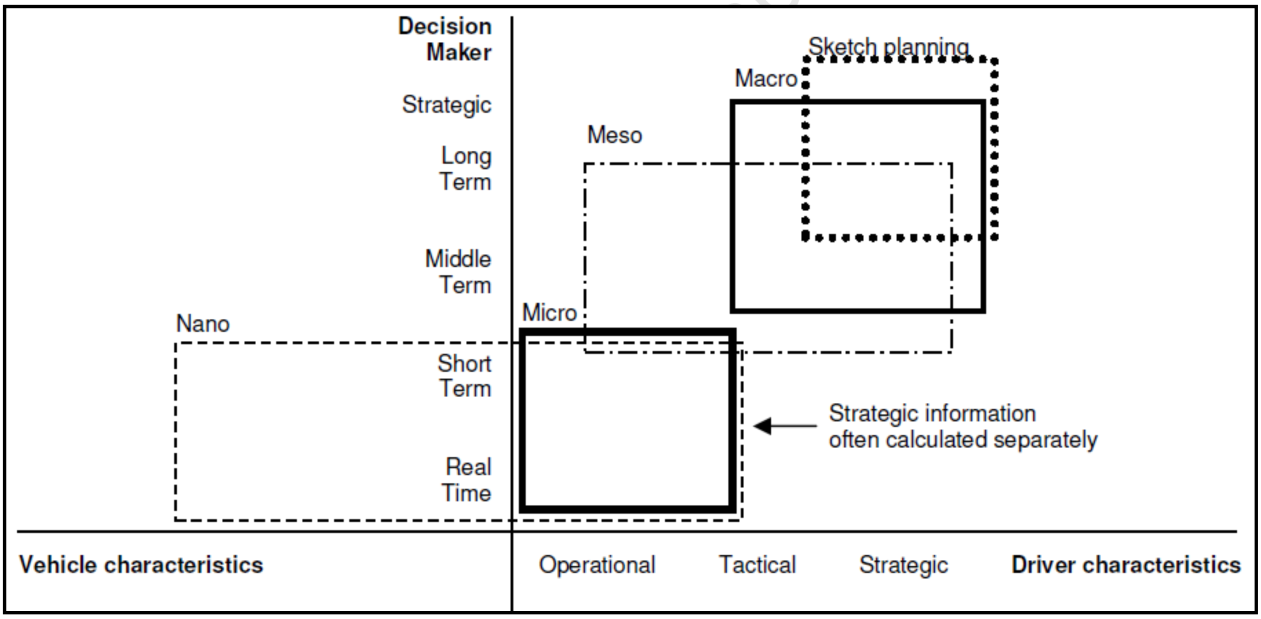


Figure 16: Relation between model characteristics and planning horizon. *Source Vanderschuren (2006).*

Smith and Blewitt (2010) describe the modelling procedure at a strategic, tactical and operational level:

- *Strategic models*: cover large areas and model networks at an aggregate level of detail. The type of models include Sketch planning models, macroscopic models and to a certain degree mesoscopic models. The models are based on the Four Step Model, however, are also defined for the static analysis procedure. An example of such a tool would be the World Bank developed Highway Development and Management Model (HDM IV).

- *Tactical models:* are used to assess the medium to short term change on a network due to an area-wide development. Accurate capacity calculations ensure that journey times are representative of the real time activity. Mesoscopic models are generally used for tactical analysis.
- *Operational models:* are in depth assessments of traffic scenarios within a network. Individual vehicles are modelled to replicate the on-site driver behaviour. Microscopic models represent this model type with dynamic nature of assessment governed by the input parameters.

The "driver characteristics – planning horizon" relationship governed the choice of modelling technique used for assessing the effects of the one-way conversion of Werner List Street. Factors studied included:

- Coverage area,
- Level of detail,
- Type of upgrade, and
- Driver familiarisation.

The Werner List one-way upgrade aimed to reduce the streets total delay and queue lengths, thereby improving traffic circulation within Windhoek's CBD. The conversion of three of the four links directs traffic from the southern parts of the CBD to the northern areas of the CBD. The assessment of longitudinal and lateral driving behaviour dictated the need to understand driver familiarisation and in turn the presented limits for vehicle manoeuvring.

It was, therefore, decided that a microscopic simulation model would suit the assessment of this operational upgrade.

3.5.3 Model Choice

3.5.3.1 Micro simulation models

Micro simulation models represent the analysis of dynamic vehicle activity within a network defined by infrastructure and driver parameters. The stochastic modelling approach allows for an accurate representation of real-life traffic scenarios continually updated through time-step calculations.

Simulation theory has modernised to a point where the use of commercially available computer models assess complex traffic scenarios. The assessment of operational upgrades commonly includes the study of Intelligent Transport Systems (ITS). Ratrout and Rahman (2009) identified commercially available software; AIMSUN, PARAMICS, INTEGRATION and CORSIM that attended to the simulation of operationally improved traffic scenarios.

University of Cape Town

The input and output variables of simulation models dictate the level of detail required to assess traffic networks. Vanderschuren (2006) lists information that is used as input data during the assignment step of the modelling procedure:

- Traffic zones,
- Physical and geometric layout of network,
- Demand specified O-D matrix,
- Vehicle characteristics,
- Driver information, and
- Time related information used to calculate release rate of traffic volume.

Further, various output variables for different software modelling packages were assessed to determine the possible range of information each package could produce. It was on this basis that the University of Cape Town decided to purchase the Paramics software package.

The assessment of the Werner List Street upgrade requires the study of output variables that can be drawn from the Paramics suite. It was, therefore, decided that the study would utilise Paramics as an assessment tool.

University of Cape Town

3.5.3.2 Quadstone Paramics

Paramics is a suite of micro simulation modules designed to simulate detailed traffic scenarios (including pedestrian movement), ranging from intersection analysis to broad level urban strategies (Quadstone, 2012). The model graphically depicts a makeup of the on-site geometric layout through the provision of nodes, links and associated objects. The calibration of vehicle parameters within the physical constraints of an assigned network and the adjustable “Time Step” function defines the dynamic nature of the modelling process.

Critical parameter definitions require attention when preparing the simulation of a network:

- Route Choice:

Cost tables, for both familiar and unfamiliar drivers, govern the route choice (assignment) of drivers within a network. The all-or-nothing assignment is applied to small network that consist of constricted route options, such as the assessment of Werner List Street.

- Lane Changing:

Paramics’ lane changing function appeals to the assessment of Werner List Street upgrade, due to the expected lane manoeuvring that would be conducted between the major intersections. Lane change manoeuvring occurs due to:

- Single urgent stimulus: caused when a vehicle is found outside its target range; the manoeuvring occurs in relation to the aggressiveness/awareness level set for an individual vehicle.
- A series of consistent non-urgent stimuli: is based on physical constraints, free-flow lane changing and the speed of total demand within that link.

Driver characteristics determine the required gap acceptance needed to perform lane change manoeuvring. The lane change between cross-section A and B, depicted in Figure 17, allows for the better vehicle positioning such that the mandatory lane change between cross-section B and C is manoeuvred in a safe manner. The distance required to complete lane manoeuvre from A to C depends on the risk level prescribed to individual vehicles.

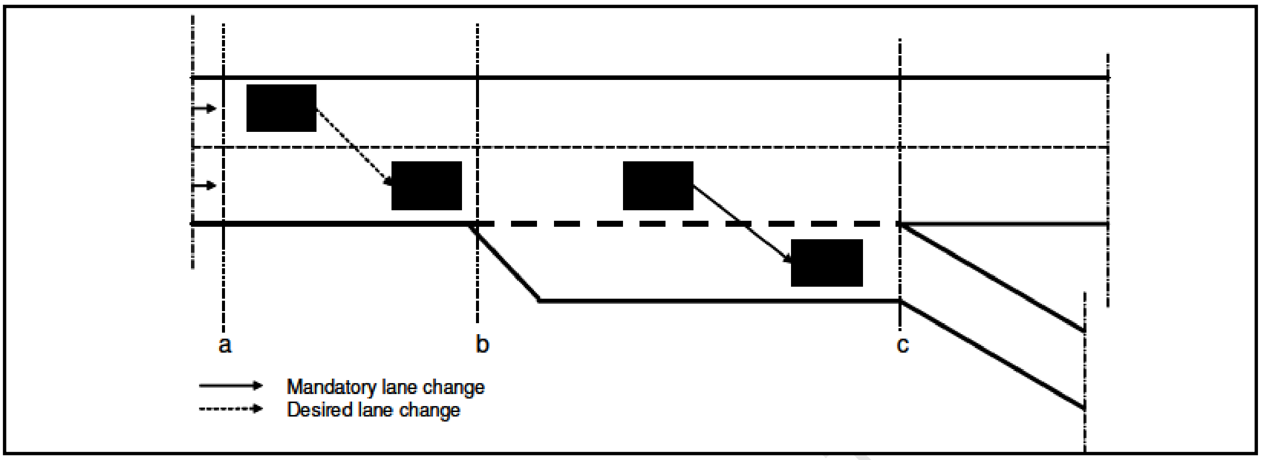


Figure 17: Lane change manoeuvring. *Source: Vanderschuren, 2006*

- Car Following:

Paramics assigns three modes of car following, namely; cruise mode, braking mode and acceleration mode. The "target point" concept governs the three modes and entails a vehicle's adjustable position at a distance s behind a leading vehicle (see Figure 18).

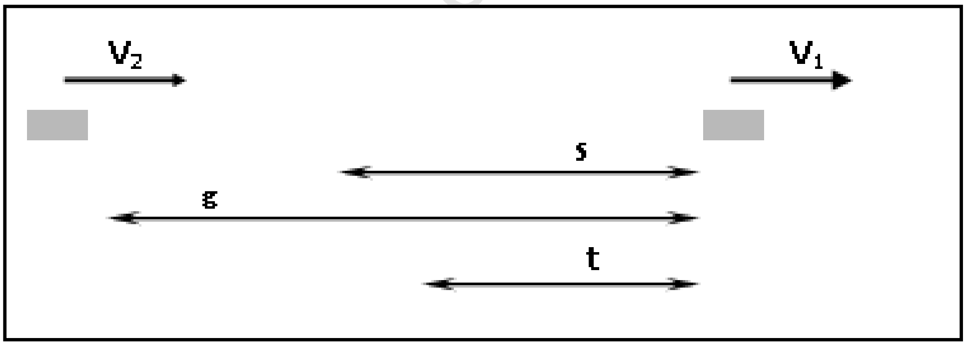


Figure 18: Target Point for car following. *Source: www.paramics-online.com*

Where:

s = hV_1 = target separation (m)

h = target headway (s)

t = adjusted target separation (m)

g = current gap (m)

Paramics assigns 1 second (default) as target headway of for each vehicle; the target headway is dependent on the perceived aggressiveness/awareness assigned to each vehicle.

- Time Step:

The modelling of decision making is critical to the dynamic nature of micro simulation. Paramics represents the re-adjustment of individual vehicles by adapting the Time Step function to the model. The Time Step function represents "decisions made for a discrete time per real time second". For each Time Step the assessment of dynamic and static parameters allows for a constant update of driver decision making with respect to lane changing, minimum gap search and link transfer. The balance between assigning values to vehicle headway and Time Steps governs the congestion effects along high speed or heavily trafficked links. The latter is of significance to the assessment of Werner List Street.

3.5.4 Network Development and Calibration

The Werner List Street model was developed with the aim of providing a true representation of the on-site physical conditions. Utilising aerial photography of the study area, provided by the City of Windhoek, geometric aspects, such as lane configuration and intersection priority dimensions were designed.

The default parameters, set in Paramics, were calibrated to meet driver behaviour and vehicle performance whilst incorporating the physical constraints of the network.

3.5.4.1 Model Input

Table 4 represents the changes made to Paramics' default parameters.

Table 4: Calibrated Parameters for Paramics

Description	Paramics Default	Werner List Upgrade	Comments on Deviation from Default
Mean Headway	1	0.8	The percentage (34%) of taxi drivers, driver behaviour within the CBD is seen to be aggressive (City of Windhoek, 2006c). The mean headway was adjusted to accommodate this assumption.
Mean Reaction Time	1	1	
Demand Weight	100	100	
Amber Time	3	3	City of Windhoek's demarcated amber time
Time Step Detail	2	2	
Cost Coefficient	1,0,0	1,0,0	
Feedback	Disabled	Disabled	
Perturbation	Disabled	Disabled	

University of Cape Town

3.5.4.2 Configuration

Seed numbers: cater for the generation of random numbers in order to produce variance in the model. The Seed value chosen for the Werner List Street traffic assessment was the default value of 6.

Road categories: for the Werner List Street assessment defined the network's road hierarchy. The main street was placed as an arterial, whilst the adjoining streets of Fidel Castro, Dr Frans Indongo, John Meinert and Banhoff were assigned collector status.

Nodes: represent the change in link characteristics, defined mainly as junctions within the network. The gradient of nodes plays a critical part in network development; the relatively flat terrain present for Werner List Street limits the impact of gradient consideration.

Links: provided for Werner List Street's network perform, mainly, two roles; the route connecting intersections along Werner List Street or the connection to the network's entry/exit zones. The following links and the associated characteristics form part of Werner List Street:

Tal Street – Fidel Castro

- Two-way street
- 3.7m width lanes
- 0.28 km length
- 60km/h speed limit
- No parking along street

Fidel Castro – Dr Frans Indongo

- One-way street (two lanes)
- 3.7m width lanes
- 0.30 km length
- 60km/h speed limit
- Parking on left hand side

Dr Frans Indongo – John Meinert

- One-way street (three lanes)
- 3.7m width lanes
- 0.31 km length
- 60km/h speed limit
- Parking on left and right hand side

John Meinert – Banhoff Street

- One-way street (two lanes)
- 3.7m width lanes
- 0.18 km length
- 60km/h speed limit
- Parking on left and right hand side

University of Cape Town

Junctions: represent points where two or more links meet. For Werner List Street, the signalised intersections with Fidel Castro, Dr Frans Indongo and John Meinert represent junctions. Signal optimisation, as discussed in Section 3.3, governs the traffic movement at intersections.

Non-signalised intersections require parameter calibration in order to replicate on-site driver behaviour. Gap acceptance and the patience threshold configuration allows for the release of vehicles into a traffic stream. The Werner List network contains one non-signalised intersection; the intersection linking Werner List Street – Banhoff Street.

Zones: define the origin and destination of commuting trips. Paramics differentiates between two zone types, namely; Area zones and Route zones. The two zones represent areas where vehicle informally load and points where traffic generation occurs respectively. Origin-Destination matrices represent traffic movement from and to the network's zones. For the Werner List Street assessment the O-D matrix representing trip distribution for morning and evening traffic is presented in Appendix B: Table B1 and Table B2.

3.5.4.3 Travel Demand

To specify the number of vehicles released from each origin zone to each destination zone the demand, profile and matrix files require editing. Vehicle configuration, additionally, defines the network's modal split. For the Werner List Street assessment the assigned vehicle breakdown, as viewed during visual inspections, is as follows:

- Family sedan (30%),
- 4 wheel drive (15%),
- Taxi – sedan (45%),
- Taxi – Minibus (2%), and
- Delivery Vehicle (8%).

Traffic was assessed during morning and evening peak periods. The vehicle demand profile over the simulated time period (one hour) was segmented into 15 minute intervals as follows:

Morning Peak: 15% - 20% - 35% - 30%

Evening Peak: 20% - 35% - 30% - 15%

The aggregate demand profiles depict a morning CBD inflow and evening outflow.

3.5.4.4 Validation

To validate traffic volumes within the Werner List network screen-line counts were conducted on two major links, Fidel Castro – Dr Frans Indongo and Dr Frans Indongo – John Meinert. Vehicle Motion Sensors (VMS) were placed on the prescribed links to assess this aspect. The GEH statistic formula (DMRB, 1997) assessed the validity of the modelled traffic flows with that of the observed within the network, measured for the duration of the morning and evening peak hours.

University of Cape Town

The assigned GEH formula (DMRB, 1997):

$$\text{GEH} = \sqrt{\frac{(Qmod - Qobs)^2}{(Qmod + Qobs)/2}} \qquad (1)$$

Where:
Qmod – Modelled traffic flow
Qobs – Observed traffic flow

Intersection counts at Werner List – Fidel Castro, Werner List – Dr Frans Indongo and Werner List-John Meinert intersections were used to gather the observed traffic flow and compared to the modelled flow for adjoining links.

The percentage of vehicles released into the network is of great importance to depicting a realistic traffic scenario. Paramics measures the number of vehicles released at the end of the simulation period; the aim is to have a 100% demand released.

University of Cape Town

3.6 Résumé

The study approach was aimed at assessing the conversion of Werner List Street, from the Fidel Castro Street intersection to that of Banhoff Street, into a one way street. The street conversion formed part of Windhoek's proposed Central Business District (CBD) traffic improvement strategy. The assessment studied queue lengths and average speed as key performance measures.

Research on Windhoek's Strategic Transport Master Plan was conducted to gain an understanding of the City's transport development aims. The STMP (City of Windhoek, 2006a) focused on three studies namely; Transport Land use study, Integrated Transport study and the mentioned CBD study. Statistics, such as economic and household growth indicators, as well authority interviews provided an insight of how policy regulation impacts the aimed development.

Traffic counts, at the network entry points and at the major intersections provided input data. Turning movements and queue lengths at major intersections were assessed to provide a basis for the traffic model's validation.

The signal sequence, provided by the City of Windhoek, was applied to the three signalised intersections in the model.

The traditional FSM, as a representation of transport and activity systems, governed the modelling approach for the traffic assessment of Werner List Street upgrade. Due to the in-depth level of detail required to assess the upgrade, the use of micro simulation modelling was prescribed. The assessment utilised the Paramics micro simulation software, due to its availability and output provisions.

Vehicle parameters, within the physical constraints of an assigned network and the adjustable Time Step function, were calibrated to represent the dynamic nature of the micro simulation process. Critical parameter definitions such as route choice and lane manoeuvring were assessed as functions of driver behaviour.

With the aid of the Paramics User Guide Manual, the network layout was configured to represent the on-site network geometry:

- Road categories,
- Nodes,
- Links,
- Junctions, and
- Zones.

The Origin – Destination Matrix utilised for the Werner List Street assessment sought to define morning and evening peak traffic movement. The vehicle demand profile defined traffic flow over 15 minute intervals for simulation period of one hour.

The validation of the developed model required input traffic counts at major intersections and network entry points. Turning movement completion and vehicle volumes along major links were the main areas of validation focus.

University of Cape Town

Chapter 4. Traffic Analysis of Werner List Street

4.1 Introduction

The analysis of Werner List Street's operational upgrade details the results obtained from the micro simulation of the designed traffic network. Input variables, as discussed in Chapter three, provided the basis for the network's calibration and the comparison of the base CBD scenario and the upgraded scenario forms the theme of this chapter.

The analysis of the household surveys, conducted by the City of Windhoek, focused on the traffic generating capacity of the Central Business District (CBD) activity area (City of Windhoek, 2004). Aided by the study of Windhoek's modal split, the CBD network's capacity to maintain an efficient public transport service was assessed. Vehicle ownership statistics defined the private to public transport distribution within the city, a feature required to assess routes that cater for mass inbound and outbound traffic.

Modal preference contributes, significantly, to the choice of vehicle use within the city. The perception of public transport as compared to the convenience associated with the use of private vehicles is viewed in the household survey's qualitative assessment of mode-type attitudes.

Interviews held with the City of Windhoek's Transport Department Chief Engineer focused on attaining information relating to the implementation of measures that address commuter perceptions and transport needs (Lisse, 2011). Key to the interviews was the qualitative study of the city's Strategic Transport Master Plan (STMP); the method used and support required to implement the STMP (2006) was of particular interest.

The data gathered from the micro simulation of Werner List Street's traffic scenario incorporates morning and evening peak traffic. The analysis aimed to substantiate critical queuing points and average speeds along Werner List Street throughout the simulation period.

The research made use of queue length data, collected through visual inspections, to validate the simulated outputs.

4.2 Windhoek's Transport Activity System

The three main aspects studied in the City of Windhoek's Household Survey of 2004 aimed to analyse the activity system of Windhoek's transport network (City of Windhoek, 2004). The assessed aspects: household characteristics, trip making characteristics and attitudes towards varying transport modes. The information gathered from the Household Survey (2004) was used to generate graphical results, as presented in this section of Chapter four.

The survey analysed 14 zones, Zone 10 being the CBD, each representing an area of homogeneous residential density as identified in the 2001 national census (see Figure 19). The sample size used in the survey was 2 474 households.

University of Cape Town

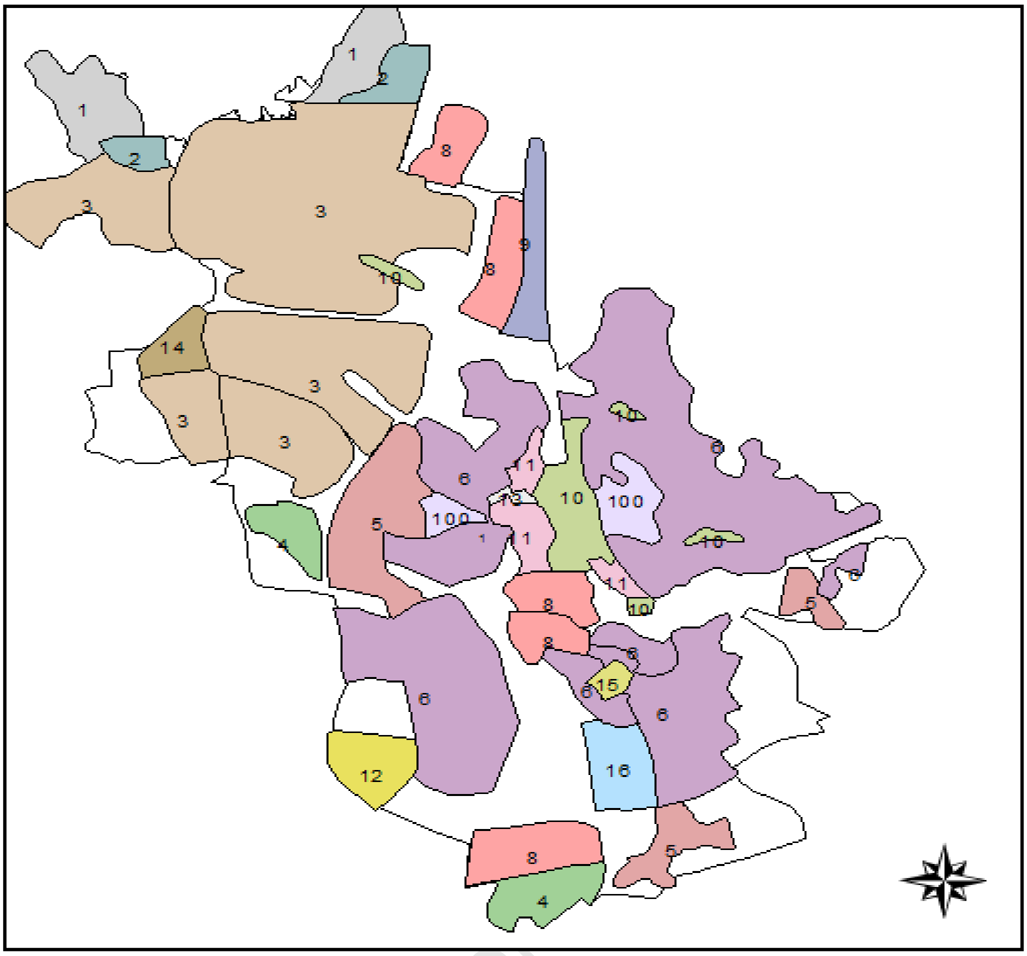


Figure 19: The 14 zones assigned to the Household Survey. *Source City of Windhoek, 2004*

4.2.1.1 Household Characteristics

The household characteristic assessed the social and economic activities of household members; factors studied included vehicle ownership, household income and household structure (City of Windhoek, 2004).

The Vehicle Ownership statistics covered aspects related to household mobility or access thereof (City of Windhoek, 2004). The percentage representation of vehicle ownership depicts Windhoek's population having, for the majority, limited access to private vehicle usage.

University of

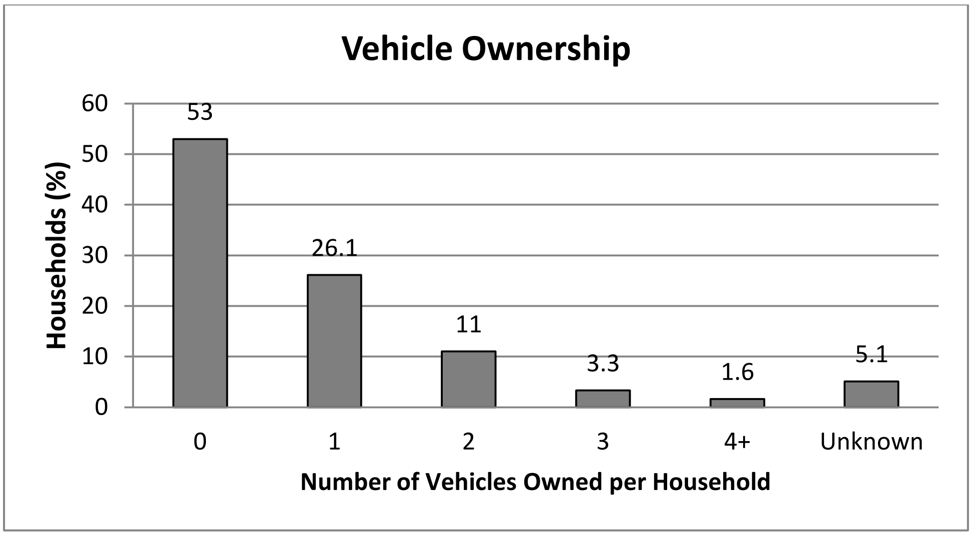


Figure 20: Household Vehicle Ownership. *Source: City of Windhoek, 2004*

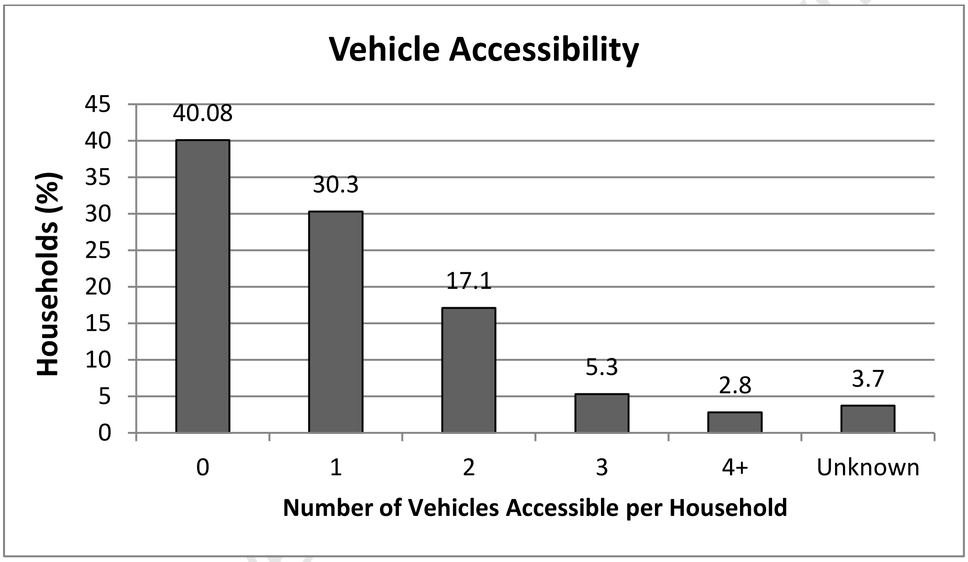


Figure 21: Household Vehicle Accessibility. *Source: City of Windhoek, 2004*

As depicted in Figures 20 and 21, at least 40% of the sample households have no access to private vehicles. Between 15% and 25% of households can concurrently provide mobility provision to two or more destinations within the city.

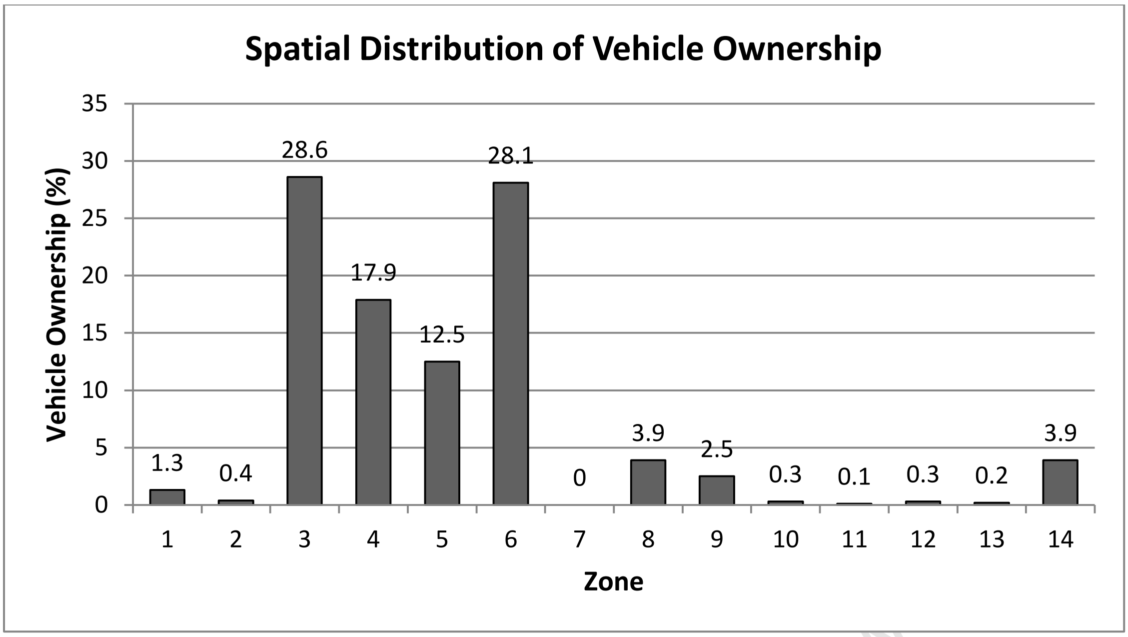


Figure 22: Zone distribution of vehicle ownership. *Source: City of Windhoek, 2004*

Figure 22 depicts the distribution of vehicle ownership for the assigned zones of Windhoek. Zone 3, 4 and 5: middle income suburbs and Zone 6: middle to high income suburbs constitute the largest proportion of vehicle ownership; a cumulative total of 87.1%. The vehicle ownership in the CBD (Zone 8) constitutes 3.9% of the studied sample.

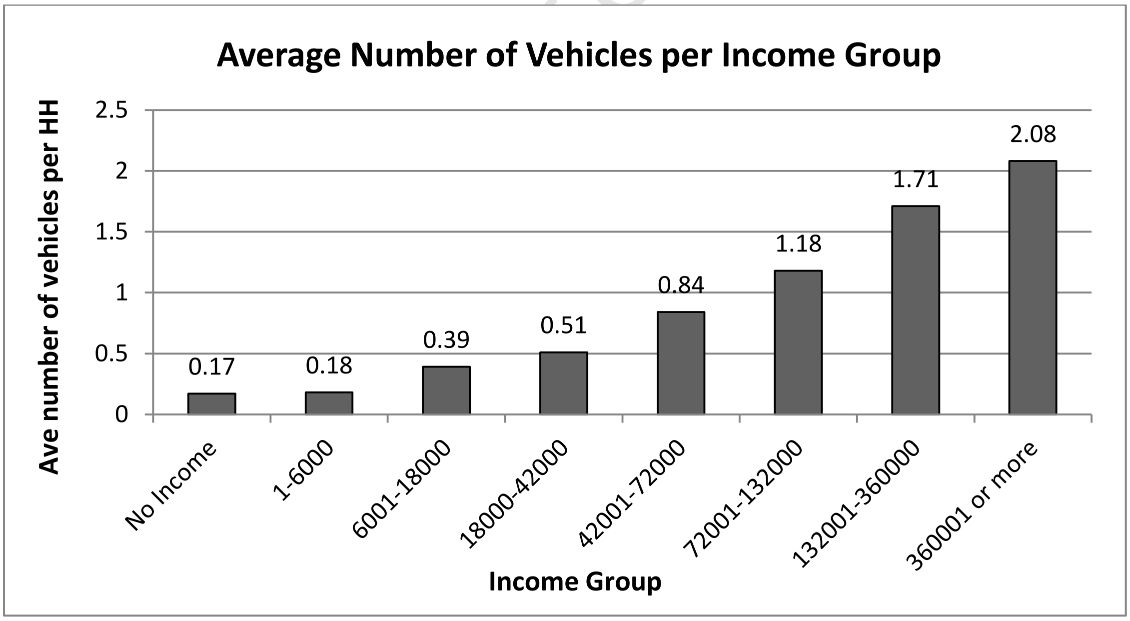


Figure 23: Vehicle ownership for varying Income Groups. *Source: City of Windhoek, 2004*

Figure 23 depicts the average number of vehicle owned for assigned income groups. The graph represents the increased vehicle ownership with a rising income level. The average number of vehicles per household is 0.69 as compared to the City of Tshwane, South Africa with 0.62 (City of Windhoek, 2004).

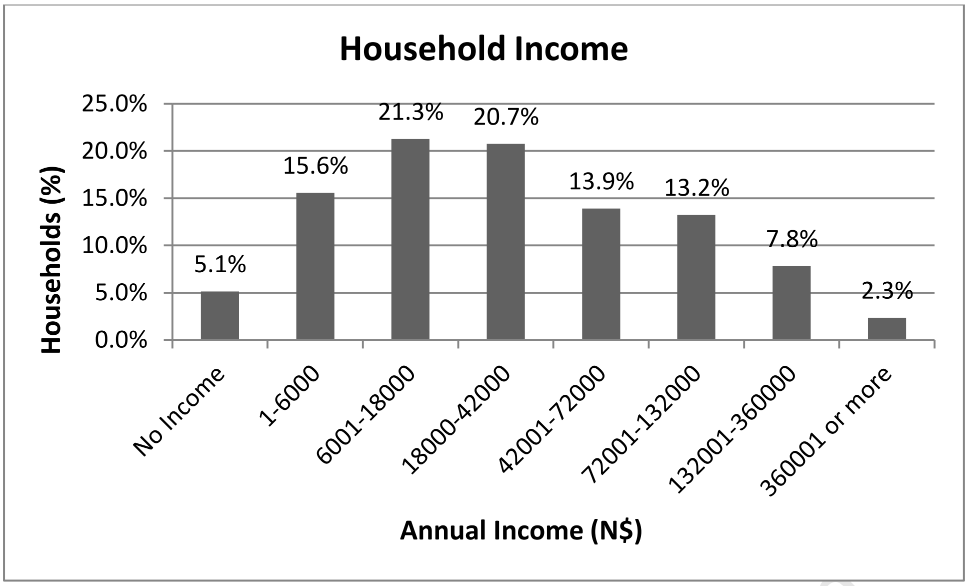


Figure 24: Household Income distribution. *Source: City of Windhoek, 2004*

Figure 24 depicts the spread for various income categories defined by low, middle and high income. The low income households represent 42% of the studied group, with the middle income representing 47.9% and 10.1% representing the high income households.

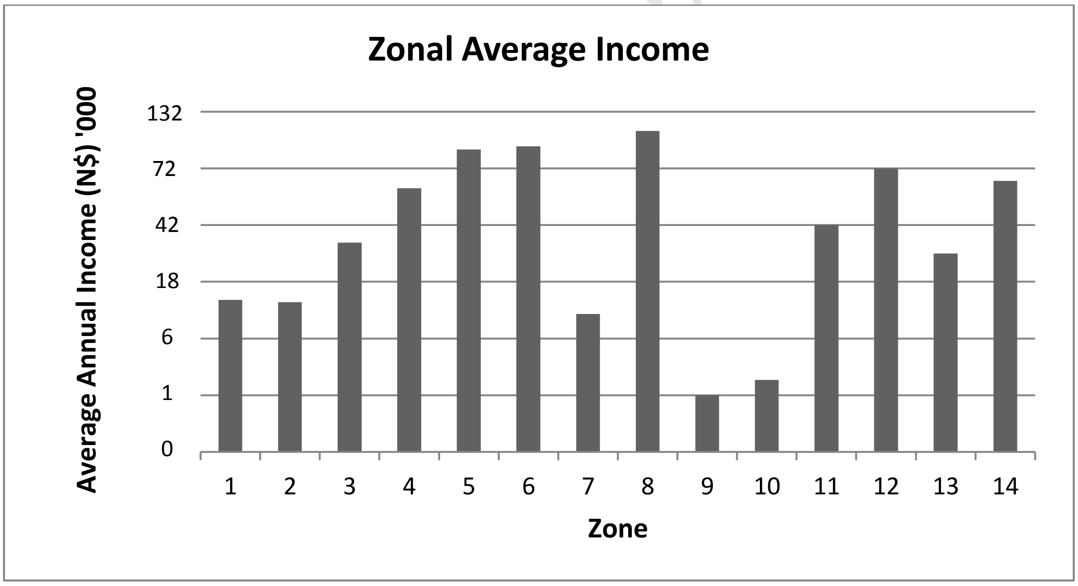


Figure 25: The average Household incomes per zone. *Source: City of Windhoek, 2004*

Figure 25 depicts the average annual income for each studied zone. Zone 5, 6 and 8 represent the high income zones containing affluent suburbs, such as Klein Windhoek, Auassblick and Avis respectively whilst Zone 1, 2, 7 and 10 of Katututura, Havanah, Okuruyangava and Windhoek West represent low income areas. Zone 9 represents the area covering the University of Namibia and being predominantly occupied by students, a low income generation was expected.

The household structure analysis aimed to assess the transport need within households of Windhoek; ascertaining characteristics related to the household setup (City of Windhoek, 2004).

Figure 26: Employment status within households for each zone.

Figure 26 depicts the household employment rate for the employable population of the 14 zones. More than 60% of the population for the majority of the zones is employed and, therefore, relies on transportation to the respective areas of employment within Windhoek. The employment ratio of the high income zones 5 and 6 is high as compared to the low income zones of 1, 2 and 10.

Figure 27 depicts the status of employment within households. The employable population make up 53.7% of the studied population of which 67% are employed. Scholars refer to school-going (primary and secondary school) people (City of Windhoek, 2004). Both this group and the pre-school group are likely to be transported, for the majority, by private vehicles or utilising public transport. Students, enrolled at tertiary institutions, contribute 5.3% and attend classes at varying times of the day with the majority ending during the assessed evening peak period.

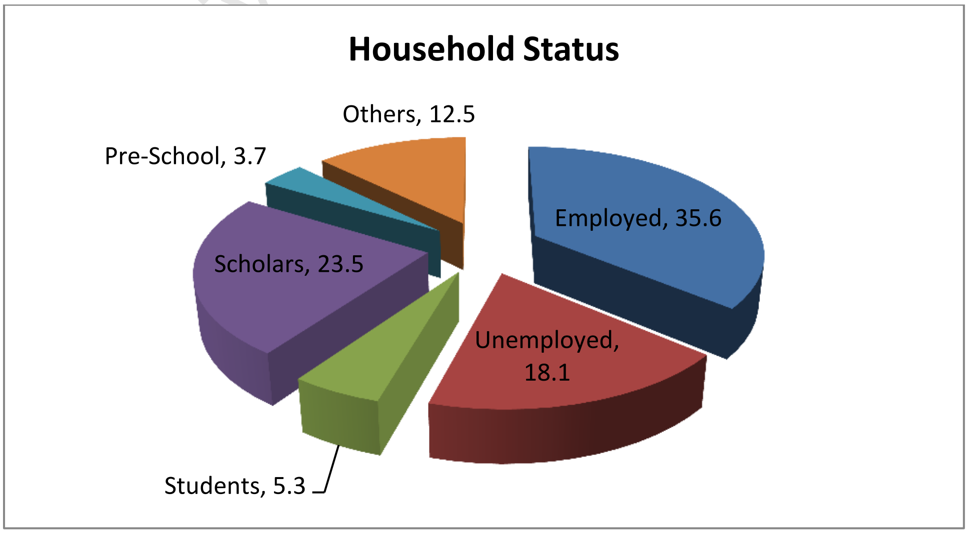


Figure 27: Household employment status for Windhoek. *City of Windhoek, 2004*

4.2.1.2 Trip-making Characteristics

The gathered statistics assessed morning (AM) and evening (PM) peak trips for varying transport modes (City of Windhoek, 2004). Statistics related to trip purpose and generation were of significant interest.

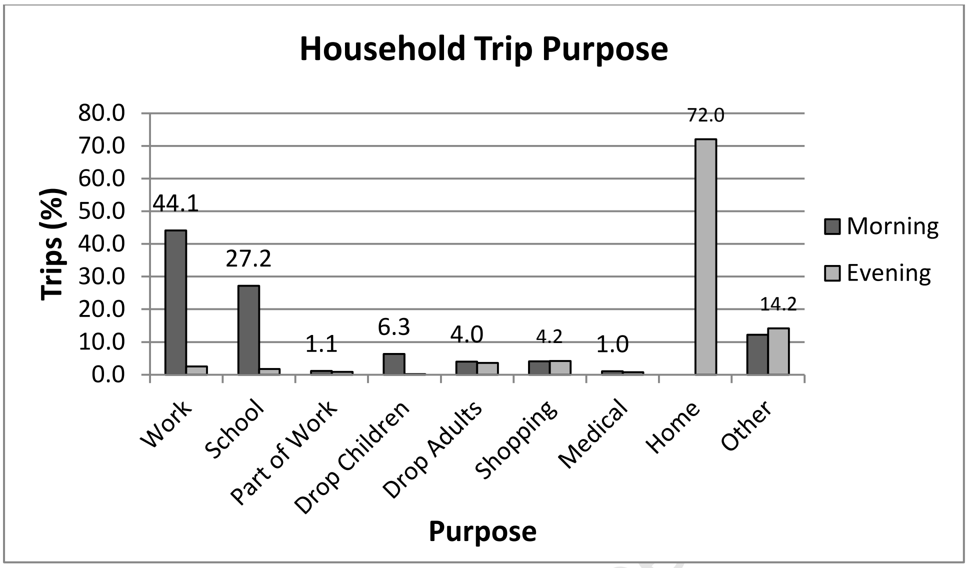


Figure 28: Household trip purposes during morning and evening peak traffic.

Figure 28 depicts the purpose of household trips for morning and evening periods. The majority (71.3%) of morning trips are dedicated to work and school. Conversely, 72% of evening trips are for the purpose of travelling home. Just over 10% of trips relate to the drop off of passengers, adults and/or children, to various destinations.

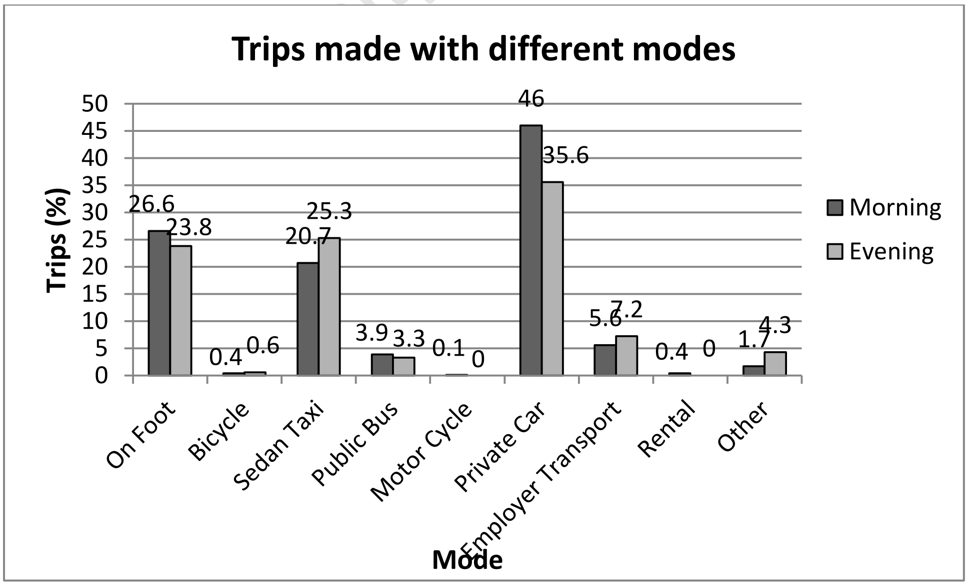


Figure 29: Trips made using different transport modes

The classification of trips in Figure 29 represents the labelled modes of travel for morning and evening peak traffic. In close relation to the 27% of trips made to school, as depicted in Figure 29, 26.6% of morning trips are made on foot. As depicted, 24.6% of morning and 28.6% of evening trips are made using public transport of which sedan taxi take up the majority. As expected private vehicle usage is the most commonly used mode of transport for both morning and evening peak travel.

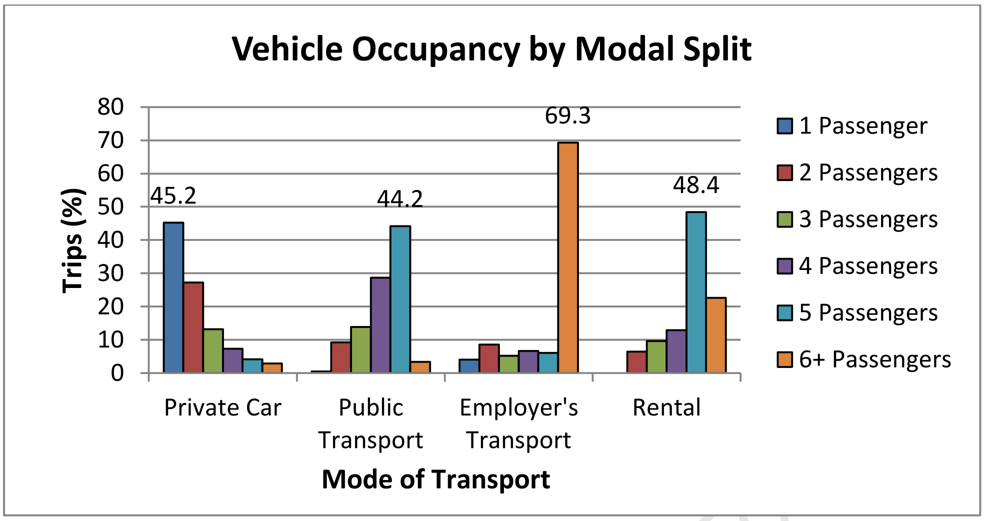


Figure 30: Vehicle Occupancy for different modes of travel

Figure 30 depicts the vehicle occupancy representation for different modes of travel with 69% of trips commuted using employers' transport include six passenger or more per trip. Public transport loads for the majority (44.2%) five passengers per trip in line with the legal limit for sedan taxis, which are the most commonly used mode of public transport as depicted in Figure 33. Private vehicle transport, uneconomically, transports one passenger as a majority (45.2%).

4.2.1.3 Transport Attitudes

Attitude statistics were used to assess the influence that transport functionality had on commuter preferences, reasoning and satisfaction. The Household Survey (2004) assessed zone and time availability of public transport (City of Windhoek, 2004).

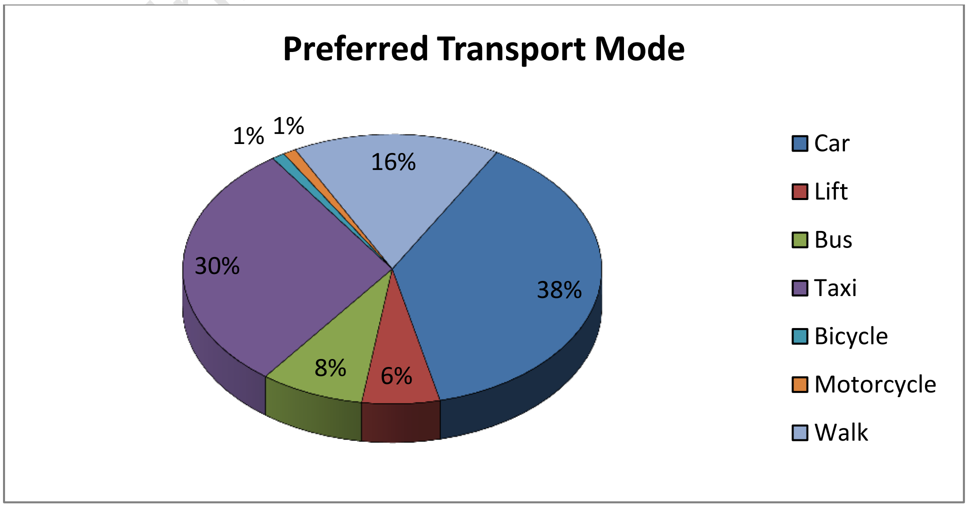


Figure 31: Preferred mode of transport

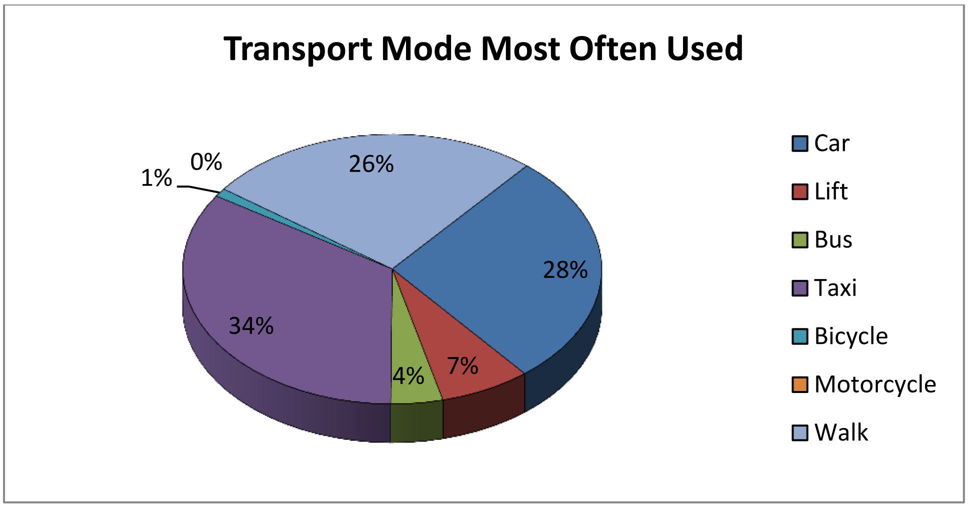


Figure 32: Mode of transport that has the highest rate of use

Figures 31 and 32 compare the preferred transport modes with that of the most commonly used modes. There is an inversely proportional difference (10%) in the walking and private vehicle modes, depicting an eagerness to move from walking to driving. Looking at the public transport use, 4% of taxi commuters would prefer not to use taxis as a mode of transport whilst an additional 4% of commuters would prefer to use the bus.

In light of the preference assigned to the mode choice, the major reason for actual mode choice was due to the accessibility of the chosen mode (City of Windhoek, 2004). Figure 33 depicts commuters' reasoning for using the available transport mode.

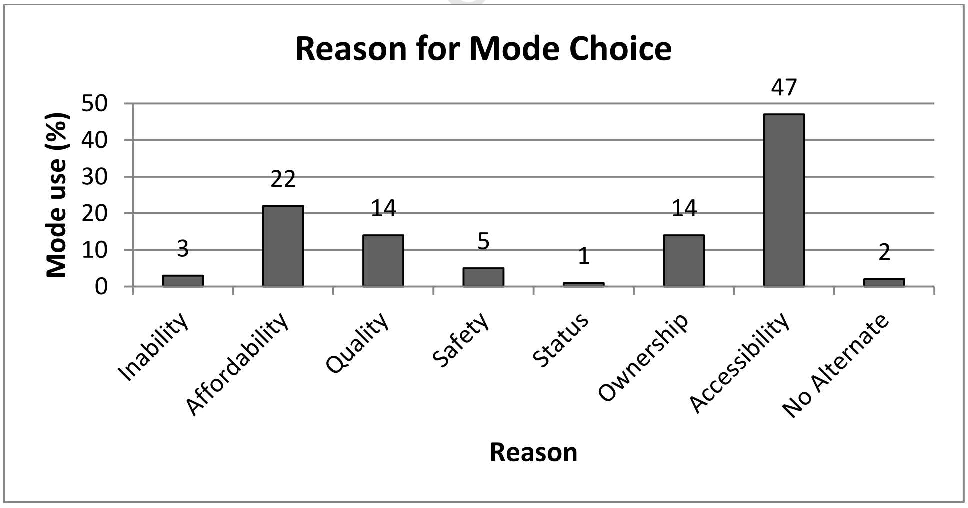


Figure 33: Reason for using transport mode

Affordability, quality and vehicle ownership count significantly to the reasoning of mode choice. The safety aspect yields low level of reasoning for mode choice, this could be attributed to low traffic volumes prevalent in small middleweight cities hence a reduced risk in traffic accidents. Accessibility (or a lack of) to transport modes counts as the major contributor to mode choice. With affluent neighbourhoods, Zone 5, 6 and 8, representing 45% of private vehicle ownership

(Figure 20) and a further 40% having no access to private vehicles (Figure 21), it is justified that accessibility is the major reason for mode choice.

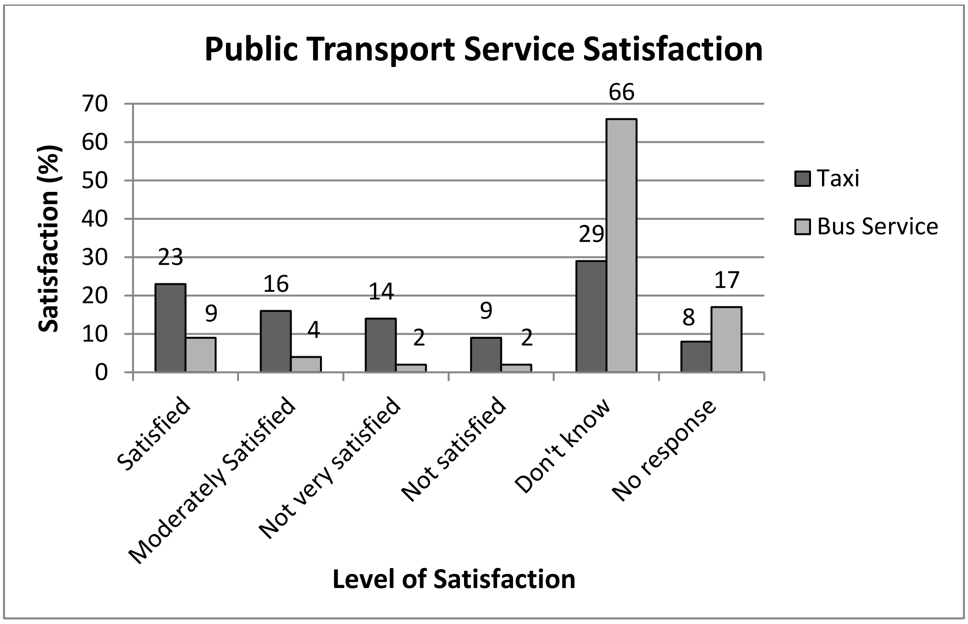


Figure 34: Satisfaction with Public Transport Service

In response to public transport commuting, Figure 34 depicts the satisfaction assigned to the service provided. For the majority, commuters have never used public transport, especially the bus service (66%). Change to the current public transport usage is, therefore, not likely as the unsatisfied portion for both modes is in the minority (9% and 2% respectively).

4.3 Base CBD Transport System

The City of Windhoek assessed the existing, at the time, CBD traffic network to establish a base case scenario (City of Windhoek, 2006c). Traffic scenario data was sourced from the raw data collected during the STMP (2006) data collection phase. The assessment provided aggregate results from for the entire CBD network during morning and evening peak period, which included:

- Volume/capacity ratios,
- average travel time,
- average speed,
- mean delay, and
- Queue lengths.

Of importance to this research, queue lengths were measured at 36 major intersections, including those connected to Werner List Street. Table 5 depicts average queue length results relevant to Werner List Street; the assessed intersections include Fidel Castro-Werner List, Dr Frans Indongo-Werner List and John Meinert-Werner List. Queue lengths were assessed using visual inspections; the average vehicle spacing was estimated at five meters (City of Windhoek, 2006c).

University of Cape

Table 5: Average queue lengths for Werner List Street base case scenario

Intersection	Approach from	Average Queue Length	
		AM	PM
Fidel Castro	North	20	15
	South	55	50
	East	90	70
	West	90	100
Dr Frans Indongo	North	15	30
	South	75	80
	East	20	15
	West	110	100
John Meinert	North	10	5
	South	55	45
	East	25	30
	West	70	65

Source: City of Windhoek, 2006c

University of Cape Town

Major stress concerns were viewed at:

- the east and west approaches of the Fidel Castro-Werner List intersection,
- the west and south approaches of the Dr Frans Indongo-Werner List intersection, and
- the west approach of the John Meinert-Werner List intersection.

For the upgraded network, queue length results were obtained from the micro simulation and the visual inspection of Werner List traffic scenario. The results were compared to those depicted in Table 5. The validation of the traffic flows obtained from simulation model, as discussed in Chapter 3, was conducted using the GEH statistic, which provided values of 4.15 and 3.23 for morning and evening peak hour traffic; falling below the required GEH of 5.

4.4 Visual Inspections

The visual inspections held at three major intersections; Werner List – Fidel Castro, Werner List – Dr Frans Indongo and Werner List – John Meinert aimed to compare the real-life traffic scenario with the results attained from the base study and the micro simulation. The inspection primarily catered to identifying queue length build-up for vehicles travelling between assigned zones.

Inspections were held during the morning (07:00-08:00) and evening (16:45-17:45) peak periods. Parallel to the measured dimension of vehicle spacing used in the Base case scenario, the inspection of the upgraded scenario utilised five meter spacing for assessing queue lengths at the major intersections. A general trend, witnessed during the inspections, was the gradual increase in vehicle volumes within the peak period and the sharp declines for the final five minutes (07:55-08:00 and 17:40 and 17:45) were on average the norm at the intersections.

Figure 35: Queue lengths for eastern approach Fidel Castro-Werner List Intersection

Queue length build-up along the eastern approach of the Fidel Castro-Werner List intersection, Figure 35, increased throughout the peak period receding between 07:55 and 08:00 (morning peak) and from 17:30 to 17:45 (evening peak). The longest queue lengths recorded for morning and evening peak periods were 85 and 70 meters respectively; both recordings occurred in the lane dedicated to turning into Werner List Street. The average queue length, determined for the eastern approach, was 75 and 70 meters for the morning and evening periods respectively. For the first 20 minutes of the peak period inspection, queue lengths in the range of 45 to 55 meters were witnessed.

Figure 36: Queue lengths for western approach of Fidel Castro-Werner List Intersection

Figure 36 depicts the queue length formation at the Fidel Castro-Werner List intersection for the eastern and western approaches respectively. Sedan taxis (represented by the numbered logo on the side and rear window) are prevalent in the western traffic stream whilst private vehicle make up the majority of the eastern approach.

For the majority, queue length measurements exceeded 60 meters for both the morning and evening peak periods with the highest recorded readings being 100 and 95 meters respectively. Similar to the eastern approach, a morning gradual queue length build-up increased after 07:20

(16:50 for the evening), 75 and 85 meters, with a sharp decline in recording between 07:50 and 08:00 (between 17:25 and 17:45 in the evening).

Figure 37: Fidel Castro southern approach

Figure 37 depicts the queue length build-up at the southern approach of the Fidel Castro-Werner List intersection. Queue lengths were recorded at 40 and 50 meters for the morning and evening peak periods.

Figure 38: Queue lengths for western approach of Dr Frans Indongo-Werner List Intersection

The queue length build-up for the western approach of the Dr Frans Indongo-Werner List intersection is viewed in Figure 38. The average queue length measured between 07:20 and 07:55 in the morning, and between 16:55 and 17:25 in the evening was 95 meters. The highest recorded queue length was 110 and 100 meters for the morning and evening peak periods; both lanes turn into Werner List Street.

Figure 39: Queue lengths at southern (left) and western (right) approaches of John Meinert-Werner List Intersection

Traffic queuing at the John Meinert-Werner List intersection, Figure 39, has relatively low queue length formation. Queue length averages for morning and evening peak periods measured at 45 and 30 meters respectively at the southern approach. Measurements at the western approach depict 60 (morning) and 65 meters (evening).

4.5 Traffic Simulation

4.5.1 Queue Length Results

The analysis of queue lengths at the major intersections along Werner List Street defines the critical stress points within Windhoek's CBD traffic network. The measured period was for one hour, defined in hours, minutes and seconds, for both morning and evening peak periods. The simulation of Werner List Street used a five minute "statistic collection warm up period" (Quadstone, 2012).

The queue lengths analysed along the western approach of Dr Frans Indongo – Werner List intersection experienced the longest queue lengths with recorded measurements of above 100 meters. The southern, eastern and western approach of the Fidel Castro – Werner List intersection experienced lengths of 70 meters during both the morning and evening peak periods. On average, the intersections along Werner List Street experienced queue lengths of below 40 meters.

University of Cape Town

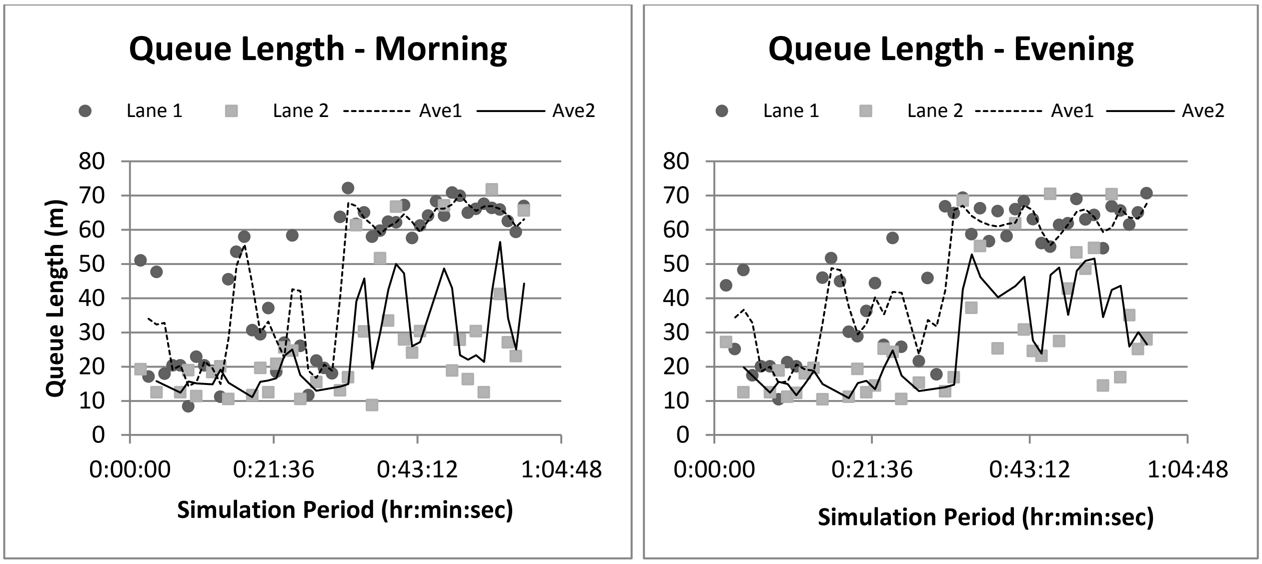


Figure 40: Queue Length Fidel Castro West

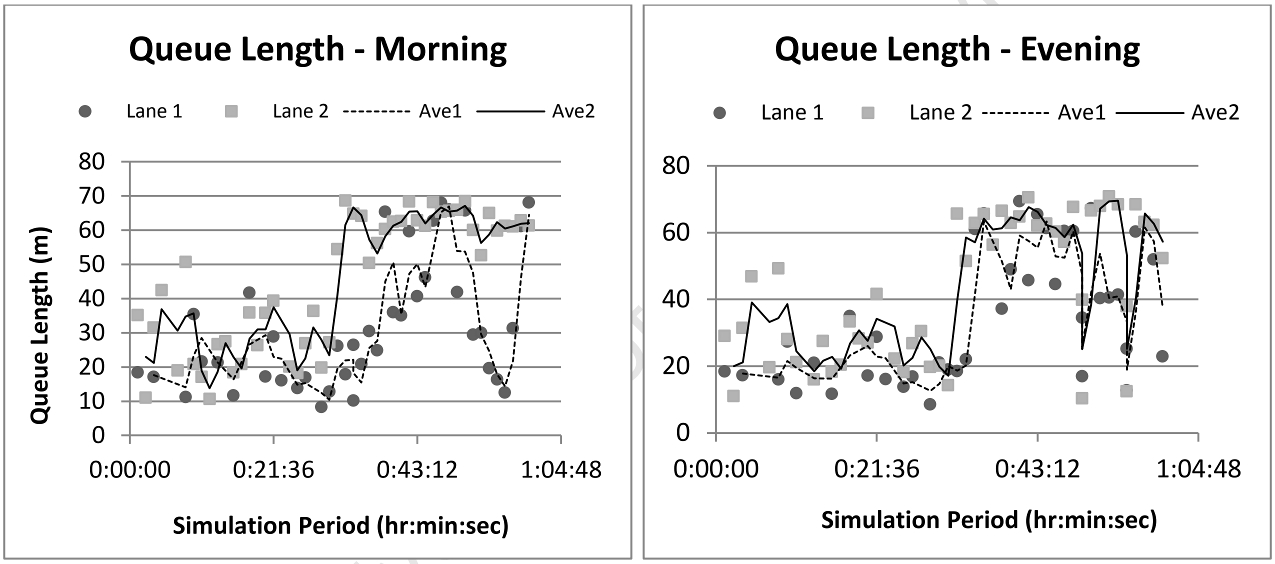


Figure 41: Queue Lengths Fidel Castro East

The analysis of the Fidel Castro – Werner List intersection, Figure 40 and 41, depict queue lengths for both morning and evening peak travel times. For the western approach of the intersection and during both peak periods, Lane 1 (west) and Lane 2 (east) collect the majority of traffic turning into Werner List Street with queue length experienced for the two periods significantly increases 30 minutes into the simulation period to average between 60 and 70 meters for morning and evening periods respectively. Lane 2 (west) and Lane 1 (east) maintain queue length levels of on average 30 and 40 meters during morning and evening peak periods respectively.

As witnessed in the visual inspection, the queue length measurements for the eastern and western approaches increase as the peak period progresses, with the lanes providing dedicated turn movements into Werner List Street experiencing high queue length levels. The average queue lengths for the visual inspection, 75 and 85 meters, are higher than the results obtained from the simulation, and are less than the results of the base study (90 and 100 meters).

Figure 42 depicts the queue length scenario for two-way southern approach of the Fidel Castro – Werner List intersection for both the morning and evening peak periods. The simulation initially produces a volatile queue length scenario for the initial 25 minutes of the simulation before steading to a constant range of between 45 and 60 meters. A higher intensity of queuing is depicted from 30 minutes onwards. The average queue lengths for both the simulation and visual inspection results depict no reduction from the results obtained in the base scenario.

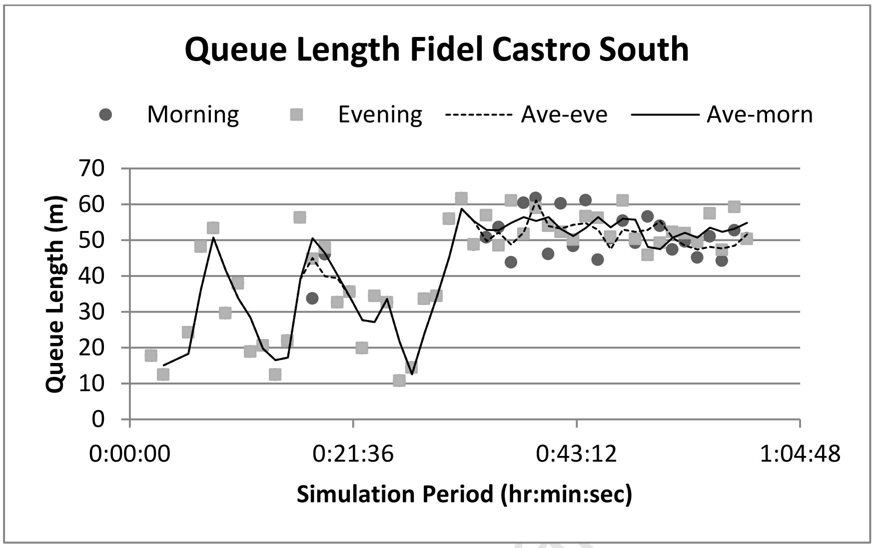


Figure 42: Queue Lengths for Fidel Castro South

The intersection linking Dr Frans Indongo and Werner Lists streets experienced queue length results as depicted in Figure 43, 44 and 45 for the morning and evening peak periods. Queue lengths along the western approach exceeded 100 meters for the majority of the simulation periods. In comparison, the visual inspection results were slightly lower than the simulated data.

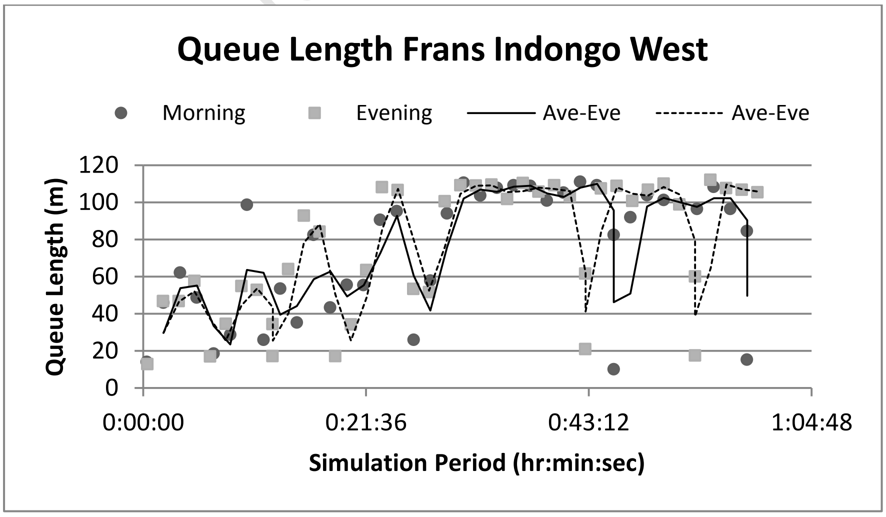


Figure 43: Queue Lengths for Frans Indongo West

In contrast to the queue lengths for the western approach, the eastern approach experienced low queue lengths, averaging between 20 and 30 meters for both morning and evening peak traffic. The queue length profile was constant throughout the simulation period.

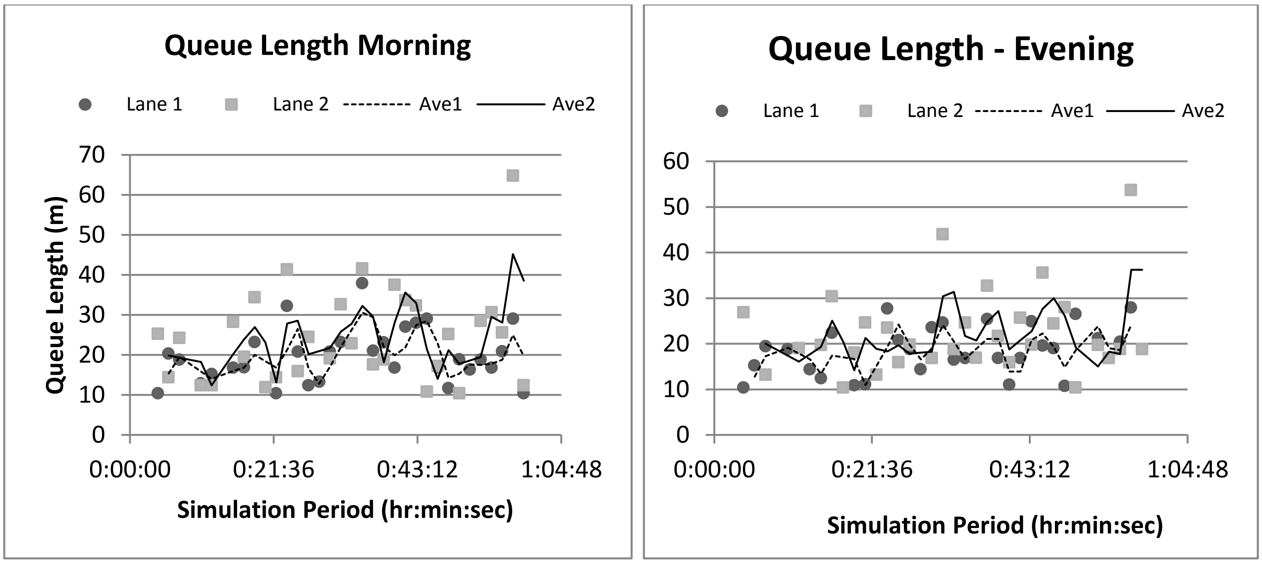


Figure 44: Queue Lengths Frans Indongo East

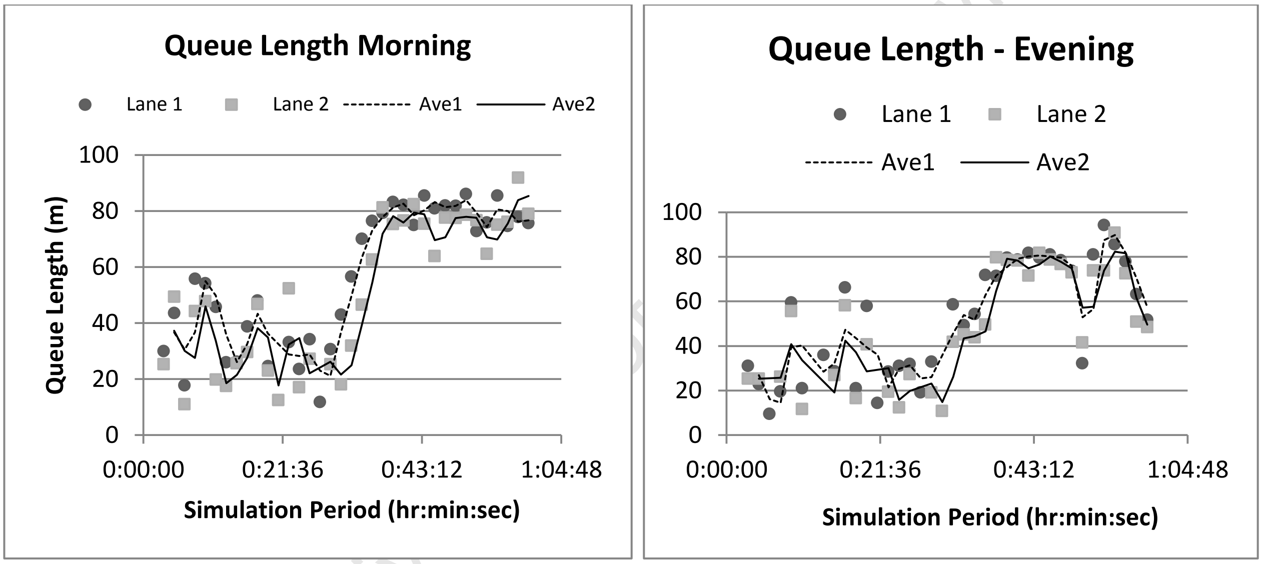


Figure 45: Queue Lengths Frans Indongo South

The results from the southern approach of the Dr Frans Indongo - Werner List intersection depict queue length profiles similar to that of Fidel Castro – Werner List with queue lengths exceeding 80 meters after 40 minutes of run time (Figure 45). Although queue length build-up at the southern approach is relatively high, there has been an improvement from the base case scenario.

The queue lengths present at the John Meinert – Werner List intersection, depicted in Figures 46 and 47, fall within a range of 10 to 25 meters on average with a relatively high frequency experienced for the southern approach. A significantly lower queue exists for the eastern approach that connects the north western area of the CBD to the middle income residential suburbs of Khomasdahl and Dorado Park. The results are similar to the average queue lengths measured during the visual inspection, of between 10, 15 and 25 meters for the eastern, southern and western approaches. Further a significant reduction in queue length build-up was experienced for the John Meinert-Werner List intersection as compared to the base study.

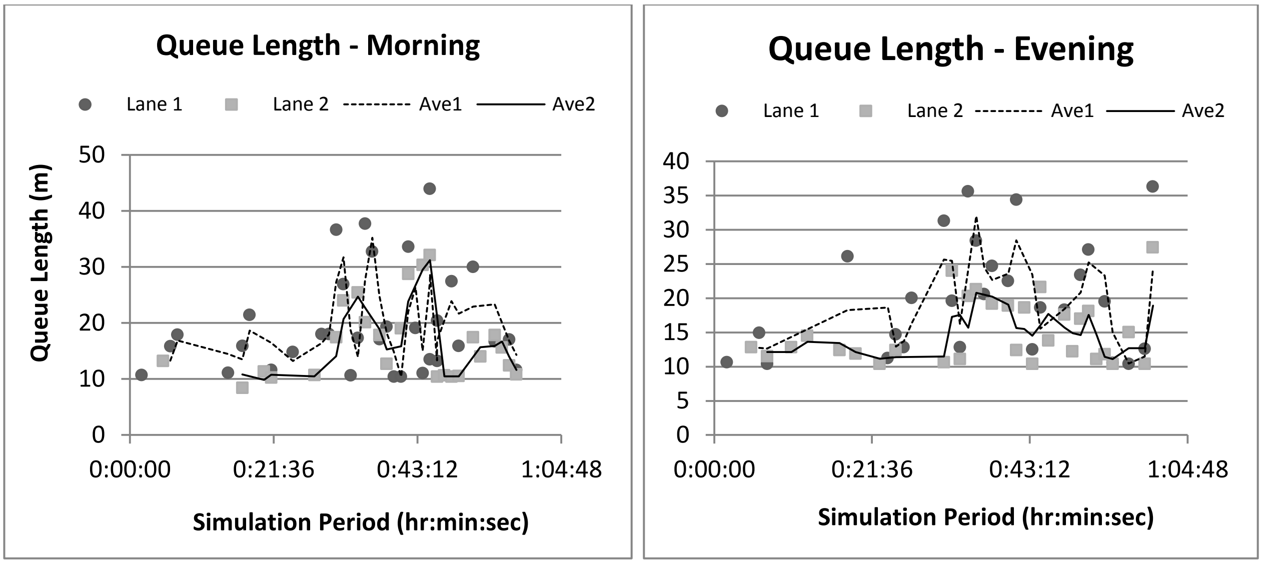


Figure 46: Queue Length John Meinert West

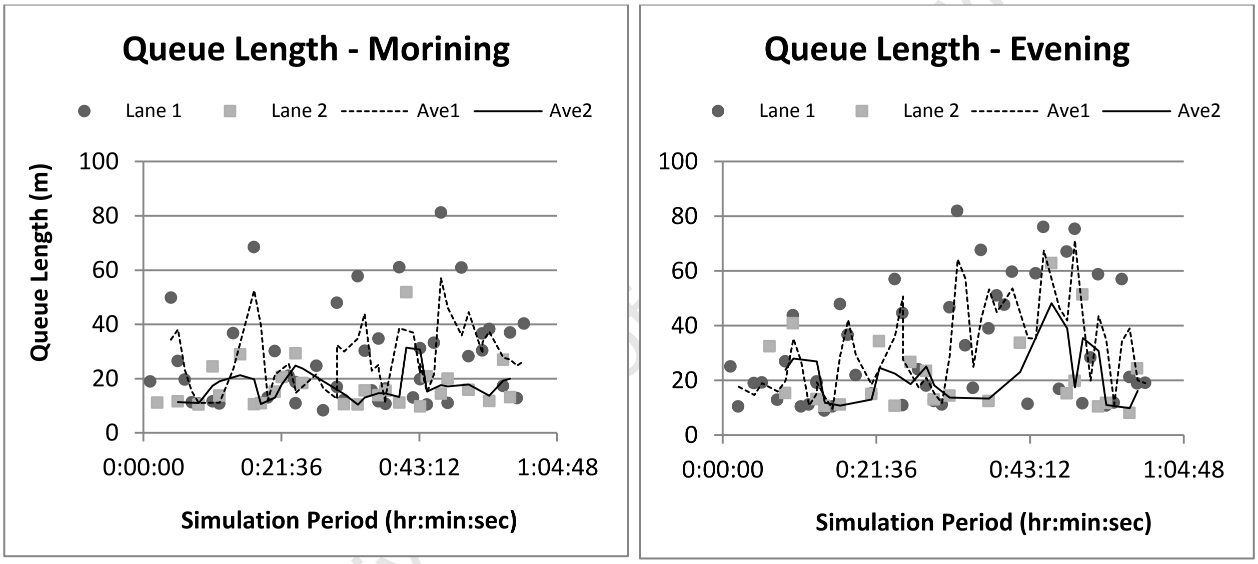


Figure 47: Queue Lengths John Meinert South

A summary of the comparable results is provided in Table 6.

Table 6: Comparison of analysed results

Intersection	Approach from	Average Queue Length Base		Average Queue Length Visual		Average Queue Length Simulation	
		AM	PM	AM	PM	AM	PM
Fidel Castro	South	55	50	55	55	45	50
	East	90	70	65	60	75	70
	West	90	100	65	65	75	85
Dr Frans Indongo	South	75	80	80	75	80	90
	East	20	15	20	25	25	15
	West	110	100	100	105	110	100
John Meinert	South	55	45	15	25	45	30
	East	25	30	10	15	20	25
	West	70	65	25	30	40	35

4.5.2 Traffic Speed

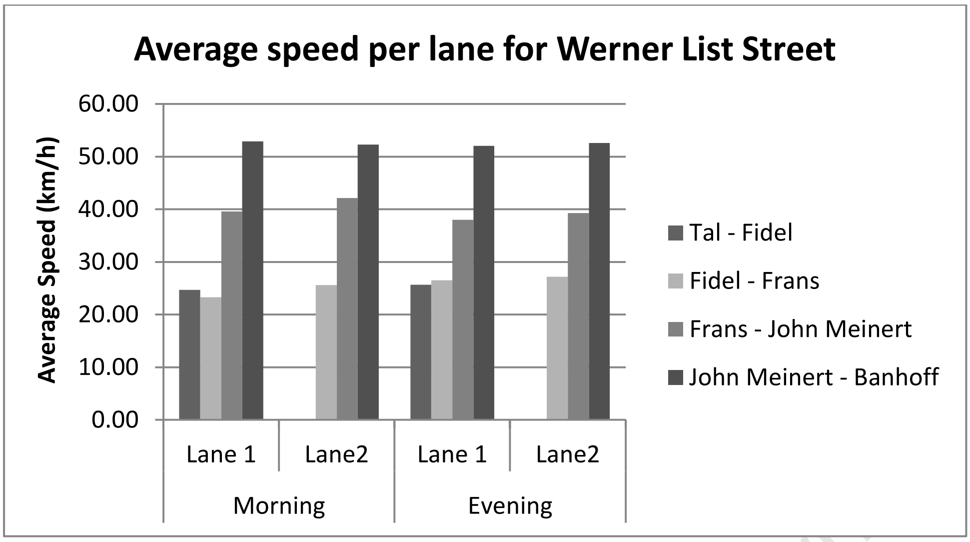


Figure 48: Average speed along Werner List Street

Figure 48 depicts the average traffic speeds along Werner List Street. The slow moving (23 km/hour) traffic of the link between Tal, Fidel Castro and Dr Frans Indongo streets for both morning and evening peak periods highlights the critical area of concern along Werner List Street.

4.6 Résumé

The traffic analysis of Werner List Street incorporates the assessment of Windhoek's activity system, the review the CBD base case traffic scenario specific to queue length build-up at Werner List Street's major intersections and the analysis the one-way conversion.

The Household Surveys (City of Windhoek, 2004) attended to income, trip-making and behavioural aspects of Windhoek. It was noted that the majority of private vehicle ownership is attributed to the affluent suburbs of Windhoek. Additionally, 40% of residents do not have access to private vehicles, resulting in a significant reliance on public transport.

Public transport usage (25%), as compared to its preferred use (38%) depicts the possibility present in attaining modal shift from private to the more productive, on average five passengers per trip, public transport. The accessibility and affordability of the varying modes needs, further, improvement to allow for the shift.

The City of Windhoek availed the CBD base case study to assess the CBD traffic network performance present, at the time (City of Windhoek, 2006c). Data, specific to Werner List Street, provided a basis from which to measure the performance of the one-way conversion. The assessment of queue length build-up, for both base and upgraded scenarios, depicted stress conditions at the west and east approaches of the Fidel Castro-Werner List intersection, and the western approach of the Dr Frans Indongo-Werner List intersection.

University of Cape Town

There is a general improvement in Werner List Street's traffic facilitation, with a significant queue length reduction experienced at the John Meinert-Werner List intersection. The western and eastern approaches of the Fidel Castro-Werner List intersection and the western approach of the Dr Frans Indongo-Werner List intersection remain areas of concern. Further, the link connecting Fidel Castro Street and Dr Frans Indongo Street experience high traffic volume, depicted by the low (23 and 28 km/hour) average speeds measured for both morning and evening peak periods.

University of Cape Town

Chapter 5. Discussion of Analysis

5.1 Overview

The economic impact that small middleweight cities will contribute to world development suggests that a greater focus is required to ensure the sustainable development of these cities. Transport facilitation for the growing urban population is a critical consideration when discussing sustainable development. This Chapter discusses the outcomes observed from the review of the Strategic Transport Master Plan (City of Windhoek, 2006a) and the analysis of the one-way conversion of Werner List Street.

Literature suggests that the preservation of future needs, within the context of current development, should dictate the policy formulation and its strategy implementation. Measuring current transport network capacity within cities forms a basis for the preservation of future traffic needs. Litman's (2012) assessment of traits that accompany current transport network and land-use development promotes the concept of either urban sprawl or smart growth. Urban sprawl primarily caters for the spatial expansion of urban infrastructure to accommodate a growing population while the smart growth concept promotes the innovative utilisation of existing infrastructure to service a growing population. Both options fall within the mandate of transport governing authorities and the choice is frequently based on the level at which the current demand stress affects the community in question's mobility.

In the urban context for developing cities, the current stresses require immediate solutions that sometimes undermine future development. Strategic planning with pragmatic micro implementation assessment is, therefore, required. Continual mobility provisions and planning, within confined areas, such as the Central Business District (CBD) of cities, form as measures of sustained development. United Nations studies suggest that a structured means to connect social and economic activities promotes sustained growth (UNCHS, 1996).

For small middleweight cities, the development of a well-structured transport network requires innovative techniques as funding restraints limit conventional methods. The notion of operational transport upgrades, therefore, takes an integral role in strategy preparation when assigning transport improvements to urban networks.

Operational upgrades to traffic flow involves the improvement of traffic controlling measures to accommodate growing traffic demand. Prevalent in CBD traffic networks, the aim is to improve traffic circulation utilising the existing infrastructure in a sustained manner. Innovative methods have been used around the world to promote the concept of improving the utilisation of the existing infrastructure with examples, such as Barcelona's space management (Barcelona Municipality, 2011) for urban delivery and Seattle's Signal Optimisation Program (City of Seattle, 2011).

University of Cape Town

Combinations of signal optimisation, lane prioritisation and forced directional movement are concepts linked to operational upgrades within CBD study areas. The constant assessment and consequential improvement to these methods receives limited attention. Key to the continual assessment of transport networks is the sustained financial support, be it via revenue generating processes or authority subsidisation, a constant support base for innovation and research allows for quantitative results from which strategic decisions can be made.

5.2 Transport Preservation in Windhoek

The City of Windhoek embarked on a Strategic Transport Master Plan (STMP) in 2006, aimed at improving transport circulation within the city as well as preserving the existing transport network such that it would cater to future traffic demand (City of Windhoek, 2006a). Key areas of focus were the operational improvements of the public transport system and an improved system of CBD traffic circulation.

In an interview conducted with the Chief Engineer for Planning, Design and Traffic Flow, it was evident that there was a significant underachievement regarding the milestones set in the STMP (Lisse, 2011). Transport network improvements received low priority listing during the past five year implementation phase; attributed to a lack of financial and regulatory support. It was, therefore, decided to focus on improvement methods that required low capital expenditure.

The one-way conversion of Werner List Street, linking traffic flow from the southern areas of Windhoek's CBD to the northern areas, formed the basis for CBD traffic circulation improvements. The assessment of the one-way conversion was conducted using visual inspections by the City's officials. To substantiate the visual assessment, this study adapted the conversion scenario to a micro simulation model utilising the raw data obtained during the CBD study of 2006. Measures of queue lengths, average speed and general driving behaviour as a result of the conversion were observed. Additionally, more detailed inspections of turning movements at major intersections along Werner List Street were conducted to validate the findings of the model.

Results from the micro simulation analysis provided the core understanding needed to address the questions posed in Chapter three that are relevant to Windhoek's transport development. The research questions focused on the influence that operational upgrades, primarily the one-way conversion of Werner List Street, had on the City of Windhoek's strategic direction. The areas identified to tackle the current policy implementation impasse aimed to improve CBD traffic circulation through the constant updating of the STMP using the analysis outputs.

5.3 Windhoek's Transport Scenario

Social and economic activities for households require adequate mobility facilitation in order to meet or surpass urban objectives for sustainable living. With the aim of understanding the effects that Windhoek's travel patterns have on CBD traffic circulation, particularly Werner List Street, an assessment of aspects that define Windhoek's mobility make-up was required. Studied aspects,

University of Cape Town

as analysed in Windhoek's Household Survey (2004), include transport accessibility, spatial distribution of mobility and modal preferences.

5.3.1 Transport Accessibility

The analysis of vehicle ownership and distribution, presented in Chapter four, depicts a large disparity between the middle to high income groups and the low income groups; private vehicle ownership for the former contributing a cumulative 87% of vehicle ownership with a total private vehicle ownership representation of 58%. Overall vehicle ownership and accessibility paint a picture of a potentially high public transport market with 40% of the commuting population having no access to private vehicle usage.

The cost of public transport significantly impacts the travel patterns of assigned to the population without access to private vehicles, assuming that a large proportion of the 42% low income group contribute in the majority to this population. With the majority (58%) of households receiving an annual income of N$ 42 000 (R42 000) or less, the cost to commute using public transport will significantly contribute to household expenditure. Affordable public transport provisions would benefit the low income areas of Katutura, Havanah and Okuruyangava, representing an average annual income of less than N$ 18 000 whilst contributing an employment range of between 55% and 67%.

5.3.2 Trip Characteristics

The 2004 Household Survey assessed trip purposes for both peak morning and evening periods of the day. In line with the interview held with the Chief Engineer for Planning, Design and Traffic Flow, the assessment produced results that defined a morning influx of commuters to places of social and economic activity (71.3%) and evening commuting back home (72%).

The modal split of produced trips depicts a heavy reliance (46%) on private vehicle usage, as compared to that of public transport (25%). Approximately 26% of trips are made by foot, representing a close proximity between origin and destination, prevalent with school children and employees living close to places of education and employment respectively.

Of interest is that the assessed vehicle occupancy for different modes of travel provided a view of how public transport promotes mass commuting. Comparatively, 44% of public transport trips provide transport of five passengers whereas only less than 10% of private vehicle trips provide the same number of passengers. Employer transport could further reduce the reliance on private vehicles as over 69% of trips transport six or more passengers at a time. Both employer and public transport would provide a drop and go service, reducing vehicle volumes and the need to avail parking areas within prime development land, such as the CBD.

University of Cape Town

5.3.3 Modal Preference

Accessibility and affordability are the major reasons assigned to Windhoek's current modal split. With a low level of satisfaction (23%) further assigned to the service provided by public transport, an effort to improve the existing service should form the core focus of Windhoek's transport development strategy.

Phase 2 of the STMP (2006) aimed at developing a strategy that would cater to increase the influence of a more efficient public transport system. The quality aspect offered by the existing transport setup contributes significantly (14%) to the mode choice used, where private vehicles constitute a high volume. An improved perception and awareness campaign would help distribute the spatial configuration of public transport.

The studied and perceived shortcomings of the existing transport system provided the basis for the analysis with three research questions developed to further understand the effects of the recommended and implemented improvements to Windhoek's Transport Network.

5.4 Base case study

The City of Windhoek embarked on assessing the CBD traffic network's performance to attain a base study (City of Windhoek, 2006c); setting a benchmark for future studies. The study of Windhoek's activity system, through the study of the Household Survey (2004) and the STMP (2006), provided the required background information and data to assess obtained results. The research focused on areas along Werner List Street, identifying queue length build-up for the major intersections; Fidel Castro Street, Dr Frans Indongo Street and John Meinert Street.

The provided data indicated high queue length levels at the eastern and western approaches of the Fidel Castro-Werner List intersection, and the western approaches of the Dr Frans Indongo-Werner List intersection and the John Meinert-Werner List intersection. The assessment of queue lengths after the implementation of the one-way conversion provided a platform to assess operational upgrades.

5.5 Assessment of Werner List Traffic

The data gathered from the micro simulation of Werner List Street's traffic scenario provided information on critical queuing points along Werner List Street and average speeds for morning and evening peak periods. Visual inspection readings substantiated traffic build-up along Werner List Street and queue length readings at the three major intersections.

A general trend found at the Fidel Castro-Werner List intersection was that for the first the 30 minutes of the simulation queue lengths of on average 30 meters were experienced for all approaches. The queuing would increase to 70 and 80 meters, as witnessed for the western southern approaches, for both the morning and evening periods. The queue lengths recorded for the lane (Lane 1) dedicated to turning into Werner List Street, at the Fidel Castro intersection,

University of Cape Town

were on average higher than the inside through lane (Lane 2); similarly, Lane 2 (dedicated Werner List Street turn) of the eastern approach recorded higher queue length averages.

The highest recorded queue length averages were those of the western and southern (along Werner List Street) approach to the Dr Frans Indongo-Werner List intersection. Queue lengths of between 80 and 100 meters were recorded at a higher frequency for the last 30 minutes of the simulation. The John Meinert-Werner List intersection experienced low queuing lengths relative to the results obtained for both the Fidel Castro and Dr Frans Indongo intersections, averaging just below 20 meters queue lengths at sparsely separated time intervals.

In contrast, results from the visual inspection, depicted a gradual rise in average queue lengths during the morning and evening peak periods. The queue length levels were, for the most part, similar to the simulation results and substantiated the improved network performance. A significant reduction in average queue lengths was measured for all approaches leading to the John Meinert-Werner List intersection.

The validation of traffic flows was conducted using the GEH statistic calculation, as defined by the DMRB (1997). Results provided values of 4.15 and 3.23 for the morning and evening peak traffic hours, within the required GEH value of 5.

Average speeds of between 20 and 30 km/hour were recorded for the links between Fidel Castro Street and Dr Frans Indongo Street. Investigating the traffic scenario at the entry points would provide further understanding of the stress areas for the entire CBD traffic network.

The critical areas of concern, for Werner List Street, are the western and eastern approaches of the John Meinert-Werner List intersection and the western approach of the Dr Frans Indongo-Werner List intersection.

University of Cape Town

Chapter 6. Conclusion and Recommendations

6.1 Conclusion

The sustainable development of existing urban transport network aims to improve and preserve the efficiency of urban transport systems. Due to financial constraints and limited institutional support the slow implementation of transport provisions is prevalent in a growing urban setup, a scenario more prevalent in small middleweight cities. The availing of transport provisions through innovative means and guided by concepts described as Smart Growth (Litman, 2006) is a possible direction small middleweight cities can adopt in the quest for development.

Small middleweight cities, as defined by McKinsey Global Institute (2011), are estimated to contribute 19% of the world's economic growth by 2025. The implementation of strategies that promote efficient use of transport facilities will require greater attention in order to accommodate this economic growth.

Windhoek, by population size, may be categorised as a small middleweight city. As the economic and financial capital of Namibia (Bravenboer, 2004), the facilitation of the population's mobility plays an integral role in the city's sustained development goals (City of Windhoek, 2006a). Windhoek's current CBD transport network is estimated to reach full capacity by 2015 (Lisse, 2011); measures to preserve the current efficiency have been proposed in the Strategic Transport Master Plan.

The City of Windhoek provided a base case CBD study to assess the existing traffic scenario (City of Windhoek, 2006c). Queue lengths were measured at 36 major intersections, including those connected to Werner List Street. The obtained output data, primarily focusing on queue length measurements, set the basis to measure the simulation outputs of the one-way conversion of Werner List Street, as analysed in Chapter four.

The one-way conversion of Werner List Street, from the Fidel Castro Street intersection to that of Banhoff Street, formed part of the CBD network's development strategy. The assessment of performance measures, such as queue lengths and average speeds aimed to identify critical stress areas along the street.

The objective of this dissertation was to investigate the effect that operational transport upgrades had on Windhoek's CBD transport circulation. The key focus was on the implementation of the one-way conversion of Werner List Street as a result of the Strategic Transport Master Plan (City of Windhoek, 2006c). As assessed along Werner List Street and at the three major intersections, the one-way conversion generally improved the network performance. Queue length measurements indicated a length reduction at the major intersections; however, the Fidel Castro-Werner List and Dr Frans Indongo-Werner List intersections require additional improvements to accommodate the current traffic scenario. The John Meinert-Werner List

University of Cape Town

intersection experienced significant queue length reductions in comparison to the base study, and more specific to the western approach.

In light of the research undertaken, the analysis sought to answer three research questions that were proposed in Chapter three.

Does the City of Windhoek's Strategic Transport Master Plan primarily cater to operational upgrades in its improvement methodology?

The proposals identified in the City of Windhoek's Strategic Transport Master Plan (City of Windhoek, 2006) primarily aimed at assessing current, at that time, transport stress whilst accommodating future traffic demand using 2010, 2015 and 2050 study horizons. Phase 1 focused, in conjunction with the Household Survey of 2004, on Windhoek's transport activity. Phase 2 assessed the effects of incorporating an integrated transport system by increasing the influence of public transport. Phase 3 studied the effects of an improved CBD transport system by upgrading the network's attributes that increased traffic circulation and reduced vehicle volumes.

A constant theme within the three studies was the accommodating of a growing transport demand as opposed to accommodating the growing vehicle volumes. Aspects, such as the decentralisation of social and economic activities from the then centre of the CBD, the utilisation of a more inclusive public transport system and the emphasis on the upgrading of traffic controlling functions formed the basis of the three phase study.

Improvements to the transport network included the discussed one-way conversion of Werner List Street, the demarcation of routes that would promote a ring route setup around the CBD, the facilitation of replacing five-seated taxis with mini-bus taxis and the physical expansion of Sam Nujoma drive to accommodate more vehicles along the CBD boundary.

Due to the financial limitations assigned to new developments, the City of Windhoek's transport department chose to prioritise improvements that aimed at preserving the existing network and accommodating future traffic demand whilst requiring low capital expenditure (Lisse, 2011). The implementation of the one-way conversion of Werner List Street is the upgrade presented in the STMP (2006) and may be viewed as an improvement resulting from the inadequate funding available for transport improvements.

It can be concluded that the theme of accommodating the transport demand suggests a strategy focused on developing Windhoek's transport network. The proposed techniques primarily focus on operational improvements with limited infrastructure expansion required during the implementation phase.

University of Cape Town

Do operational upgrades, alone, improve traffic circulation within the Windhoek's CBD?

The assessment of Werner List's one-way conversion focused on performance measures that effect traffic circulation and identified the areas along Werner List Street that hampered circulation. It was noted that the CBD experiences an aggregate traffic inflow during the morning period and an aggregate traffic outflow during the evening period, accommodating north bound traffic across the CBD. A reduction in impedance levels is, therefore, required to accommodate the aggregate traffic flow for the two peak periods.

Seeing that the proposed Network Continuity and Ring Route implementation failed to materialise, the one-way conversion of Werner List Street forms the only basis from which to assess the performance of Windhoek's operational upgrades.

Chapter four identified commuting demand originating from the west and south of Windhoek and entering Werner List Street through the western and eastern approaches of Fidel Castro Street and Dr Frans Indongo Street.

The net effect, for Werner List Street, is a high volume traffic scenario for the section of the Werner List Street linking Fidel Castro and Dr Frans Indongo streets. The measure of queue lengths for each of the adjoining intersections' legs (western and eastern approaches), as well as the average traffic speed along the link between Fidel Castro and Dr Frans Indongo depicts an area requiring further attention.

Attending to the implementation of the network continuity and ring route improvements in conjunction with one-way conversion would possibly reduce the vehicle volumes entering the CBD network, hence reducing the queue formation at the relevant stress areas of Werner List Street. The impedance experienced at both the Fidel Castro-Werner List and Dr Frans Indongo-Werner List intersections limits the success achieved by the one-way conversion.

The queue length formation at intersections, identified in the base study (City of Windhoek, 2006c), requiring attention reduced after the implementation of the one-way conversion of Werner List Street, with significant reduction experienced at the John Meinert-Werner List intersection.

It may be concluded that the sole implementation of the one-way conversion improved the overall network stress areas. The discussed queue length build-up, however, requires additional attention and thus the assessment of a wholesome upgrade scenario (inclusive of ring route formation) can better represent operational upgrades.

Can assessment outputs, obtained from traffic modelling, provide a basis to direct and update the implementation of the STMP's (2006) methodology?

Though part of the STMP (2006), the implemented one-way conversion of Werner List Street may be viewed as a reactive measure, due to the lack of available funding for the implementation of

University of Cape Town

alternate upgrade methods (Lisse, 2011). The assessment of the improvement, however, provides a benchmark for the network's further improvements.

The only assessment conducted prior to this dissertation, was that of visual inspections by the city authorities (Lisse, 2011). A statistical assessment, such as traffic simulation and modelling, of stress areas could provide analytical data to support future arguments in sourcing the necessary funds to improve the network's development.

The identification of the stress areas within the network, i.e. the Fidel Castro-Werner List and Dr Frans Indongo-Werner List intersections, tunnels the areas requiring immediate attention in order to improve traffic circulation with Windhoek's CBD. Queue length formation is most critical at the two intersections' western approaches with the connecting link experiencing low average speeds.

It is with this thought in mind that outputs generated from traffic modelling substantially assist in identifying areas requiring improvement within the assigned strategy domain. The analysis of Werner List Street provided output information on areas requiring further attention. This information may be used to support the implementation of the improvements, such as ring route formation, aimed at reducing traffic volumes and in turn queue lengths. It may, therefore, be concluded that modelling outputs can provide a basis for directing the STMP (2006).

6.2 Recommendations

6.2.1 Implementation of Strategic Transport Master Plan

The STMP's (2006) three phase report details the methodology required to accommodate Windhoek's growing transport demand. With key focuses on making provisions for a more inclusive public transport sector influence and an improved CBD traffic circulation scenario, the STMP aimed to outline a framework for sustainable transport network development. Currently, only one of the proposed network upgrades has been implemented. Institutional support in areas requiring pragmatic implantation, from a financial and regulatory point of view, has been lacking.

The primary concern for CBD traffic is the estimated growth in vehicle volumes commuting the CBD network during peak periods of the week. The stagnate nature of the network's upgrade strategy, in effect, creates a transport facilitation shortage, thereby reducing the efficiency of mobility in critical areas of commuting such as Werner List Street. Institutional support is, therefore, imperative to achieving the objectives set out in the STMP.

Consideration should additionally be assigned to the implementation of improvements that occur outside of the CBD network that significantly influence CBD circulation. The reduction of vehicle volumes within the CBD by making external (from the CBD network) provisions for through traffic performs the required duty. A detailed investigation into the proposed lane expansions at critical bottle-neck areas and ring routes implementation should be conducted.

University of Cape Town

Improved public transport penetration and regulation is required. The low level of preference ascribed to the utilisation of the bus service has been assigned, for the majority, to unawareness and the inaccessibility of the service. Further, the sedan taxi service has received criticism for its disorganisation and disregard of traffic regulations. Provisions for the following should form part of a detailed study:

- Dedicated bus and taxi lanes within the CBD and at peak flow periods.
- Improved real estate (shopping malls) development designs to incorporate taxi pick-up and drop-off points at strategic entry/exit points.
- A penetrative bus service with increased frequency during peak periods accommodating the commuting to/from areas of social and economic importance.

6.2.2 Data Updating and Network Monitoring

A continuous update of Windhoek's CBD traffic scenario provides a platform to promote the implementation of congestion preventative measures. The constant monitoring of the identified stress areas within Windhoek's transport network has been minimal, since the inception of the STMP (2006). Visual inspections are the current *modus operandi* for monitoring the entire network, offering limited quantitative information and requiring a large human contingent.

Advancements in modern technology reduce the need to attach large a human resource portfolio to the network monitoring process with the possibility of acquiring both static and dynamic information at different positions for multiple periods of the day. Examples of such technology include:

- *Lane occupancy detectors:* Used to measure lane occupancy during each signal cycle. Over time, the statistics may be used to depict the level of stress present at major intersections (Follmer and Ream, 2008).
- *Tolltag AVI Transponders:* Through the transferring of antenna readings to a central controller, speed measurements can be measured at varying points along a street (Follmer and Ream, 2008).

The mentioned techniques can be used in conjunction with visual inspection to assess the network's performance level. The quantitative nature of results obtained from modern technology may provide support to encourage a more aggressive institutional influence on the proposed improvements to Windhoek's CBD network.

6.2.3 Operational Upgrades

The one-way conversion of Werner List Street represents the implementation of a relatively inexpensive transport upgrade as compared to infrastructure upgrades. The current level of performance along Werner List Street accommodates the existing peak traffic. There are, however, areas of concern where intersection queue lengths are longer than expected and average speed readings depict slow moving traffic. These measurements support the concerns

University of Cape Town

aired by the Chief Engineer for Planning, Design and Traffic Flow (Lisse, 2011) that Windhoek's CBD network will struggle to accommodate the growing traffic demand by 2015.

A detailed study into the influence that external (outside the CBD) upgrades have on the traffic scenario of the current capacity of Werner List Street could possibly limit the queuing present at the Fidel Castro-Werner List and Dr Frans Indongo-Werner List intersections.

The recommended improvements to, and constant monitoring of Windhoek's traffic network requires an effective institutional drive from a financing, regulatory and implementation point of view. The current STMP (2006) implementation rate suggests that a low level of prioritisation is assigned to recommended upgrades. The incorporation of modern technology, for monitoring purposes, should provide statistical support to implementing the measures set out in the STMP (2006).

University of Cape Town

Chapter 7. References

Akcelik, R. (1980), *Time-dependent expressions for delay, stop rate and queue length at traffic signals,* Australian Road Research Board, Australia

Baraster, D. and Berechman, Y. (2000). *The economic development effects of transport investments*, Paper presented at the TRANS-TALK Workshop, Brussels, Belgium. November 2000

Barcelona Municipality (2011) *Street management improvements for loading/unloading enforcement* (SMILE) www.eltis.org/studies/121E.HTM Accessed March 2012

Bravenboer B. (2004), *Windhoek capital of Namibia*. Gamsberg Macmillan, Windhoek, Namibia

Brockerhoff, M. and Brennan, E. (1998), *The poverty of cities in developing regions*, Volume 24, Issue 1. Population Council Article, Internet: www.jstor.org/stable/2808123, Accessed February 2012

Bultynck, P. (1998), *Urban transport policy: a sustainable development tool,* Proceedings of CODATU VIII Conference, The Sub-Saharan Africa Transport Policy Program (SSATP): Urban transport component. Rotterdam, Netherlands

Calthorpe, P (2002), *The urban network: a framework for growth*, Calthorpe and Associates www.calthorpe.com/publications/urban-network-new-framework-growth, Accessed January 2012

City of Seattle. (2011), *Traffic signal optimisation program,* www.seattle.gov/transportation/signaloptimization.htm, US Department of Transport, Accessed on 12 March 2012

City of Windhoek. (1995), *Projected figures: Statistics from the 1995 residency survey,* www.windhoekcc.org.na/repository/About%20the%20City/Population%20in%20Windhoek.pdf, Windhoek, Namibia: City of Windhoek Municipality, Accessed on 05 August 2011

City of Windhoek. (1996), *The windhoek structure plan,* Windhoek, Namibia

City of Windhoek. (2004), *Household survey report,* Windhoek, Namibia

City of Windhoek. (2006a), *Transportation land-use study: a regional model,* Windhoek, Namibia

City of Windhoek II. (2006b), *Strategic land-use study* Windhoek, Namibia

City of Windhoek III. (2006c), *Central business district traffic network study,* Windhoek, Namibia

Dierks, K. (2005). *A chronological history of Namibia*, www.klausdierks.com/FrontpageMain.html Accessed on 10 August 2011

University of Cape Town

DMRB (1997). *Traffic appraisal for road schemes,* Design Manual for Roads and Bridges, Volume 12, Department of Transport, United Kingdom, *http://www.dft.gov.uk/ha/standards/dmrb/vol12/section1/12s1p1.pdf* Accessed November 2012

European Transport Safety Council, (1999), *Police enforcement strategies to reduce traffic casualties in Europe,* Rue du Cornet, Brussels, Belgium

Farah (2010), *Toward an integrated transport policy: institutions, infrastructure and logistics – the case in Chile,* www.cepal.org/usi/noticias/bolfall/0/41570/FAL-282-WEB-ENG.pdf, Accessed January 2012

Federal Highway Administration. (2008), *Traffic signal timing manual,* US Department of Transportation, Maryland, Texas, US

Follmer, R. and Ream, J. (2008), *Performance measures for traffic signal operations: final report,* Felsburg Holt and Ullevig Consultants, Denver Regional Council of Governments, Denver, Colorado, US

Giannopoulos, G. A. (2005), *Main transport challenges in south eastern Europe, after enlargement,* Hellenic Institute of Transport, Aristotle University of Thessaloniki, Greece

Goldman, T. and Gorham, R. (2006) *Sustainable urban transport: four innovative directions*. CUNY Institute for Urban Systems, City College of New York, New York, USA

Hodgson, G. M. (2006), *What are institutions?* Journal of Economic Issues, Volume XL Issue 1, New Mexico, US

Hoogendoorn S, Hegeman, G. Dijker, T. (1985), *Traffic flow theory and simulation,* Delft, Faculty of Civil Engineering and Geosciences, Delft University, Netherlands

Jinyuan L, Xin P and Xiqin W. (2007), *State-space equations and the first-phase algorithm for signal control of single intersections,* Department of Electronic Engineering, Tsinghua University, Beijing 100084, China

Kane, L. (2002), *The urban transport problem in south africa and the developing world: a focus on institutional issues*, Faculty of Engineering and the Built Environment, Department of Civil Engineering, University of Cape Town (SA), Working Paper

Kane, L. (2000), *Institutional initiatives in the developing world: a review of the 1990's,* 20th South African Transport Conference South Africa, 16 – 20 July 2001

Koukoumidis E, Peh L. and Martonosi M. (2011), *Signalguru: leveraging mobile phones for collaborative traffic signal schedule advisory*, Princeton University, New Jersey, US

University of Cape Town

Lisse, H. (2011), Interview. Chief Engineer, Planning, Design and Traffic Flow: City of Windhoek Municipality, June 2011

Litman, T. (2006), *Issues in sustainable transportation,* Victoria Transport Policy Institute, Victoria, Canada

Litman,T. (2010), *Planning Principles and Practices,* Victoria Transport Policy Institute, Victoria, Canada

Litman, T. (2012), *Evaluating public transit benefits and costs,* Victoria Transport Policy Institute, Victoria, Canada

Liu, J. Pan, X. Wang, X. (2007), *State-space equations and the first-phase algorithm for signal control of single intersections,* Department of Electronic Engineering, Tsinghua University, Beijing, China

Manheim, M.L. (1979), *Fundamentals of transportation systems analysis*, MIT Press, Cambridge, Massachusetts, US

Map of Windhoek Central Business District. en.wikipedia.org/wiki/File:Karte_Windhoek-Central.png Accessed January 2012

Map of Windhoek Surroundings, www.namibian.org/travel/lodging/private/okapuka.htm Accessed February 2012

McKinsey Global Institute (2011), *Urban world: mapping the power of cities,* McKinsey and Company, Washington DC, US

McNally, M. (2007), *The four step model,* Irvine, Department of Civil and Environment Engineering, University of California, US

Montgomery, M. (2009), *Urban poverty and health in developing countries*, Population Bulletin 64, Issue 2, Population Reference Bureau, Washington DC, US

Morgan, G. (1997), *Images of organization*, Sage Publications, California, US

Mulley, C., Nelson, J.D. and Nielsen, G. (2005), *Network planning for high quality public transport,* 9th Thredbo Conference on competition and ownership in land transport, Thredbo, New South Wales, Australia

Namwandi, T. M. (2011), *Promotion of public transport in Windhoek*, Masters Degree Thesis, School of Natural Resources and Tourism, Polytechnic of Namibia, Windhoek, Namibia

National Planning Commission (NPC) (2012), *Namibia 2011 population and housing census,* National Planning Commission, Windhoek, Namibia

University of Cape Town

New and Innovative Concepts for Helping European Transport Sustainability. Innovative urban transport concepts*,* www.niches-transport.org/index.php?id=155, Accessed February 2012

OECD (2002), *Impact of transport infrastructure investment on regional development,* OECD publication, France

Perold, A. D. Anderson, S. (2005), *An appropriate strategic modelling approach for South Africa,* South African Transport Conference, Pretoria, South Africa

Phu N. T. (2003), *Value capturing: a realistic funding source for urban transportation in ho chi minh city*, School of Industrial Management, Ho Chi Minh City University of Technology, Vietnam

Purandare J. and Pandurangi A. (2008), *Urban transport financing: a strong case for public private partnership,* PricewaterhouseCoopers, Mumbai, India

Quadstone (2012), Paramics 6.7 modeller user guide manual, Quadstone, Edinburgh, Scotland

Robertson D. I, Bretherton R. D. (1991), *Optimizing networks of traffic signals in real-time: the scoot method*, Vehicular Technology Centre, Wokingham, United Kingdom

Runji J. (2003), *Road sector reform in Namibia*, Paper presented at the Senior Road Executive seminar, Pretoria, South Africa

Schick, T. Vaughn, L (2002), *How to think about weird things: critical thinking for a new age,* Boston, US

Slinn, M. Matthews, P. Guest, P. (2005), Traffic engineering design: principles and practice, Elsevier Butterworth Heineman, UK

Smith, J. Blewitt, R. (2010), *Traffic modelling guidelines,* Transport for London, London, UK

Southern African Cities Network (2011), *The financing of city services in southern Africa,* Johannesburg, South Africa

Schalenkamp H, Berhens R. and Wilkinson P. (2010), *Regulating mini-bus taxis: a critical review of progress and a possible way forward*, Faculty of Engineering and the Built Environment, Department of Civil Engineering, University of Cape Town, South Africa

Saxena, A. (2001), *Monitoring of urban infrastructure in cities and its fringe areas through remote sensing,* Architecture and Planning Department, Maulana Azad College of Technology, Bhopal, India

SADC (2001), *Regional transport challenges within the southern african development community and their implications for economic integration and development,* www.tralac.org/wp-

University of Cape Town

content/blogs.dir/12/files/2011/uploads/MRI2008Chapter2Mutambara.pdf, Accessed: January 2012

UNDESA (2009), *World urbanization prospects,* United Nations, New York, US

UNDESA (2010), *Rethinking poverty*, Report on the world social situation, United Nations, New York, US

United Nations (1996), *An urbanizing world: global report, World urbanisation population* UNCHS, United Nations, New York, US

Vanderschuren, M. (2006), *Intelligent transport systems for South Africa,* University of Cape Town, Cape Town, South Africa and University of Twente, Enschede, Netherlands

Watson, B.P. (1977), *A bus service for Windhoek*, Town Planning Division: City of Windhoek, Windhoek, Namibia

Webster F V. (1958), *Traffic signal settings,* Road Research Technical Paper Number 39, London, UK

Wegener, M. (2005), *Overview of land-use transport models*, Handbook in Transport, Volume 5: Transport, Geography and Spatial Systems pg 2 – 3. United Kingdom

World Bank (2002), *Cities on the move, a world bank urban transport strategy review,* Washington DC, US

World Bank (2002), *Upgrading of low income settlements: country assessment report*, web.mit.edu/urbanupgrading/upgrading/case-examples/overview-africa/country-assessments/reports/namibia-report.html, Accessed March 2012

World Commission on Environment and Development (1987), *Our common future*, United Nations, Oxford University Press, New York

WHO, (2010), *Joint fao/who expert committee on food additives*, United Nations Food and Agriculture Organisation, Rome, Italy

WHO, (2004), *World report on road traffic injury prevention: summary,* WHO Library Cataloguing-in-Publication Data, Geneva, Switzerland

Wuppertal Institute for Climate, Environment and Energy (2005), *Sustainable transport – solutions for a growing demand*. Promotion of Resource Efficiency Projects, Wuppertal, Germany

Zegras, C (2006), *Sustainable transport indicators and assessment methodologies*, Background Paper Plenary Session 4, Biannual Conference and Exhibit of the Clean Air Initiative for Latin American cities, Sao Paulo, Brazil

University of Cape Town

Zegras, C (2003), *Financing transport infrastructure in developing country cities: evaluation of and lessons from the nascent use of impact fees in Santiago de Chile*, Paper presented at the Transportation Research Board, Washington DC, US

Zuidgeest, M. and van Maarseveen M. (2000), *Transportation planning for sustainable development*, Traffic and Transportation Management, Department of Civil Engineering and Management, University of Twente, Enschede, Netherlands

University of Cape Town

APPENDICES

APPENDIX A: INTERVIEW QUESTIONS WITH CHIEF ENGINEER: TRANSPORT DEPARTMENT

APPENDIX B: ORIGIN – DESTINATION MATRICES

APPENDIX C: CITY OF WINDHOEK SIGNAL SEQUENCE

University of Cape Town

Appendix A

INTERVIEW QUESTIONS WITH CHIEF ENGINEER: TRANSPORT DEPARTMENT

University of Cape Town

Appendix B

ORIGIN – DESTINATION MATRICES

University of Cape Town

Appendix C

CITY OF WINDHOEK SIGNAL SEQUENCE

Source: City of Windhoek, 2010

University of Cape Town

Appendix B: Origin-Destination Matrices

Zone List

Zone 1 – Entrance at Tal Street
Zone 2 – Entrance at Fidel Castro Street East
Zone 3 – Entrance at Fidel Castro Street West
Zone 4 – Entrance at Dr Frans Indongo Street East
Zone 5 – Entrance at Dr Frans Indongo Street West
Zone 6 – Entrance at John Meinert Street East
Zone 7 – Entrance at John Meinert Street West
Zone 8 – Entrance at Banhoff Street East
Zone 9 – Entrance at Banhoff Street West
Zone 10 – Post Street Mall East
Zone 11 – Sanlam Complex Parking
Zone 12 – Defence Force Parking
Zone 13 – Shoprite Complex Parking
Zone 14 – Post Street Mall West

Morning Peak Period

	z 1	z 2	z 3	z 4	z 5	z 6	z 7	z 8	z 9	z 10	z 11	z 12	z 13	z 14	Total
zone 1	0	36	113	0	121	126	16	2	0	30	9	83	5	0	**572**
zone 2	107	0	492	0	97	0	209	0	23	115	36	21	6	0	**1106**
zone 3	134	217	0	0	121	88	96	14	0	124	45	3	12	0	**854**
zone 4	0	0	0	0	233	0	116	0	0	0	0	0	31	0	**380**
zone 5	0	0	0	0	0	136	512	16	0	0	0	0	59	0	**723**
zone 6	0	0	0	0	0	0	630	0	18	0	0	0	0	0	**648**
zone 7	0	0	0	0	0	405	0	40	0	0	0	0	0	0	**445**
zone 8	0	0	0	0	0	0	0	0	168	0	0	0	0	0	**168**
zone 9	0	0	0	0	0	0	0	142	0	0	0	0	0	0	**142**
zone 10	0	0	0	0	15	0	3	14	0	0	0	0	0	56	**88**
zone 11	0	0	0	0	3	0	0	0	0	0	0	0	0	0	**3**
zone 12	13	6	13	0	0	0	0	0	0	0	0	0	0	0	**32**
zone 13	0	0	0	0	0	3	2	4	0	0	0	0	0	0	**9**
zone 14	0	0	0	0	0	0	0	0	0	127	0	0	0	0	**127**
Total	**254**	**259**	**618**	**0**	**590**	**758**	**1584**	**232**	**209**	**396**	**90**	**138**	**113**	**56**	**5297**

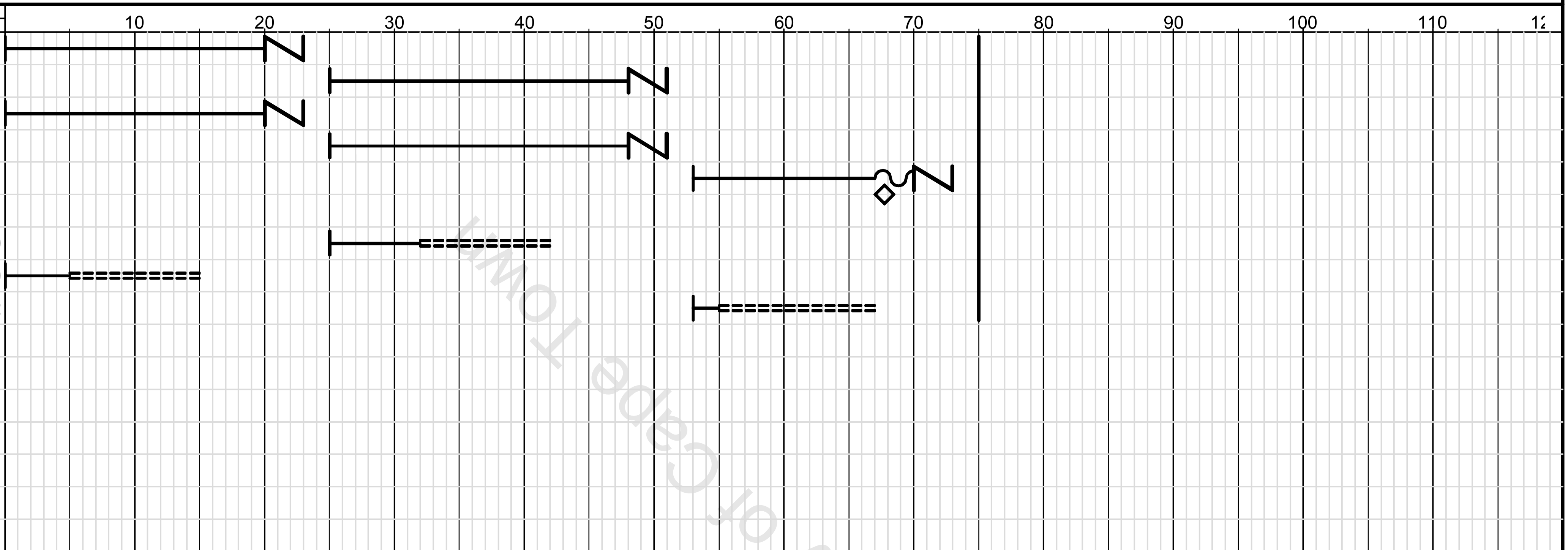
University of Cape Town

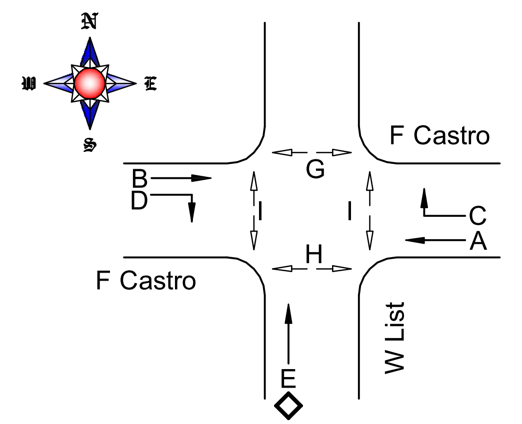
Evening Peak Period

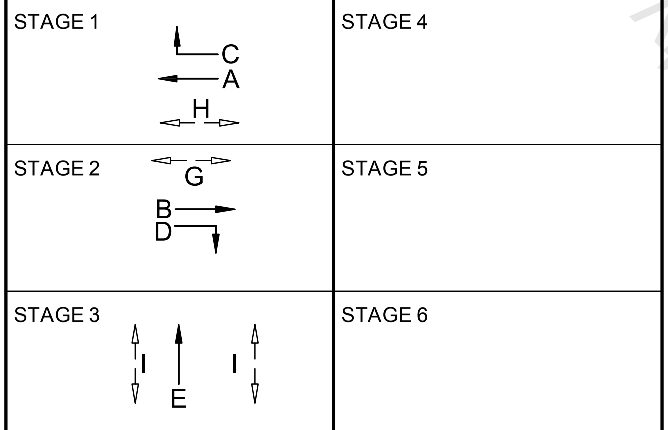
	z 1	z 2	z 3	z 4	z 5	z 6	z 7	z 8	z 9	z 10	z 11	z 12	z 13	z 14	Total
zone 1	0	91	173	0	178	94	12	2	0	15	0	5	0	0	**570**
zone 2	49	0	346	0	198	0	157	0	26	21	10	3	0	0	**810**
zone 3	40	478	0	0	142	90	72	8	0	21	8	0	0	0	**859**
zone 4	0	0	0	0	314	0	126	0	0	0	0	0	4	0	**444**
zone 5	0	0	0	0	0	80	301	10	0	0	0	0	4	0	**395**
zone 6	0	0	0	0	0	0	302	0	66	0	0	0	0	0	**368**
zone 7	0	0	0	0	0	416	0	29	0	0	0	0	0	0	**445**
zone 8	0	0	0	0	0	0	0	0	221	0	0	0	0	0	**221**
zone 9	0	0	0	0	0	0	0	292	0	0	0	0	0	0	**292**
zone 10	0	0	0	0	33	51	71	3	0	0	0	0	0	288	**446**
zone 11	0	0	0	0	36	31	56	2	0	0	0	0	0	0	**125**
zone 12	112	25	14	0	12	14	10	0	0	0	0	0	0	0	**187**
zone 13	0	0	0	0	0	26	42	20	0	0	0	0	0	0	**88**
zone 14	0	0	0	0	0	0	0	0	0	10	0	0	0	0	**10**
Total	**201**	**594**	**533**	**0**	**913**	**802**	**1149**	**366**	**313**	**67**	**18**	**8**	**8**	**288**	**5241**

University of Cape Town

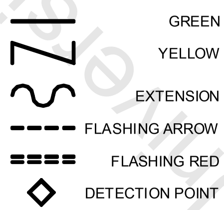
SIGNAL GROUP	TIME MIN	TIME MAX
A	20	20
B	23	23
C	20	20
D	23	23
E	14	17
G	7	+10
H	5	+10
I	2	+12







LEGEND



Intersection phasing plan:

Plan Type	Day type	Time	Cycle
Night (4)	0	20:00 to 06:30	50
	13	06:30 to 20:00	50
Inbound (1)	11	06:30 to 08:30	75
Off Peak (2)	11	08:30 to 12:45	60
Outbound (3)	11	12:45 to 13:30	75
Inbound (1)	10	13:30 to 14:15	75
Off Peak (2)	10	14:15 to 16:30	60
Outbound (3)	10	16:30 to 18:00	75
Off Peak (2)	11	18:00 to 20:00	60
Off Peak (2)	7	13:30 to 18:00	60

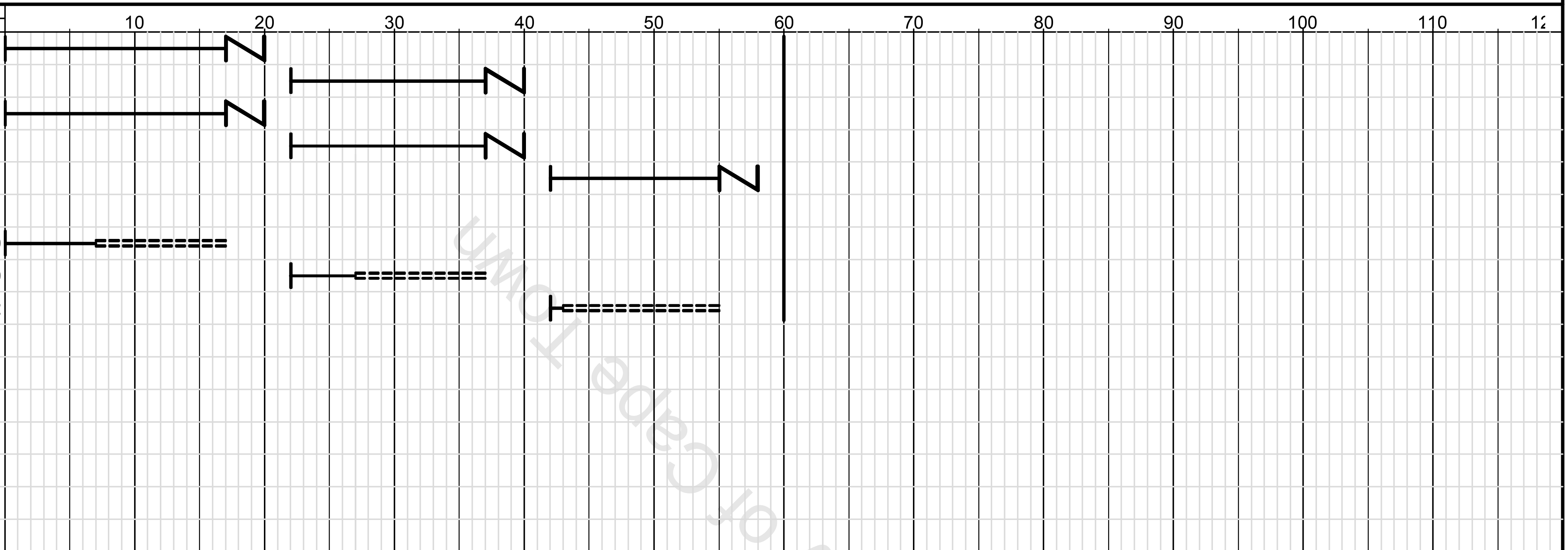
Day types as follows: 0 = Every Day including Holidays; 1 = Sundays; 2 = Mondays; 3 = Tuesdays; 4 = Wednesdays; 5 = Thursdays; 6 = Fridays; 7 = Saturdays; 8 = Holidays; 9 = Monday to Thursday; 10 = Monday to Friday; 11 = Monday to Saturday; 12 = Every Day except Holidays; 13 = Holiday or Sunday.

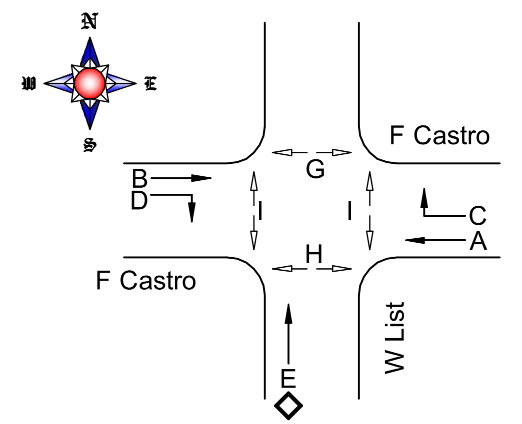
Transportation Planning,
Design & Traffic Flow Division

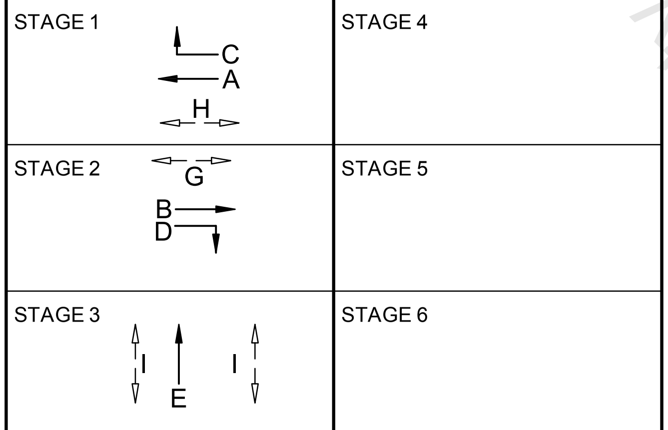
DRAWN: HW Lisse	PLAN NO: 1 of 4 (Revision 1)	MODE OF OPERATION	INTERSECTION: F CASTRO / W LIST
DATE: APR 2010	CYCLE: 75 s	Semi VA refer to F Castro	
DRAWING: Castro/List P1	PLAN NAME: Inbound		INTERSECTION NO: 1011
DESIGN: HW Lisse	OFFSET: 34 s		

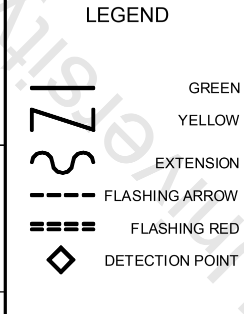
University of Cape Town

SIGNAL GROUP	TIME MIN	TIME MAX
A	15	15
B	17	17
C	15	15
D	17	17
E	13	13
G	7	+10
H	5	+10
I	1	+12









Intersection phasing plan:

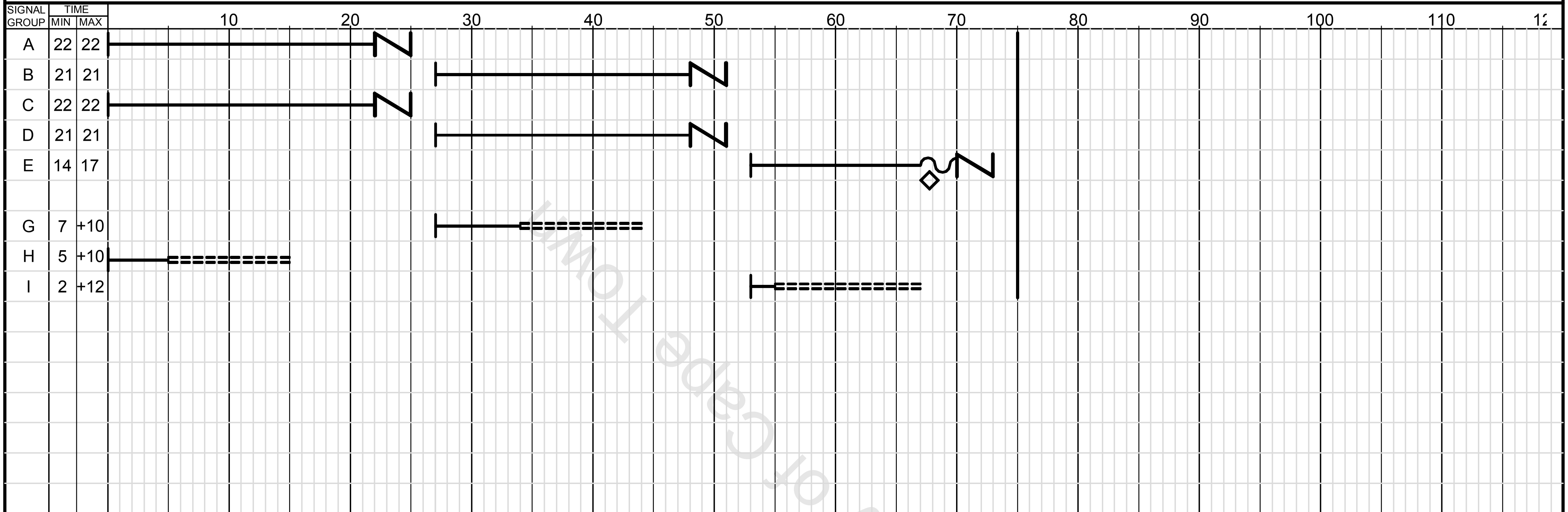
Plan Type	Day type	Time	Cycle
Night (4)	0	20:00 to 06:30	50
	13	06:30 to 20:00	50
Inbound (1)	11	06:30 to 08:30	75
Off Peak (2)	11	08:30 to 12:45	60
Outbound (3)	11	12:45 to 13:30	75
Inbound (1)	10	13:30 to 14:15	75
Off Peak (2)	10	14:15 to 16:30	60
Outbound (3)	10	16:30 to 18:00	75
Off Peak (2)	11	18:00 to 20:00	60
Off Peak (2)	7	13:30 to 18:00	60

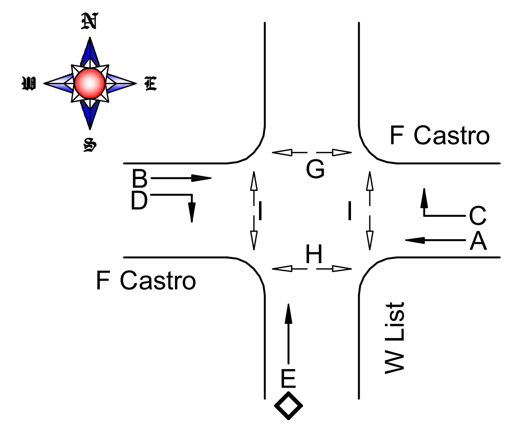
Day types as follows: 0 = Every Day including Holidays; 1 = Sundays; 2 = Mondays; 3 = Tuesdays; 4 = Wednesdays; 5 = Thursdays; 6 = Fridays; 7 = Saturdays; 8 = Holidays; 9 = Monday to Thursday; 10 = Monday to Friday; 11 = Monday to Saturday; 12 = Every Day except Holidays; 13 = Holiday or Sunday.

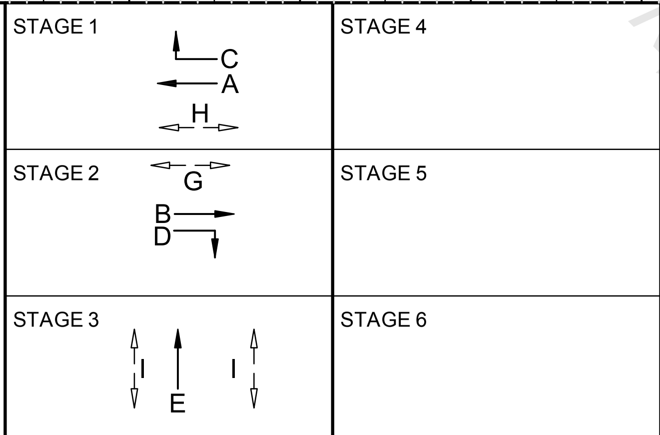
Transportation Planning, Design & Traffic Flow Division

DRAWN:	HW Lisse	PLAN NO:	2 of 4 (Revision 1)	MODE OF OPERATION	INTERSECTION: F CASTRO / W LIST
DATE:	APR 2010	CYCLE:	60 s	Fixed refer to F Castro	
DRAWING:	Castro/List P2	PLAN NAME:	Off Peak		INTERSECTION NO: 1011
DESIGN:	HW Lisse	OFFSET:	29 s		

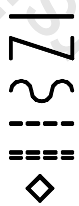
University of Cape Town







LEGEND



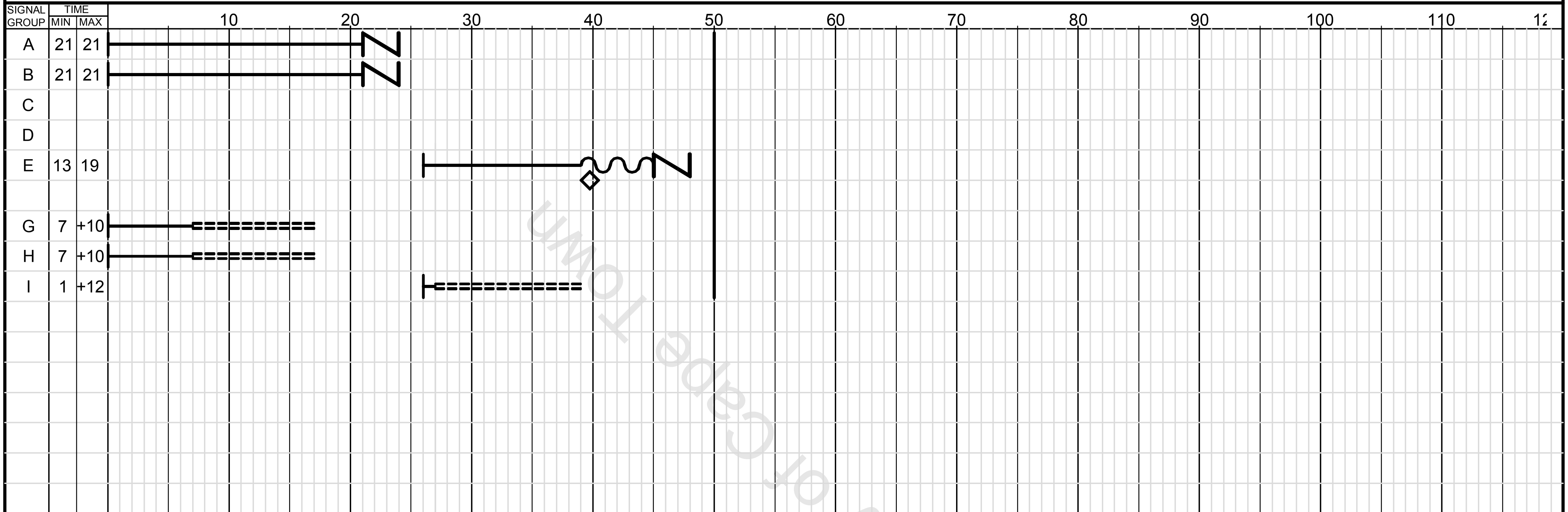
Intersection phasing plan:

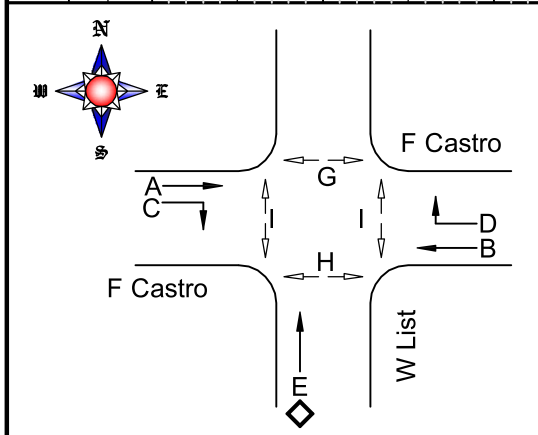
Plan Type	Day type	Time	Cycle
Night (4)	0	20:00 to 06:30	50
	13	06:30 to 20:00	50
Inbound (1)	11	06:30 to 08:30	75
Off Peak (2)	11	08:30 to 12:45	60
Outbound (3)	11	12:45 to 13:30	75
Inbound (1)	10	13:30 to 14:15	75
Off Peak (2)	10	14:15 to 16:30	60
Outbound (3)	10	16:30 to 18:00	75
Off Peak (2)	11	18:00 to 20:00	60
Off Peak (2)	7	13:30 to 18:00	60

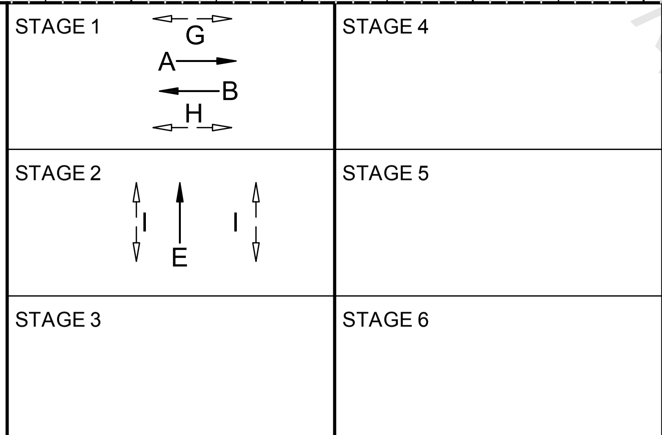
Day types as follows: 0 = Every Day including Holidays; 1 = Sundays; 2 = Mondays; 3 = Tuesdays; 4 = Wednesdays; 5 = Thursdays; 6 = Fridays; 7 = Saturdays; 8 = Holidays; 9 = Monday to Thursday; 10 = Monday to Friday; 11 = Monday to Saturday; 12 = Every Day except Holidays; 13 = Holiday or Sunday.

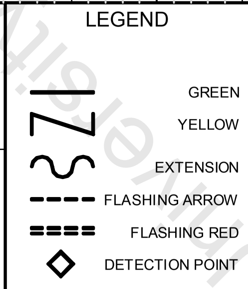
Transportation Planning, Design & Traffic Flow Division	DRAWN: HW Lisse	PLAN NO: 3 of 4 (Revision 1)	MODE OF OPERATION	INTERSECTION: F CASTRO / W LIST
	DATE: APR 2010	CYCLE: 75 s	Semi VA refer to F Castro	
	DRAWING: Castro/List P3	PLAN NAME: Outbound		INTERSECTION NO: 1011
	DESIGN: HW Lisse	OFFSET: 34 s		

University of Cape Town









Intersection phasing plan:

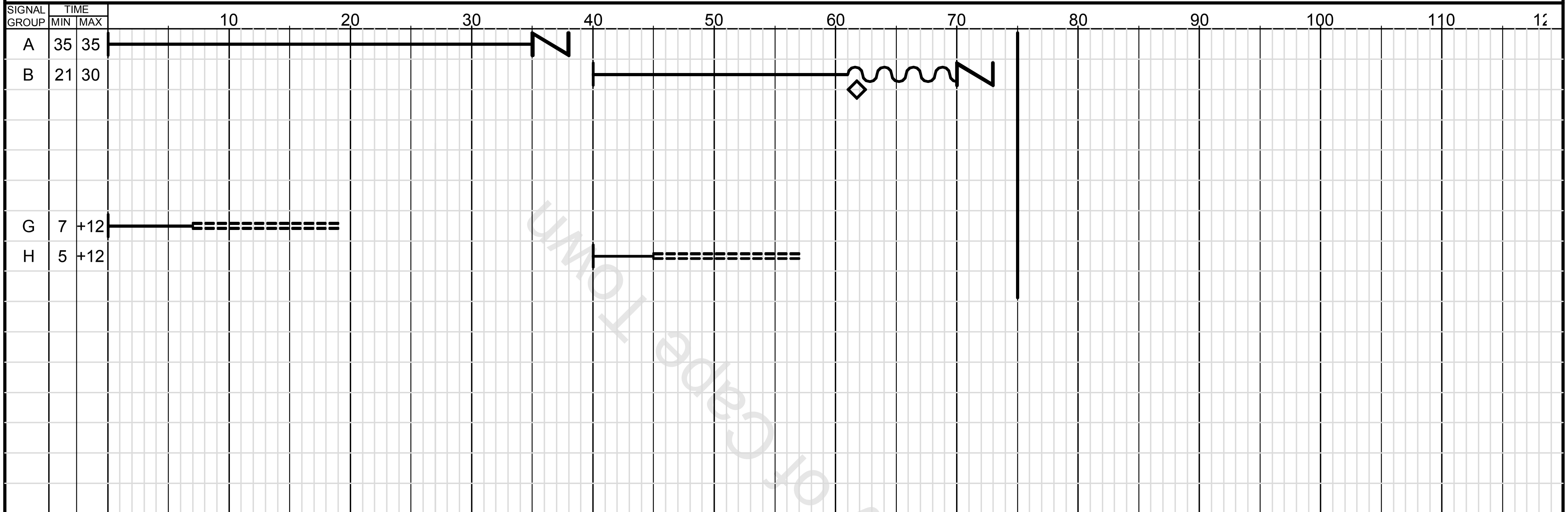
Plan Type	Day type	Time	Cycle
Night (4)	0	20:00 to 06:30	50
	13	06:30 to 20:00	50
Inbound (1)	11	06:30 to 08:30	75
Off Peak (2)	11	08:30 to 12:45	60
Outbound (3)	11	12:45 to 13:30	75
Inbound (1)	10	13:30 to 14:15	75
Off Peak (2)	10	14:15 to 16:30	60
Outbound (3)	10	16:30 to 18:00	75
Off Peak (2)	11	18:00 to 20:00	60
Off Peak (2)	7	13:30 to 18:00	60

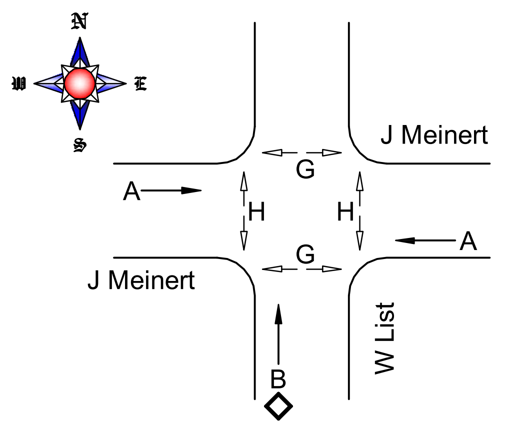
Day types as follows: 0 = Every Day including Holidays; 1 = Sundays; 2 = Mondays; 3 = Tuesdays; 4 = Wednesdays; 5 = Thursdays; 6 = Fridays; 7 = Saturdays; 8 = Holidays; 9 = Monday to Thursday; 10 = Monday to Friday; 11 = Monday to Saturday; 12 = Every Day except Holidays; 13 = Holiday or Sunday.

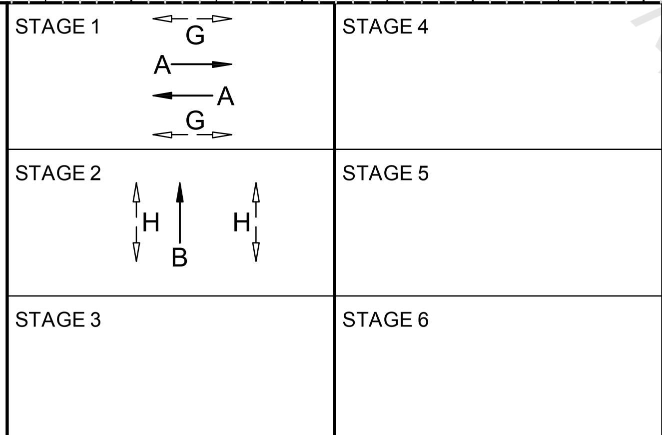
Transportation Planning, Design & Traffic Flow Division

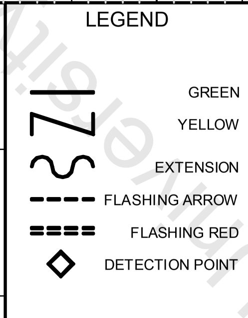
DRAWN:	HW Lisse	PLAN NO:	4 of 4 (Revision 1)	MODE OF OPERATION	INTERSECTION: F CASTRO / W LIST
DATE:	APR 2010	CYCLE:	50 s	Semi VA refer to F Castro	
DRAWING:	Castro/List P4	PLAN NAME:	Night		INTERSECTION NO: 1011
DESIGN:	HW Lisse	OFFSET:	33 s		

University of Cape Town









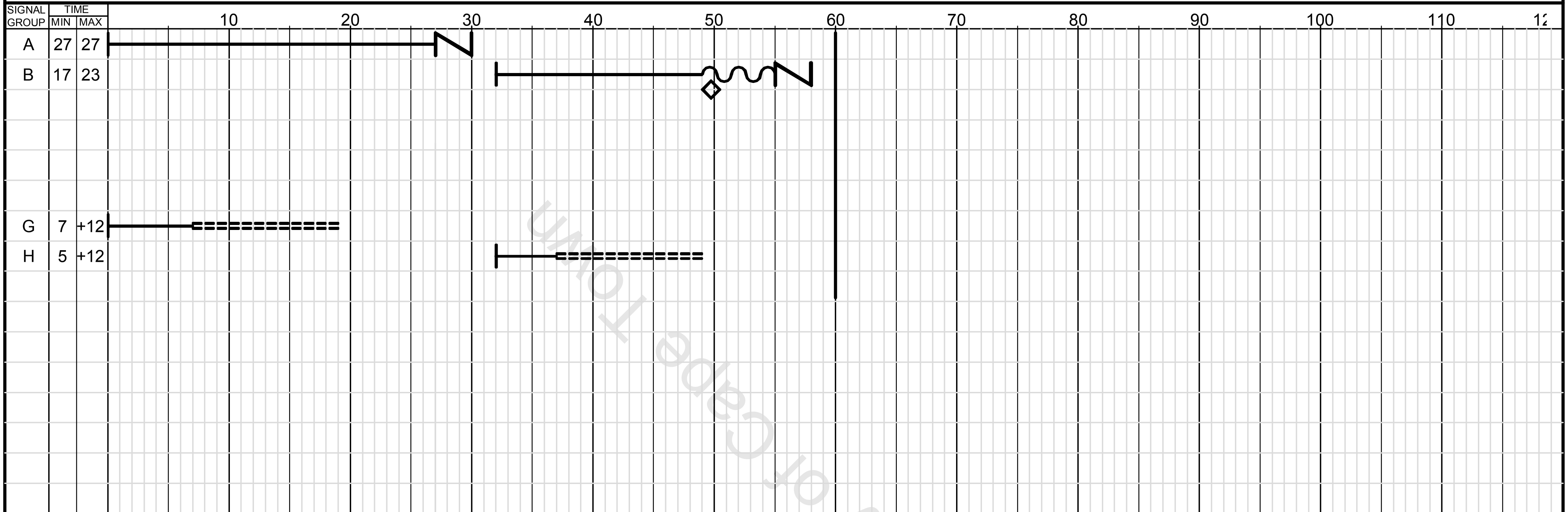
Intersection phasing plan:

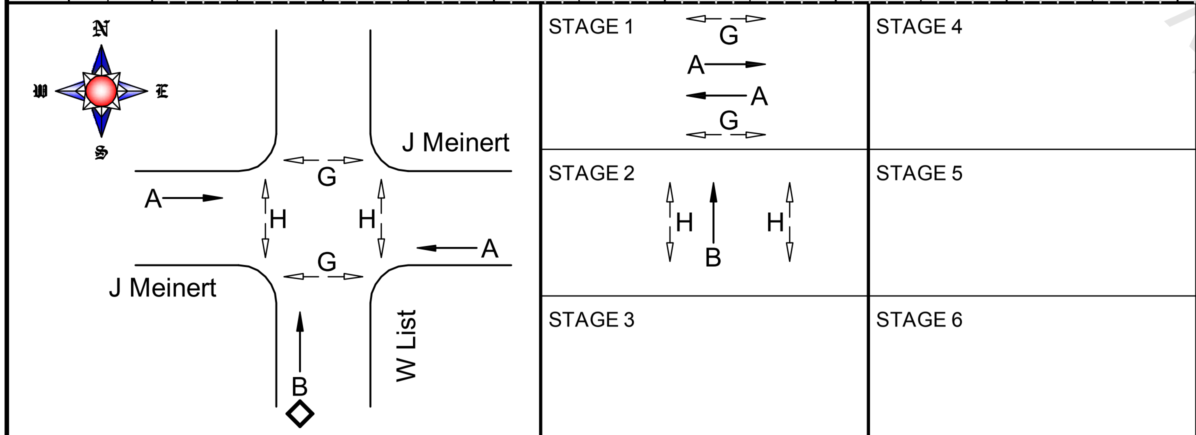
Plan Type	Day type	Time	Cycle
Night (4)	0	20:00 to 06:30	50
	13	06:30 to 20:00	50
Inbound (1)	11	06:30 to 08:30	75
Off Peak (2)	11	08:30 to 12:45	60
Outbound (3)	11	12:45 to 13:30	75
Inbound (1)	10	13:30 to 14:15	75
Off Peak (2)	10	14:15 to 16:30	60
Outbound (3)	10	16:30 to 18:00	75
Off Peak (2)	11	18:00 to 20:00	60
Off Peak (2)	7	13:30 to 18:00	60

Day types as follows: 0 = Every Day including Holidays; 1 = Sundays; 2 = Mondays; 3 = Tuesdays; 4 = Wednesdays; 5 = Thursdays; 6 = Fridays; 7 = Saturdays; 8 = Holidays; 9 = Monday to Thursday; 10 = Monday to Friday; 11 = Monday to Saturday; 12 = Every Day except Holidays; 13 = Holiday or Sunday.

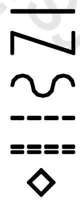
Transportation Planning, Design & Traffic Flow Division	DRAWN: HW Lisse	PLAN NO: 1 of 4 (Revision 1)	MODE OF OPERATION: Semi VA refer to J Meinert
	DATE: APR 2010	CYCLE: 75 s	INTERSECTION: J MEINERT / W LIST
	DRAWING: Meinert/List P1	PLAN NAME: Inbound	INTERSECTION NO: 1022
	DESIGN: HW Lisse	OFFSET: 19 s	

University of Cape Town





LEGEND



Intersection phasing plan:

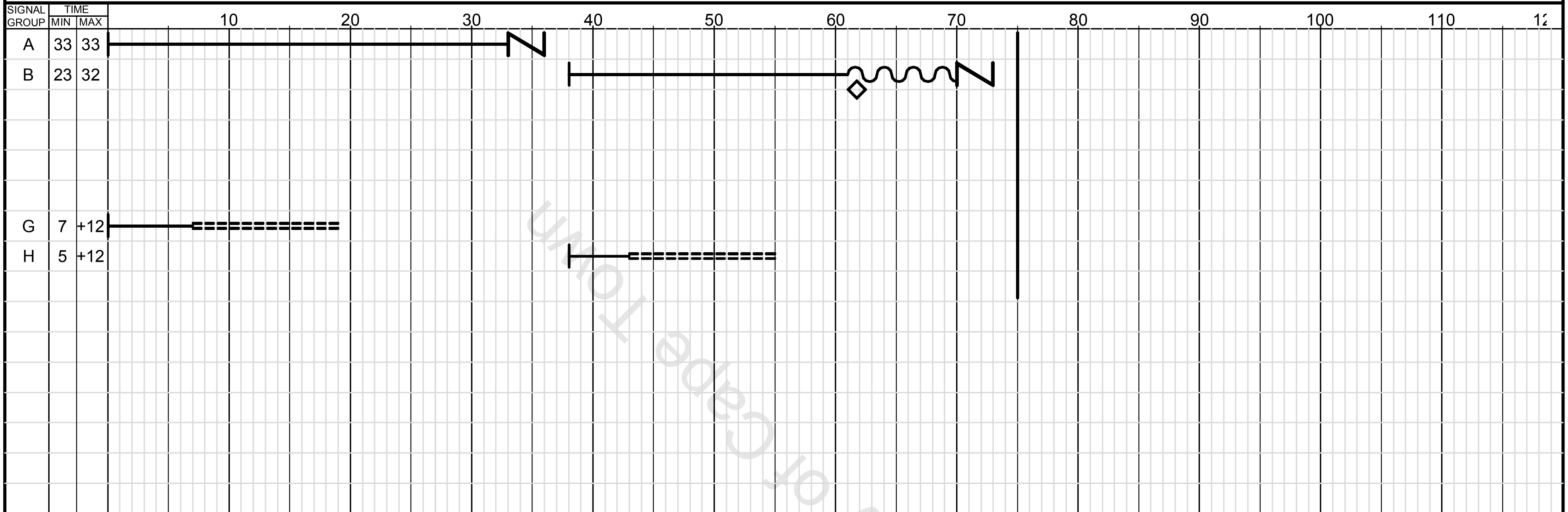
Plan Type	Day type	Time	Cycle
Night (4)	0	20:00 to 06:30	50
	13	06:30 to 20:00	50
Inbound (1)	11	06:30 to 08:30	75
Off Peak (2)	11	08:30 to 12:45	60
Outbound (3)	11	12:45 to 13:30	75
Inbound (1)	10	13:30 to 14:15	75
Off Peak (2)	10	14:15 to 16:30	60
Outbound (3)	10	16:30 to 18:00	75
Off Peak (2)	11	18:00 to 20:00	60
Off Peak (2)	7	13:30 to 18:00	60

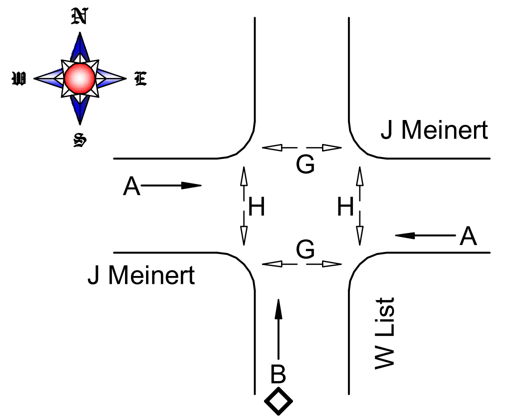
Day types as follows: 0 = Every Day including Holidays; 1 = Sundays; 2 = Mondays; 3 = Tuesdays; 4 = Wednesdays; 5 = Thursdays; 6 = Fridays; 7 = Saturdays; 8 = Holidays; 9 = Monday to Thursday; 10 = Monday to Friday; 11 = Monday to Saturday; 12 = Every Day except Holidays; 13 = Holiday or Sunday.

Transportation Planning, Design & Traffic Flow Division

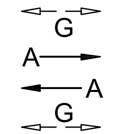
DRAWN: HW Lisse	PLAN NO: 2 of 4 (Revision 1)	MODE OF OPERATION	INTERSECTION: J MEINERT / W LIST
DATE: APR 2010	CYCLE: 60 s	Semi VA refer to J Meinert	INTERSECTION NO: 1022
DRAWING: Meinert/List P2	PLAN NAME: Off Peak		
DESIGN: HW Lisse	OFFSET: 18 s		

University of Cape Town

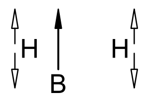




STAGE 1



STAGE 2



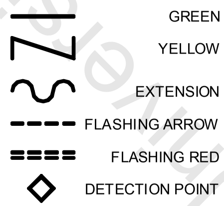
STAGE 3

STAGE 4

STAGE 5

STAGE 6

LEGEND



Intersection phasing plan:

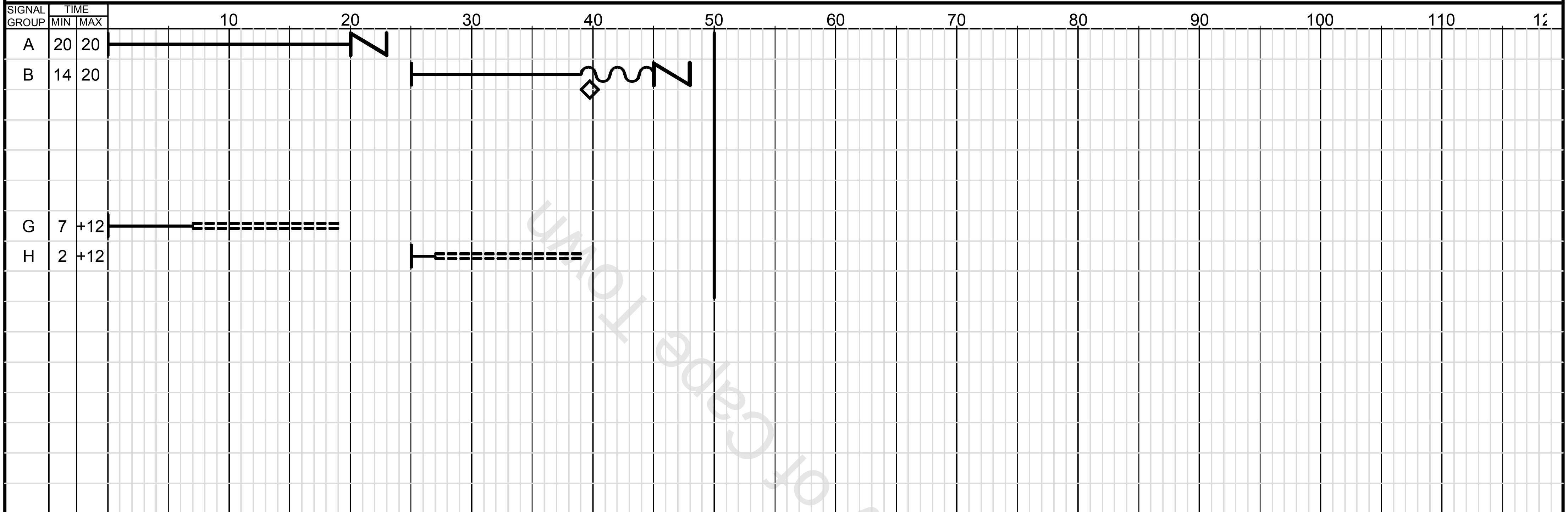
Plan Type	Day type	Time	Cycle
Night (4)	0	20:00 to 06:30	50
	13	06:30 to 20:00	50
Inbound (1)	11	06:30 to 08:30	75
Off Peak (2)	11	08:30 to 12:45	60
Outbound (3)	11	12:45 to 13:30	75
Inbound (1)	10	13:30 to 14:15	75
Off Peak (2)	10	14:15 to 16:30	60
Outbound (3)	10	16:30 to 18:00	75
Off Peak (2)	11	18:00 to 20:00	60
Off Peak (2)	7	13:30 to 18:00	60

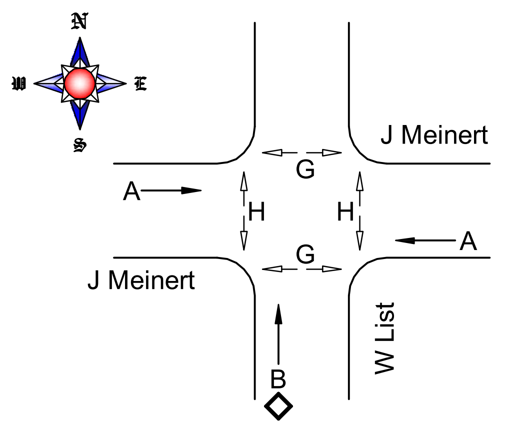
Day types as follows: 0 = Every Day including Holidays; 1 = Sundays; 2 = Mondays; 3 = Tuesdays; 4 = Wednesdays; 5 = Thursdays; 6 = Fridays; 7 = Saturdays; 8 = Holidays; 9 = Monday to Thursday; 10 = Monday to Friday; 11 = Monday to Saturday; 12 = Every Day except Holidays; 13 = Holiday or Sunday.

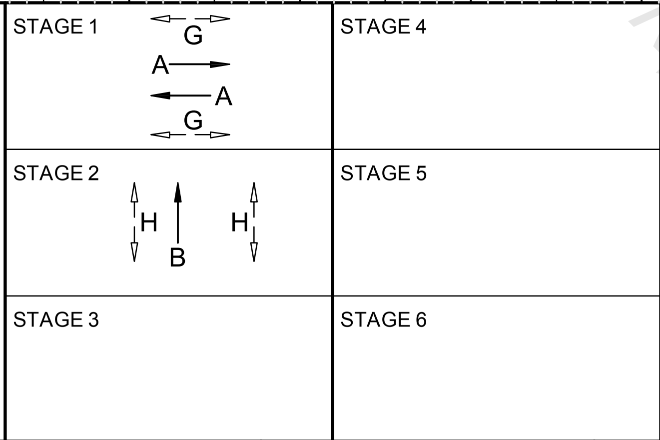
Transportation Planning, Design & Traffic Flow Division

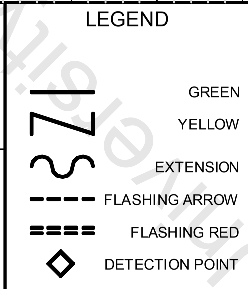
DRAWN: HW Lisse	PLAN NO: 3 of 4 (Revision 1)	MODE OF OPERATION: Semi VA refer to J Meinert	INTERSECTION: J MEINERT / W LIST
DATE: APR 2010	CYCLE: 75 s		INTERSECTION NO: 1022
DRAWING: Meinert/List P3	PLAN NAME: Outbound		
DESIGN: HW Lisse	OFFSET: 17 s		

University of Cape Town









Intersection phasing plan:

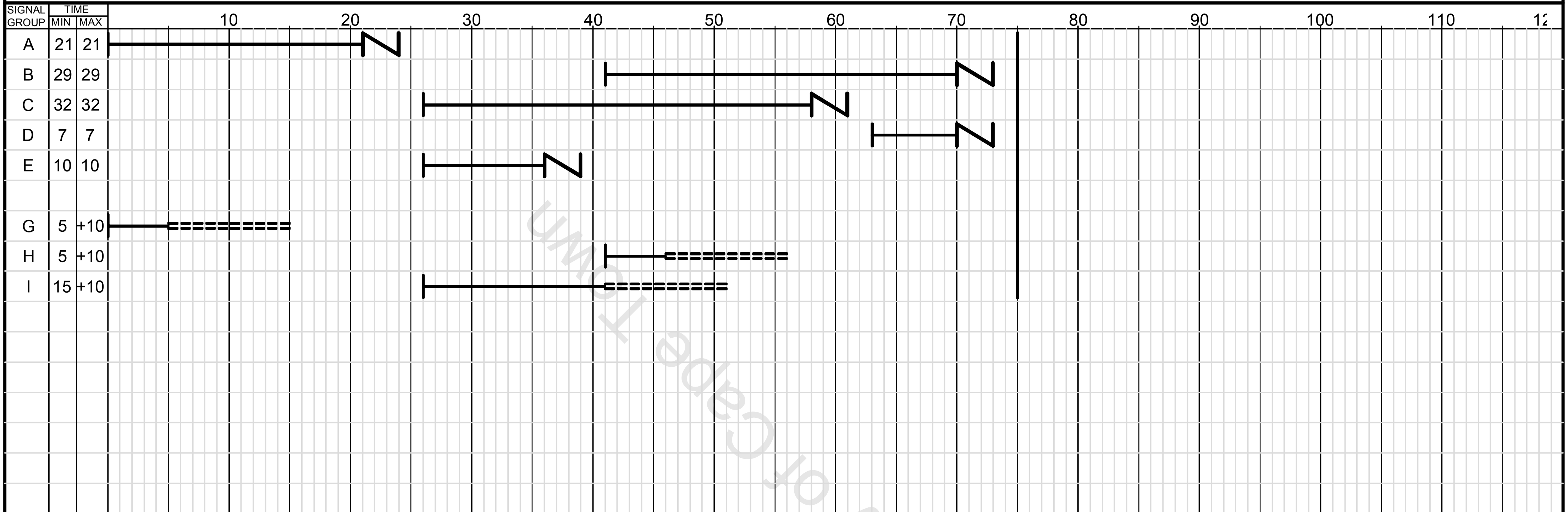
Plan Type	Day type	Time	Cycle
Night (4)	0	20:00 to 06:30	50
	13	06:30 to 20:00	50
Inbound (1)	11	06:30 to 08:30	75
Off Peak (2)	11	08:30 to 12:45	60
Outbound (3)	11	12:45 to 13:30	75
Inbound (1)	10	13:30 to 14:15	75
Off Peak (2)	10	14:15 to 16:30	60
Outbound (3)	10	16:30 to 18:00	75
Off Peak (2)	11	18:00 to 20:00	60
Off Peak (2)	7	13:30 to 18:00	60

Day types as follows: 0 = Every Day including Holidays; 1 = Sundays; 2 = Mondays; 3 = Tuesdays; 4 = Wednesdays; 5 = Thursdays; 6 = Fridays; 7 = Saturdays; 8 = Holidays; 9 = Monday to Thursday; 10 = Monday to Friday; 11 = Monday to Saturday; 12 = Every Day except Holidays; 13 = Holiday or Sunday.

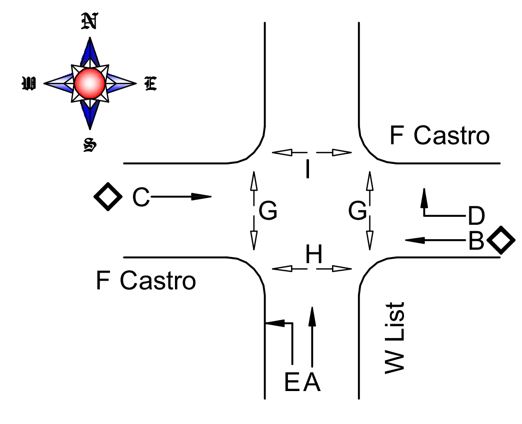
Transportation Planning,
Design & Traffic Flow Division

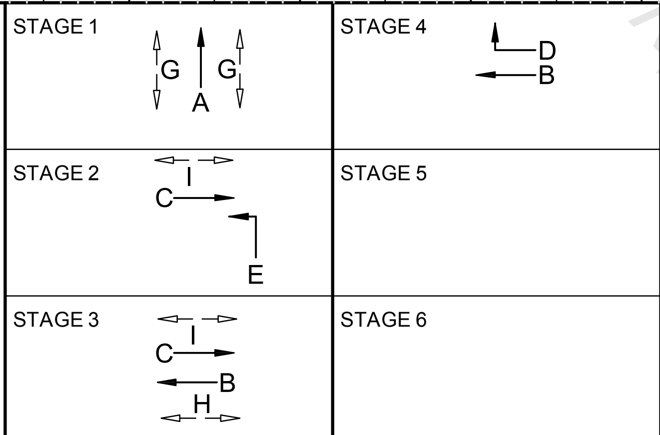
DRAWN:	HW Lisse	PLAN NO:	4 of 4 (Revision 1)	MODE OF OPERATION	INTERSECTION: J MEINERT / W LIST
DATE:	APR 2010	CYCLE:	50 s	Semi VA refer to J Meinert	INTERSECTION NO: 1022
DRAWING:	Meinert/List P4	PLAN NAME:	Night		
DESIGN:	HW Lisse	OFFSET:	41 s		

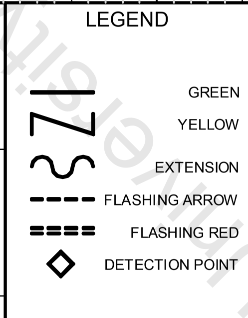
University of Cape Town



University of Cape Town







Intersection phasing plan:

Plan Type	Day type	Time	Cycle
Night (4)	0	20:00 to 06:30	50
	13	06:30 to 20:00	50
Inbound (1)	11	06:30 to 08:30	75
Off Peak (2)	11	08:30 to 12:45	60
Outbound (3)	11	12:45 to 13:30	75
Inbound (1)	10	13:30 to 14:15	75
Off Peak (2)	10	14:15 to 16:30	60
Outbound (3)	10	16:30 to 18:00	75
Off Peak (2)	11	18:00 to 20:00	60
Off Peak (2)	7	13:30 to 18:00	60

Day types as follows: 0 = Every Day including Holidays; 1 = Sundays; 2 = Mondays; 3 = Tuesdays; 4 = Wednesdays; 5 = Thursdays; 6 = Fridays; 7 = Saturdays; 8 = Holidays; 9 = Monday to Thursday; 10 = Monday to Friday; 11 = Monday to Saturday; 12 = Every Day except Holidays; 13 = Holiday or Sunday.

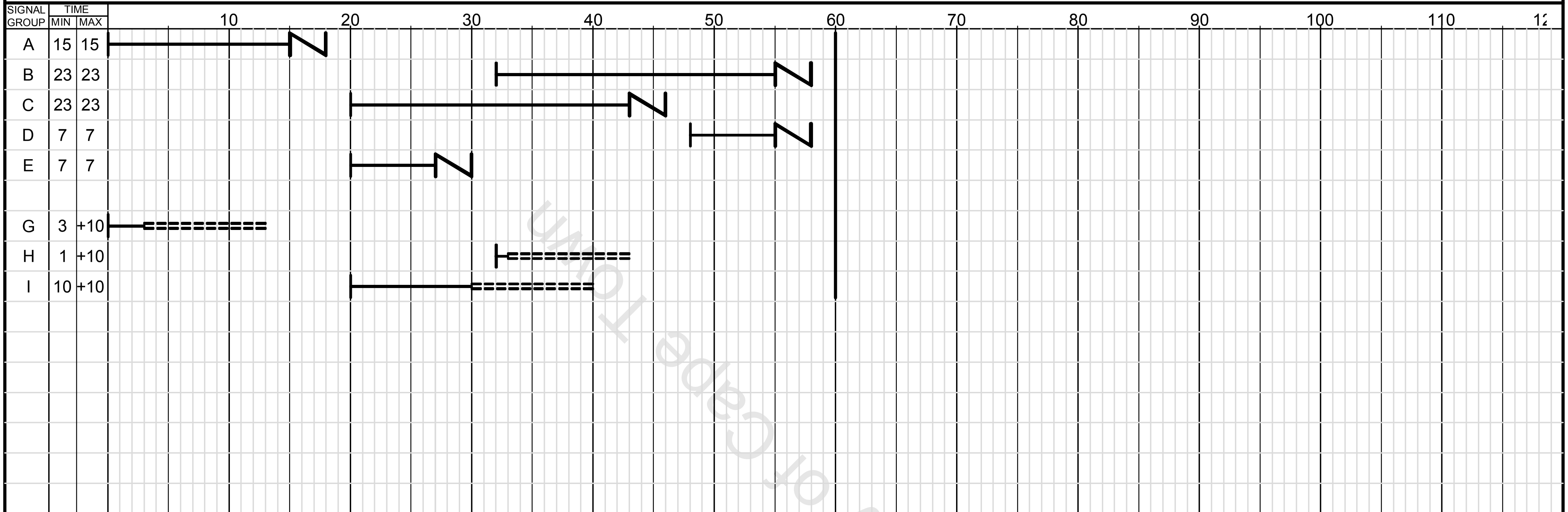
Transportation Planning, Design & Traffic Flow Division

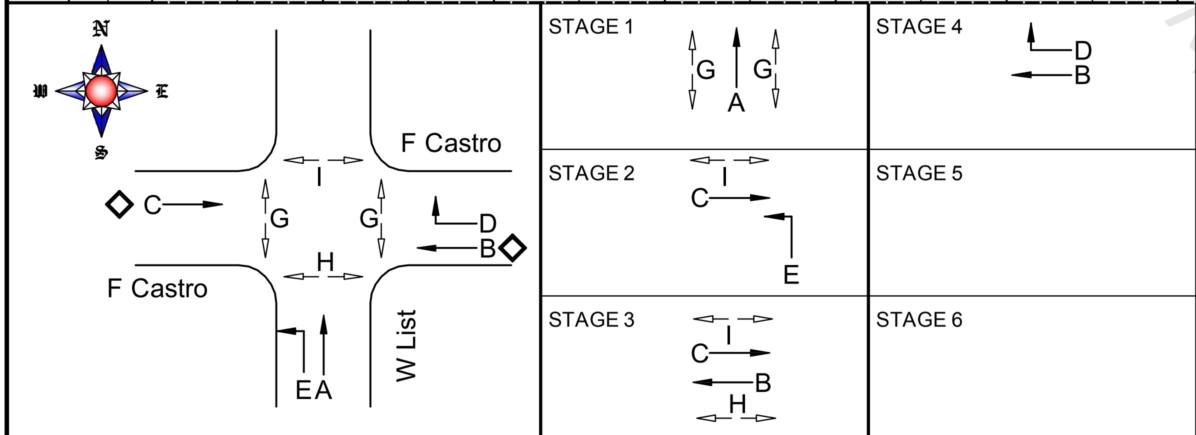
DRAWN:	HW Lisse	PLAN NO:	1 of 4 (Revision 1)
DATE:	APR 2010	CYCLE:	75 s
DRAWING:	Indongo/List P1	PLAN NAME:	Inbound
DESIGN:	HW Lisse	OFFSET:	15 s

MODE OF OPERATION: Fixed refer to W List

INTERSECTION: F INDONGO / W LIST

INTERSECTION NO: 1026





LEGEND

- GREEN
- YELLOW
- EXTENSION
- FLASHING ARROW
- FLASHING RED
- DETECTION POINT

Intersection phasing plan:

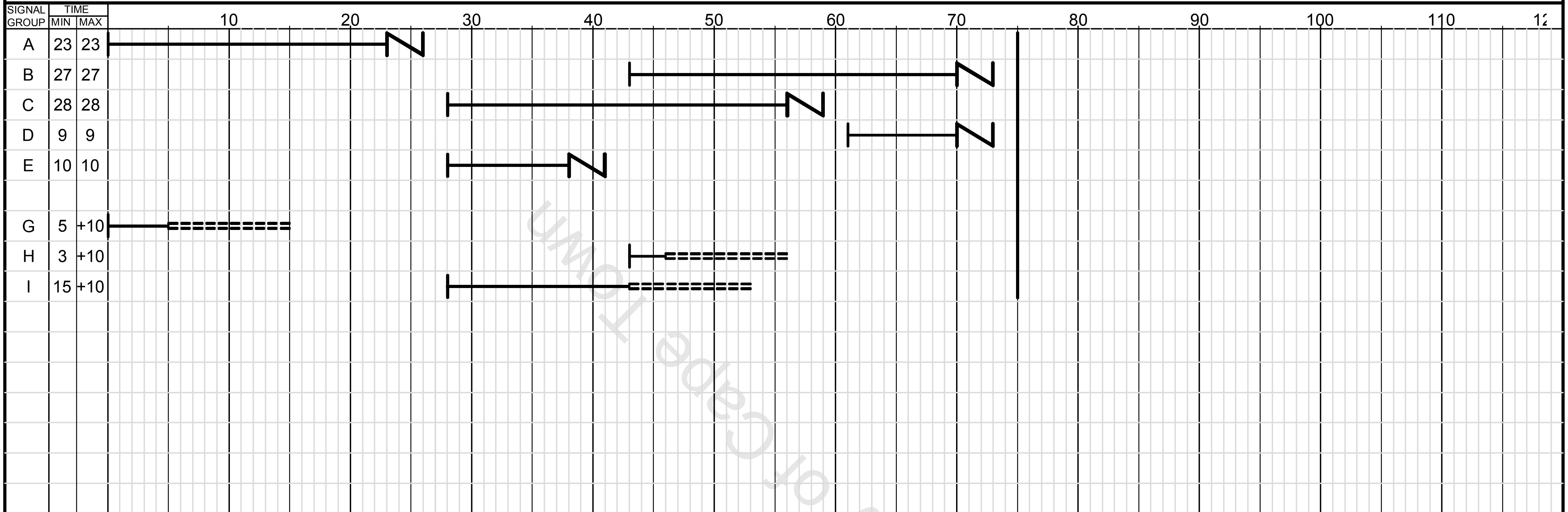
Plan Type	Day type	Time	Cycle
Night (4)	0	20:00 to 06:30	50
	13	06:30 to 20:00	50
Inbound (1)	11	06:30 to 08:30	75
Off Peak (2)	11	08:30 to 12:45	60
Outbound (3)	11	12:45 to 13:30	75
Inbound (1)	10	13:30 to 14:15	75
Off Peak (2)	10	14:15 to 16:30	60
Outbound (3)	10	16:30 to 18:00	75
Off Peak (2)	11	18:00 to 20:00	60
Off Peak (2)	7	13:30 to 18:00	60

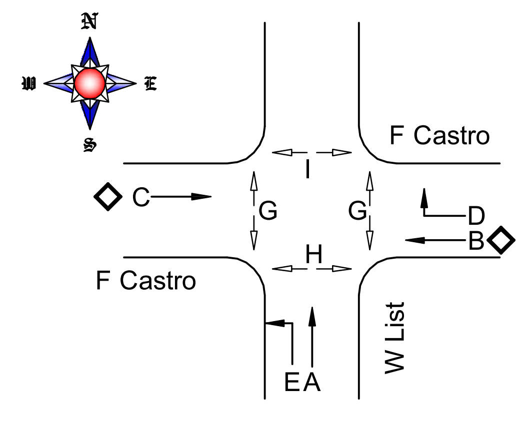
Day types as follows: 0 = Every Day including Holidays; 1 = Sundays; 2 = Mondays; 3 = Tuesdays; 4 = Wednesdays; 5 = Thursdays; 6 = Fridays; 7 = Saturdays; 8 = Holidays; 9 = Monday to Thursday; 10 = Monday to Friday; 11 = Monday to Saturday; 12 = Every Day except Holidays; 13 = Holiday or Sunday.

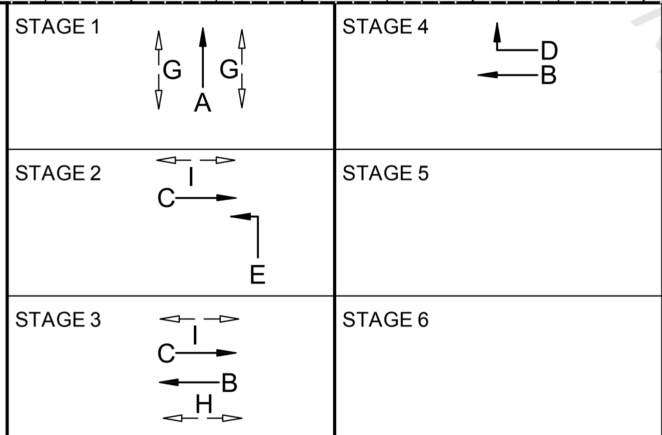
Transportation Planning, Design & Traffic Flow Division

DRAWN:	HW Lisse	PLAN NO:	2 of 4 (Revision 1)	MODE OF OPERATION	INTERSECTION: F INDONGO / W LIST
DATE:	APR 2010	CYCLE:	60 s	Fixed refer to W List	
DRAWING:	Indongo/List P2	PLAN NAME:	Off Peak		INTERSECTION NO: 1026
DESIGN:	HW Lisse	OFFSET:	11 s		

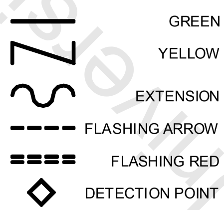
University of Cape Town







LEGEND



Intersection phasing plan:

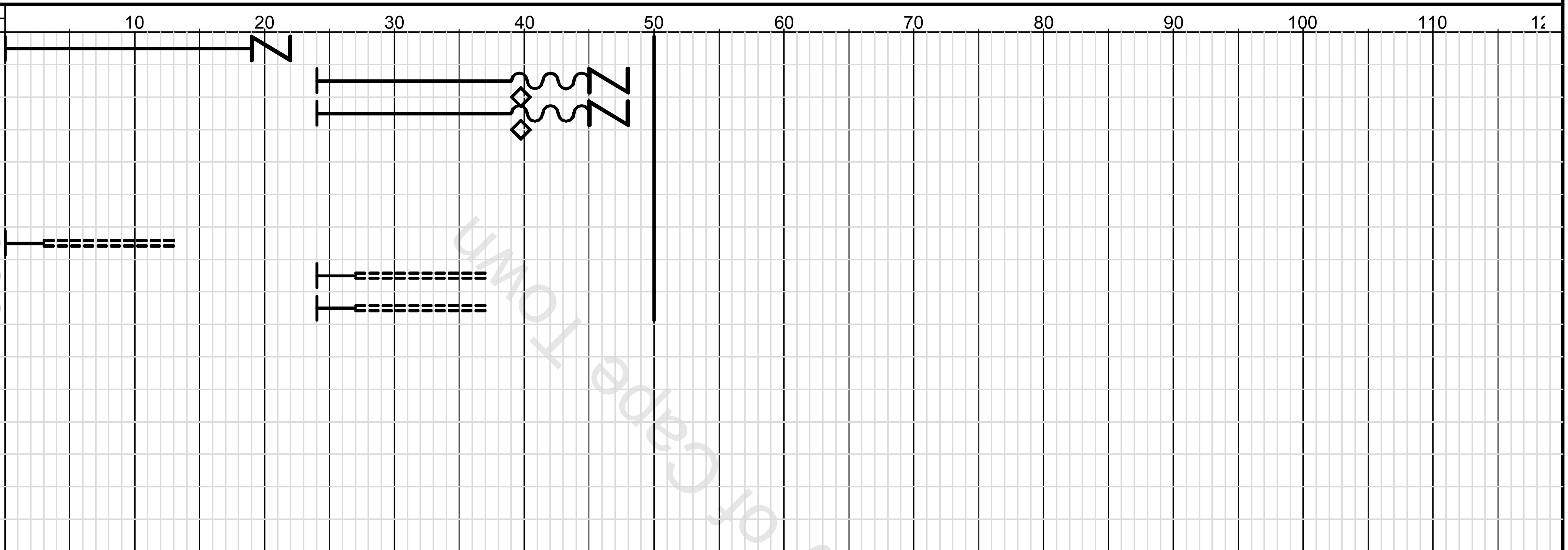
Plan Type	Day type	Time	Cycle
Night (4)	0	20:00 to 06:30	50
	13	06:30 to 20:00	50
Inbound (1)	11	06:30 to 08:30	75
Off Peak (2)	11	08:30 to 12:45	60
Outbound (3)	11	12:45 to 13:30	75
Inbound (1)	10	13:30 to 14:15	75
Off Peak (2)	10	14:15 to 16:30	60
Outbound (3)	10	16:30 to 18:00	75
Off Peak (2)	11	18:00 to 20:00	60
Off Peak (2)	7	13:30 to 18:00	60

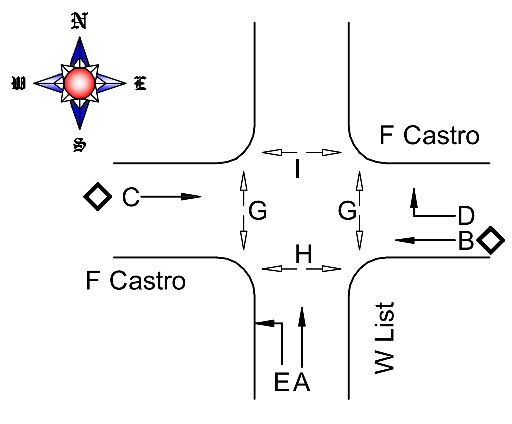
Day types as follows: 0 = Every Day including Holidays; 1 = Sundays; 2 = Mondays; 3 = Tuesdays; 4 = Wednesdays; 5 = Thursdays; 6 = Fridays; 7 = Saturdays; 8 = Holidays; 9 = Monday to Thursday; 10 = Monday to Friday; 11 = Monday to Saturday; 12 = Every Day except Holidays; 13 = Holiday or Sunday.

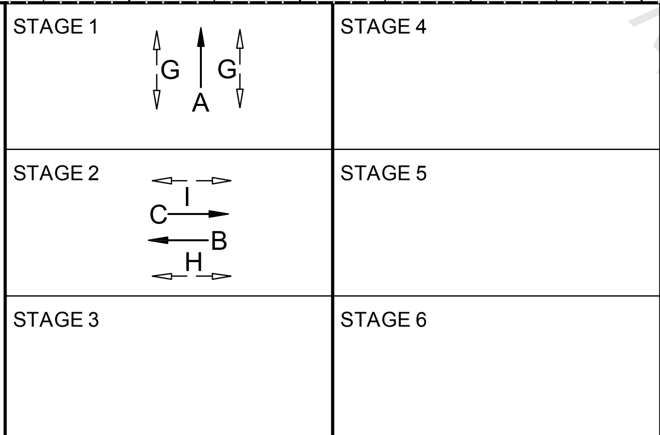
Transportation Planning, Design & Traffic Flow Division	DRAWN: HW Lisse	PLAN NO: 3 of 4 (Revision 1)	MODE OF OPERATION	INTERSECTION: F INDONGO / W LIST
	DATE: APR 2010	CYCLE: 75 s		
	DRAWING: Indongo/List P3	PLAN NAME: Outbound	Fixed refer to W List	INTERSECTION NO: 1026
	DESIGN: HW Lisse	OFFSET: 15 s		

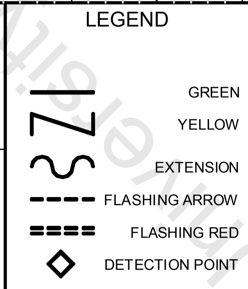
University of Cape Town

SIGNAL GROUP	TIME MIN	TIME MAX
A	19	19
B	15	21
C	15	21
D		
E		
G	3	+10
H	3	+10
I	3	+10









Intersection phasing plan:

Plan Type	Day type	Time	Cycle
Night (4)	0	20:00 to 06:30	50
	13	06:30 to 20:00	50
Inbound (1)	11	06:30 to 08:30	75
Off Peak (2)	11	08:30 to 12:45	60
Outbound (3)	11	12:45 to 13:30	75
Inbound (1)	10	13:30 to 14:15	75
Off Peak (2)	10	14:15 to 16:30	60
Outbound (3)	10	16:30 to 18:00	75
Off Peak (2)	11	18:00 to 20:00	60
Off Peak (2)	7	13:30 to 18:00	60

Day types as follows: 0 = Every Day including Holidays; 1 = Sundays; 2 = Mondays; 3 = Tuesdays; 4 = Wednesdays; 5 = Thursdays; 6 = Fridays; 7 = Saturdays; 8 = Holidays; 9 = Monday to Thursday; 10 = Monday to Friday; 11 = Monday to Saturday; 12 = Every Day except Holidays; 13 = Holiday or Sunday.

Transportation Planning, Design & Traffic Flow Division

DRAWN: HW Lisse	PLAN NO: 4 of 4 (Revision 1)	MODE OF OPERATION	INTERSECTION: F INDONGO / W LIST
DATE: APR 2010	CYCLE: 50 s	Semi VA refer to W List	INTERSECTION NO: 1026
DRAWING: Indongo/List P4	PLAN NAME: Night		
DESIGN: HW Lisse	OFFSET: 37 s		

University of Cape Town

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

Henock M. Ntinda

Student Number: NTNMAN002

Centre for Transport Studies

Supervisor: A/Prof Marianne Vanderschuren

This letter serves to investigate the general traffic flow status in Windhoek. Questions asked are aimed at providing a background study of Windhoek's major arterial traffic flow, which will provide supporting information for the Masters of Science (MSc) dissertation write up of Henock Ntinda.

The questions posed are aimed at providing a background understanding of the City of Windhoek's transport systems. The questions are not limiting, answers can be expanded to provide a greater scope of the governing policy that City of Windhoek employs to manage Windhoek's transport system.

1. City of Windhoek's Transport Management Framework

- Is there a defined framework utilised to manage and administer Windhoek's transport system?
- Where can access to such a framework be obtained?
- At present, how does the transport infrastructure within the city cater for the different transport modes? Does the Transport Management Framework aim to change or maintain the current modal split?
- In terms of budget allocation and relative to other transport activities (say pavement rehabilitation); does the city's Transport Management Framework play a significant role?
- What effect does a crisis (e.g. 2011 pavement degradation) have on the budget allocation for activities such as the management of the transport system?

2. Statistical Information/Data Collection

- Which methods (manual traffic counts, vehicle sensing controllers, loop systems, etc) does the City of Windhoek use to collect data (traffic flow, volume, etc)?
- In line with the methods used, how significant a role does Intelligent Transport Systems (ITS) play in assisting with data collection?

University of Cape Town

- Where can statistical data relating to Windhoek's traffic scenario (congestion levels on major arterials and at major intersections), over the past five years, be obtained?

3. Traffic Simulation

- Does the City of Windhoek (or its hired consultants) utilise traffic simulation modelling to analyse the city's transport system at a macro, meso or micro level? If yes, which simulation package is commonly used and which parameters are looked at for calibrating the default parameters to the local conditions?
- Correlating the realistic traffic flow (measured manually or using equipment) with that of the simulated; what level of confidence - regression analysis R^2 - does the City of Windhoek find acceptable?
- Does City of Windhoek utilise Geographic Information Systems (GIS) to relate the results gained from the traffic flow analyses with the geographic human activity within the city?

Thank you.

University of Cape Town