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(iii) I am now presenting the thesis for examination the thesis for examination for the Degree of MsC.

Oshoveli Tuli Hiveluah

(Student No: HVLOSH001)
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To my wife Marcia and my son Joel, thank you for your unwavering support and reassurance throughout the duration of this thesis.

To my family, my mom (Ulitala) my dad (Tuli), my three sisters: Oshosheni, Nangula and Ndamona Hiveluah thank you for your support and encouragement.

To my supervisor, Marianne: Thank you for all your help and your continual support and guidance throughout the entire research project.
ABSTRACT

The research attempted to model the trip generation and the subsequent modal splits resulting thereof. The sketch planning tool to be developed attempted to predict within reasonable accuracy limits, the travel trends and hence the transport modes used for the undertaking of these trips.

To gain an in-depth understanding of the task, the “status quo” mobility conditions for Windhoek had to be well understood. Only once when the existing trends are fully understood, can one begin to derive a model that is able to model, the expressed mobility trends. In analysing the existing mobility trends, the following hypotheses were tested:

1. Is travel influenced in any way by household disposable income?
2. Do male travellers undertake more trips in comparison to their female counterparts?
3. There is a significant reduction in mobility as people get older (their physical condition deteriorates)?

For this task, a spectre of journals and publications, from developing and developed countries were consulted in order to understand and gain useful insights in modelling practices in other countries. Of the publications consulted, only three are presented here. Once the general household and mobility trends established, a correlation analysis followed, to eliminate the redundant variables collected during the preliminary stages of data collection.

With the mobility tool’s objectives in mind, a preliminary model approach was decided upon, which was similar to the classical four-step model, which despite its criticisms provided a simple and systematic approach to modelling transport demand. The model approach was altered, by the elimination of the trip distribution and assignment steps to the suit the stated objectives.
The uncertainties in the model were dealt with by introducing upper and lower bound analyses. The former approach was used because it recognizes the limitations of modelling mobility at a citywide level. Upon the establishment of the acceptable error margins, analyses were performed in order to estimate the person-trips generated and the resultant modal split, both by zone and on citywide level.
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1. BACKGROUND

Never before has our society been so dependent on travel. The ability to move today has become an essential activity in our daily lives. The very idea of movement and the ability to overcome distance has evolved to such levels that neither our economies nor industries are able to function without it. To understand current mobility patterns, it is important to ask ourselves two questions the following: Why are existing mobility patterns the way they are? Secondly, what caused the current mobility levels to reach their current level?

From a transport-modelling perspective, the first question can be answered in several ways. The primary answer to the above is that, people travel, since there is a need to communicate with each other and perform activities, which are segregated in space. The secondary reason why people travel is their perception to accrue a certain form of benefit that results from travel.

With the aid of recent technological advancements in the automobile industry (invention of the automobile), movement is no longer confined and limited as in the past (when pedestrian movement was the predominant mode of transport). The present ability to overcome space more easily and quickly has resulted in the generation of footloose development patterns, which in turn has necessitated an increase in the current travel demand. Today, the private automobile has facilitated movement in the cities to such an extent, that it has become an indispensable mode of transport that all urban inhabitants feel the need to own.

Due to the ever-increasing popularity of the motorcar and hence, its subsequent dependency, the capita trip-generation rates are on the rapid increase and are bringing about undesirable mobility side-effects such as:

a) Injuries and loss of lives due to traffic related accidents;

b) Air pollution;

c) Traffic congestion;
d) Increased demand for transportation infrastructure;

e) More sophisticated law enforcement efforts to curb automobile related crimes;

f) Increased road damage and

g) Deterioration of public transport infrastructure and service levels.

These are just some of the many problems, which have led transportation planners and
engineers to derive tools, which would enable them to explore and attempt to foresee
transportation related problems before they escalate beyond controllable levels. This form
of forward preventative thinking marked a very important step in the right direction, from
the classical ‘1950’s and 1960’s predict and provide’ approach (Behrens & Kane 2002).

Given the above facts, it is understandable why mobility modelling is fast becoming an
important tool for studying the interactions between man, organisation and their
associative mobility patterns (see Table 1). It is very reason that prompted the subsequent
development sketch-planning tool Windhoek, the capital city of Namibia.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Spatial Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living</td>
<td>Living area (residence)</td>
</tr>
<tr>
<td>Working</td>
<td>Working area (place of employment)</td>
</tr>
<tr>
<td>Shopping</td>
<td>Groceries or leisure shopping</td>
</tr>
<tr>
<td>Schools/Universities</td>
<td>School, University attendance</td>
</tr>
<tr>
<td>Leisure</td>
<td>Sports, holidays, walks</td>
</tr>
<tr>
<td></td>
<td>Travel Demand</td>
</tr>
</tbody>
</table>

Table 1: Relationship between activities and space

---

5
1.1. INTRODUCTION

Windhoek, the capital city of Namibia, is a fast growing developing city, situated in the Khomas Region (central area) of Namibia. The town has an estimated population of 268,000 people from various cultural backgrounds. As any other developing city, it has been experiencing fast economic and infrastructural growth, coupled with all the problems associated with it. Similar to other rapidly growing cities, Windhoek’s fast population growth has come about due to both: increasing natural population growths and in-migration. In the last decade, the fast growths have left the City Council (City of Windhoek) struggling to deliver adequate basic services: water, electricity and sanitation to its inhabitants. The former statement is also applicable to the provision of basic public transport infrastructure and services.

The difficulties being experienced can be attributed to many factors. The most pronounced of these is that Windhoek has one of the most highly skewed income distributions in Africa, thus resulting in the unfair distribution of resources between the low and high-income groups (Gini factor). The former has trend has produced great differences in income levels, which has led to the marginalisation of the urban poor as far as basic services and transportation procurement is concerned. Authorities have acknowledged the existence of the trend and any new developments have the solid goal aiming to alleviate and uplift the living standards of the urban low-income groups.

The mobility sketch-planning tool under discussion is in its preliminary steps development. It will be the first “in house” developed transport-planning tool, that will enable planners and engineers, to understand and gain a deeper insight into the existing transportation demands that exist within the city. The tool will equip them with first hand knowledge about the ‘status quo’ of existing mobility patterns and existing traffic (pedestrian and vehicular) in and around the city. The model will investigate the variables that play an important role in influencing peoples’ travel decisions. It will also go on further to determine the trips generated by mode, as well as their associated modal split patterns. Given the capacities of the existing transport infrastructure, practitioners will be able to make informed decisions about transportation infrastructure provision.
The developed sketch-planning tool will focus on modelling trip generation and distribution steps. The tool will firstly attempt to understand the underlying factors that affect personal travel decision-making. To understand these phenomena, it is important to ask why people travel?

To understand why people travel, it is important to establish that, people travel because they perceive that they will derive a certain benefit from undertaking the trip. The former statement implies that prior to undertaking a trip, a traveller first assesses whether they will derive a benefit from making the trip. The assessment of benefits against the disutility of travel is what eventually an individual to undertake a trip or not.

In a three dimensional space, where segregation of both activities and location exists, there need to communicate often arises. The first obstacle that needs to overcome in order to facilitate the required communication, space that segregates the two entities needs to be overcome through the elimination of the distance barrier, by means travel. The act of travel, in itself is in unproductive activity and thus a traveller does not accrue any benefits from it. Therefore, prior to undertaking a trip, an individual considers the pros and cons behind undertaking each trip.

Even though the above-mentioned explanation does not provide a realistic picture of the complex considerations that occur, prior to making, however it provides a simplistic way of representing human decision making, which if applied in the correct context allows human decision making to be modelled.

The sketch-planning tool described in this report, will resemble the classical four-step model with modifications having been made in the omission of the distribution and trip assignment steps respectively. The tool will serve as an exploratory tool for practitioners, to explore the trends that could occur as a result the current development trends and as well as other variables. Since analyses performed were carried out on a citywide scale, in order to manage data more effectively, it was decided to sub-divide the town into zones, which were analysed accordingly.
1.2. PROBLEM STATEMENT

Windhoek, similar to other fast growing towns, is faced with problems of delivering adequate transport customer services to its residents. At present, there are no locally produced tools in place, which allow decision-making bodies, town councils or municipalities, to monitor and estimate the current transportation demand. Engineers and planners often have to resort to the use of foreign developed tools. The foreign developed transport planning tools often are simply calibrated to suit local conditions without taking any of existing conditions into consideration. If the local conditions are analysed and understood prior to the development of the modelling tool, then foreign case studies can be applied with caution.

However, the most prominent problems facing engineers and planners, is the shortage and often lack of adequate data to perform the required analyses to model transport demand. Local authorities, usually resort to utilising observed trend estimates from countries whose trends are similar to those experienced in Windhoek.

The sketch planning tool under discussion, being in its preliminary steps of development, will enable decision making authorities to estimate transport demand (public and private), by taking existing social and demographic patterns into account, and enable public transport service providers to be informed and hence be pro-active in the provision of adequate of public transport service.

Secondly, this tool will be the first of its kind in Namibia, and it will form an important basis for the possible estimation of trips by trip purpose namely school, work serving passenger and aggregated average trips. The modes to be modelled by tool will be the locally utilised modes of transport, which are car, taxi, bus, cyclists, and pedestrians.

Thirdly, the sketch-planning tool under development will of multi-modal in nature, thus hoping to increase the awareness level for non-motorised transport modes. Lastly, it will prompt local authorities to both consider a wider variety of options as far as transportation service delivery is concerned.
1.2. OBJECTIVE OF THE THESIS

The aim of the thesis is to document the development of the sketch-planning tool for Windhoek. The tool produced will serve as an exploratory rather than a predictive tool. The tool will within defined accuracy limits, predict the expected travel trends under three specified scenarios, which are as follows:

I. **Upper Bound Case:** The upper bound scenario refers to a scenario, where the probabilistic occurrence is low.

II. **Expected Case:** The expected scenario refers to a scenario, where the probabilistic occurrence is high.

III. **Lower Bound Case:** The lower bound case refers to a scenario, where the probabilistic occurrence is rare.

Note: The above scenarios were determined and selected according to the city’s population growth, economical patterns, as well as other factors (presented in this document), which influence on aggregated mobility is deemed to be of importance.

The secondary aim of the thesis is to explore the existing mobility trends in and around the Windhoek. The former objective will be achieved through the thorough analysis of the existing travel trends in order to establish existing transport trends.

The final aim is to provide planners, engineers and other decision makers with an effective response tool. This will enable practitioners to both explore and monitor aggregated mobility patterns of Windhoek’s residents, under varying economic and demographic conditions. Thus allowing decision makers to formulate holistic solutions to problems identified.
1.4. SCOPE AND LIMITATIONS

A transport-modelling tool is only as reliable as the data used to compile it. One of the biggest problems faced during the development of the tool is the shortage of reliable and well-documented data that could be used for the development the model concerned. This section deals with the difficulties experienced during data collection and the preliminary steps of model development. Obstacles that often face model developers are the shortage of adequate data and the respective accuracies and reliability associated with the data banks. These remain common problems, especially in developing countries, where the collected data is often insufficient and unreliable (Vasconcellos, 2001).

1.4.1. ACCURACY AND RELIABILITY OF DATA

The gathering of both accurate and reliable data is the most complicated process in the compilation of a model. The accuracy and reliability of the data source will determine the subsequent results produced during the different steps of data output generation (Atkins, 1989). Since data quality in developing countries is often poor. The former problem can result in escalation modelling errors through the proceeding steps of analysis.

In addition to the above, it is important to bear in mind that collected data is never perfect and usually contains errors e.g. transcription, omissions, and other numerous flaws (Atkins, 1986). Vasconcellos pointed out that in most cases, data quality tends to be poor, because it was collected for a different purpose, thus the manner and the presentation of the collected makes it difficult for transport modelling tools to be developed (Vasconcellos, 2001).

The second set of problems to be discussed under this section are the legal and political aspects associated in gaining access to collected information from government or private institutions. Currently, there is a great degree of “gate keeping” as far as information sharing is concerned. Both government and private institutions are generally reluctant to share information, irrespective of whether it is supposed to be freely available to the public or not. This phenomenon makes it particularly difficult for the model practitioners to gather accurate data thus necessitating practitioners to make use of the synthetic data.
generation methods to patch incomplete data banks, thus reducing the reliability of the data significantly.

1.4.2. INSUFFICIENT DATA BANKS

In addition to the problems associated with inaccurate and reliable data, models generally require large data volumes for effective model development and calibration. In Windhoek’s case, where transport data capturing efforts are seldom and far between, the available data pool was not large enough to calibrate the model effectively. Moreover, to develop a reliable and accurate model, data banks stretching as far back as fifteen years are required. Since such data banks are rare, many developing countries are forced to make use synthetic model calibration techniques to generate additional data required or simply making use of what is available.

The poor management by the public authorities in managing public databases is also one of the factors that have contributed to the incompleteness of the collected data thus making the existing data banks often inadequate (Behrens, Diaz, Plat & Pochet, 2004). In such situations, the most useful source of information is the National Census data. However, care needs to be taken in utilising such data banks as in some developing countries, where censuses are only conducted when funds are available, thus resulting in a highly irregular data banks.

1.4.3. OMISSION OF DISTRIBUTION AND ASSIGNMENT STEPS

The focal objective of Windhoek’s mobility sketch planning tool was to determine the total person trips generated by a population, under specified socio-economic conditions and the determination of the subsequent modal split that result thereof. With the above objective in mind, the inclusion of the trip distribution and assignment steps would then be redundant. It was thus decided to omit these two steps form the model. The omission of the above steps will limit the model domain, as the sketch-planning tool will be unable link the trip origins to their respective trips ends. As a result, the tool is unable to generate an origin/destination matrix, as the generated trips would have no trip ends.
1.4.5. SCENARIO ANALYSES

Chapter 5 of this report lists three cases: expected, lower and upper bound. The three cases represent three distinct scenarios, which can influence Windhoek’s mobility patterns. The scenarios, describe anticipated population demographic trends, socio-economic and mobility trends. The mobility exploration tool did not incorporate the effects of infrastructural interventions on the resultant mobility patterns. As a result, the tool cannot be used to assess the effects of infrastructural interventions with the hope of determining the resultant mobility trends.

1.5. REPORT CONTENT

This section of the report will give a brief overview of the report at hand. Section two, will outline what a travel demand model is, and elaborate on its applications in our society today. The proceeding sections will view the theories associated with travel demand modelling as well as their constitutive steps. This particular section explores the classical four-step model and outlines the modelling approaches associated with each step (trip generation, trip distribution, modal split and assignment). Section 2.6, entails the application of the classical four-step model to the Windhoek case study and hence makes amendments to the respective steps when necessary.

Sections 3.2.1, 3.2.2 and 3.2.3; describe three international case studies, where a particular modelling approach was adopted in the development of the sketch-planning tool specific to the study area under discussion. The approaches used in the case studies are used as “good practice” approaches under which a sketch-planning tool can be developed. In addition, the case studies were useful in the determination of the important variables needed for the development of Windhoek’s model thus eliminating any redundant variables. Once the mobility have been chosen, a formal expression for trip generation and modal splits will be generated (in sections 3.7 and 3.8).

Section four of the report, describes the city of Windhoek in more detail, by analysing the existing conditions found within the city. Particular attention is paid to the transportation characteristics of the areas concerned, such as zone trip summaries, vehicular spatial
distribution, and vehicle ownerships. Additional data presented in this section are of a social demographic nature, where general regarding household demographics are concerned e.g. works status, employment status and access to transport, which all play an important role in influencing household mobility patterns.

Section five of the report, deals with the scenario analyses, which are in fact detailed descriptions of the anticipated economic and transportation trends. These trends are based on empirical data obtained from the Municipality of Windhoek. Several publications and journals from developed and developing countries were consulted for this task. The presented scenarios will attempt to portray the expected, lower and upper bound cases that can potentially culminate from various economic and social activities in Windhoek for the forthcoming 15 years. The scenarios were compiled in consultation with journals written by Coster and Jette, which outlined the mobility behaviours of certain population groups in United States. The reason for introducing the three scenarios in the analyses is to communicate to the user the uncertainties involved in the predictions made.

Section 6 of the report outlines the findings from the modelling. Each finding is discussed in turn and its respective trends explained when possible. The thesis concludes with summarising the results obtained. The report also goes on to recommend the possible approaches that could be utilised to in address the transportation needs, if any, that have emanated from the model findings, as well as other recommendations concerning the meeting of the needs of the residents of Windhoek.
2. MODELLING

The proceeding section of the report, sections 2.1, 2.2, 2.3 and 2.4 will look at the basic terminology and transport modelling approaches that are commonly utilised in modelling transport. This section will also outline each constituent step of the conventional four-step model and outline the methodologies and calculations associated with each step.

Prior to exploring the theories on which basic transportation modelling is founded upon, it is important to develop a comprehensive definition that explains what a transport model is. Literature can offer many definitions in this regard. The formulated definition presented below, was developed in consultation with various publications and sources. In the broadest sense, a transportation model is a:

"a series of mathematical concepts, equations and algorithms that attempt to replicate human decision making within a particular context, which have been derived from observed data and trends in a particular study area, and it attempts to predict the amount and to what degree travel will occur, when transportation infrastructure has been subjected to various changes in time."

(Unknown)

Another definition presented here is as follows:

"A model is a series of mathematical equations and that represent how choices are made when people travel"

(Beimborn, 1995)

Given the above description, it is evident that a transport model attempts to replicate human decision-making, at least as far travel is concerned. Depending on the function of the model, the former statement is subject to change. To understand this in more detail, it is important to ask the question: "Why do people travel and why do they feel the need to travel?"
The answer to the question can be explained by the fact that people travel because they perceive that they will derive a certain benefit from undertaking the trip at hand. The former implies that before any trip is undertaken, the traveller will assess whether he/she will derive a benefit from ensuing the trip. The mere act of assessing the benefits to be accrued is what finally leads to undertaking the trip. The above explanation is simplistic, as human interactions tend to be generally very subjective and complex. Hence, a model’s representation of these interactions is not only simplistic but also inaccurate, especially at micro modelling level. On a more aggregated scale, e.g. settlements and town level, the discrepancies between the actual humanistic travel behaviour patterns and the model tend to be more realistic. Therefore, it is thus of utmost importance to consider the limitations and the applicability of these theories in transportation models.

In a three dimensional space, where segregation of both activities and location exists, whenever the need to communicate arises, the first obstacle to be overcome is the overcoming of the space barrier, that prevents the communication of the parties concerned, through travel. Theoretically speaking, two locations cannot coexist in the same space; therefore, it implies that on an aggregated scale, the need to travel to and from a location is necessary to enable the desired communication possible.

In the twenty first century, where technological advancements have added a new dimension to travel, physical travel is no longer a necessity as in the past. Numerous technological tools have eliminated the need for physical travel. A few of these technologies are the internet, e-mail, the telephone, cell phones, faxes and not to forget the personal computer. Today’s society feels the need to communicate constantly. The advancements in travel and the telecommunications industries evolved to such an extent and simplified communication, that human beings perceive the existence of the available communication tools as indispensable.

It also appears that our society’s sole aim is to be mobile and in touch, the resultant demand to be mobile is starting to pose problems, especially in cities with large populations. The movement of individuals on a small scale is not the problem, but on an
aggregated scale, as in many cities in the world today, it is. The establishment of the importance of mobility in our towns is what prompted transport engineers to model movement of people, in order to be informed and ready to implement suitable strategies to facilitate urban travel. For this reason, transport models play a crucial role in the analysis of movement.

The next section reviews the governing principles used in modelling transport, which is essentially a four-step model that comprises of the trip generation, trip distribution, modal split and traffic assignment steps respectively.

2.1. MODELLING THEORY
As mentioned in the preceding section, the classical urban transport model comprises of four distinct but interconnected steps. These are trip generation, trip distribution, modal split and the traffic assignment step (Sinn, Matthews & Guest, 1998). Depending on the level of modelling, these steps are usually modified accordingly to suit the required situation.

![Classical four-step transport-planning model](Figure_1)

*Figure 1: Classical four-step transport-planning model*

*Sources: Beinborm, 1995; and Sinn, Matthews & Guest 1998*
Figure 1, indicates the hierarchical structure of the classical four-step model as well the initial key inputs. Before any modelling can commence, it is necessary to have the following data in place: base year data, study area (subdivided into suitably sized zones), zone attributes (such as employment, household sizes, general population demographic data, vehicle ownerships, household trip generation rates and travel behaviour related data for the study area under investigation.

2.2. TRIP GENERATION

A trip is defined as a one-way travel journey between the origin and a destination end. Trip generation is the number of trips starting or ending at an area or zone (Sinn, Matthews & Guest, 1998). Trip generation is the first step of the classical four-step transport model (Beimborn, 1995). This step also involves clear division of the study area into smaller sub-units to make computations easier and more manageable. This step involves the utilisation of land-use, population and economic forecasts to estimate the number of person-trips to be generated from each zone (Beimborn, 1995). In the analyses concerned, each zone is treated separately and its zone attributes are determined.

Typical data to be collected can be as follows:

- Zone population;
- Inhabitant ages and genders;
- Household income levels;
- Vehicle ownerships;
- Household size;
- Transport mode of used for trips (work and non-work based) and
- Average trip lengths (by plotting of desire lines on maps).

Sources: Federal Highway Administration (FHWA) Sacramento Land/Use Transportation Model; (Beimborn, 1995), (Lee, D, 1973), (Ono and Lee, 1989), (Vasconcellos, 2001)
It is important to bear in mind, that depending on the required modelling level, additional data may be sought which in turn depends on the exact model requirements in terms of inputs and outputs. Once the required data has been collected, compiled, and analysed, a correlation analysis is carried out. This latter determines the variables that are necessary for the modelling phase, thus eliminating all the redundant variables that might exist within the collected data pool (Devore & Farnum, 1999). The second reason performing the variable correlation is to determine the relative strength and nature of the relationship that exists between the variables (Devore & Farnum, 1999).

![Figure 2: Interactions between origin and destination trips ends.](source: Sinn, Matthews & Guest, 1998)

To capture all trips generated by a zone, it is necessary to consider the trips originating in a particular zone, and terminating at another, as well as the trips originating within another, and terminating within the zone under consideration.

Table 2: Push and pull factors that could influence trip generation and attractions

<table>
<thead>
<tr>
<th>PUSH FACTORS</th>
<th>PULL FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Unemployment</td>
<td>• Access to employment</td>
</tr>
<tr>
<td>• Poor access to services</td>
<td>• Access to services</td>
</tr>
<tr>
<td>• Poor access to facilities</td>
<td>• Facilities (shopping &amp; institutional)</td>
</tr>
<tr>
<td>• Low level service public transport</td>
<td>• High service public transport</td>
</tr>
<tr>
<td>• Air Pollution</td>
<td>• Fresh air</td>
</tr>
<tr>
<td>• Crime</td>
<td>• Safety</td>
</tr>
<tr>
<td>• Distance</td>
<td>• Accessibility</td>
</tr>
</tbody>
</table>

18
The calculation of the total aggregated trips generated by a zone is achieved by applying mathematical relationships, which describe the push and pull factors that attract or deter travellers from travelling to a particular zone. A list of potential "push and pull" factors that could potentially play a large role in shaping travel patterns are presented in Table 2.

The results obtained during this step are used as inputs into the secondary step, which is known as the trip distribution step. Once the collected data has been analysed, the relative strengths of the influencing factors is determined, and then finally a reasonable estimate of generated trips can be made.

2.3. TRIP DISTRIBUTION

Trip distribution describes the number or proportion of trips from the zone origin spread amongst all destination zones (Sinn, Matthews & Guest, 1998). The second step of the classical transport four-step model is the trip distribution step (Beimborn, 1995). This step involves the linking of the trip beginnings and trip ends to form origin-destination pattern of trips (Beimborn, 1995), which is represented as a matrix, known as the origin destination matrix.

Figure 3: The distribution of trips to their respective zones

*Source: Beimborn, 1995*
Once the trips ends have been connected (see Figure 3) with their respective trips origins, and then the trip chains can be represented in the form of a matrix (origin/destination).

This is a common representation of generated trip matrix because it enables the generated table to be represented in a simplified fashion, hence making any subsequent computations relatively straightforward. The abbreviations Ti and Dj are used in the representation of trip origins and trip ends respectively. In summing the columns of the matrix, the total number of trip ends (Dj) of a zone is obtained. Similarly, in summing the rows of the matrix, total trip origins at a zone is calculated.

During this step, it is important to bear in mind that the matrix obtained represents the base year conditions for the study area concerned. Depending on the existing trends in the settlement under investigation and past trends, the data can be updated by the application of theoretical update methods.

Table 3: Limitations of the growth factor and synthetic update methods

<table>
<thead>
<tr>
<th>METHOD</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Growth factor update method</td>
<td>• Simple</td>
<td>• Short-horizon period</td>
</tr>
<tr>
<td>(singly and doubly constrained)</td>
<td>• Exhibits good consistency with the</td>
<td>• In-accuracies in the base matrix may propagate during updating process</td>
</tr>
<tr>
<td></td>
<td>collected data</td>
<td>• Cannot deal with incomplete Origin/Destination matrices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Method is unable to deal with changing transport networks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Large data volumes needed to generate and calibrate base year matrix</td>
</tr>
<tr>
<td>• Synthetic update method</td>
<td>• More realistic</td>
<td>• A bit more complex: require complex functions to calibrate the base matrix</td>
</tr>
<tr>
<td></td>
<td>• Longer horizon period</td>
<td>• Data Hungry</td>
</tr>
<tr>
<td></td>
<td>• Less data collection effort needed</td>
<td>• The method is very theoretical and not really based on what is observed in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>practice</td>
</tr>
</tbody>
</table>

Source: Sinn, Matthews & Guest, (1998), M. Van Maarseveen Presentation (June 2004)

The former statement implies that if the rates of change in trips (origins and destinations) are known, then by applying observed or calculated growth rates, it is then possible to
update the matrix to required year of projection. There are several updating methods available but only two (Growth factor and Synthetic Update) of these will be discussed here partly as other methods are generally hybrids of the two methods presented in this report. The relative advantages and disadvantages of each of the methods will be discussed (see Table 3). Despite the various critiques associated with the two methods, they still provide a useful tool in updating the base matrix. The choice of the method used depends on the user as well as on the required outputs of the model.

2.4. MODAL SPLIT

Modal split is defined as the share (or split) of the generated trios among the different, available transport modes in the area concerned e.g. car, public transport, walk, cycle (Sinn, Matthews & Guest, 1998). Modal split is the critical part of the travel demand modelling process (Beimborn, 1995) and is the third step of the classical four-step model. During this step, the generated trips are split up into categories as follows: by transit, by carpool, by automobile, on foot or by bicycle (Beimborn, 1995). Since few formal definitions for modal split could be found, but by considering the theoretical background behind this step, the modal split could be defined as the constituting share that a certain transport makes of the total trips made by mode.

During this step, trips between a given origin and destinations are split into trips (Beimborn, 1995) made by the prevalent transport modes (the most utilised modes) in the area concerned. The transport modes: private automobiles, transit (buses and taxis), and possibly walking and cycling (Beimborn, 1995). The study of the latter transport modes, the non-motorised and transit systems have been neglected in the past (Vasconcellos, 2001). This was partly due to the high technological commitment to the development of a transport-planning model that favoured automotive modes. However, their inclusion in mobility analyses is gaining importance. This trend has prompted practitioners and researchers to invest more time and effort in attempting to model and understand non-motorised transport (Vasconcellos, 2001). These breakthroughs came about because of an increasing number of studies conducted in developing countries where often, non-
motorised transport modes constitute the majority split of the total transport modes available, e.g. China, India, and Sri-Lanka (Vasconcellos, 2001).

An additional benefit in analysing modal split is that it gives a useful indication of existing utilisation levels of the different transport modes. The former in turn enables decision makers to invest in encouraging the use of certain modes. Table 4, lists various factors that influence modal split.

The factors can be subdivided into the following categories: personal, household, travel distance and transportation system quality. Research has indicated that where modal split is concerned; choosing a mode of transport is highly dependant upon personal or household income, which in turn can be linked to employment levels (Vasconcellos, 2001).

Table 4: Factors that affect modal split

<table>
<thead>
<tr>
<th>Category</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal</td>
<td>Income, Profession, Captive Car, Age, Vehicle Availability</td>
</tr>
<tr>
<td>Household trip characteristics</td>
<td>Personal home-based work trips, Person home-based education al trips, Person home-based shopping trips, Person home-based other trips</td>
</tr>
<tr>
<td>Household characteristics</td>
<td>Income, Dwelling Type, Distance to public transport stop, Household Structure, Number of cars</td>
</tr>
<tr>
<td>Travel Distance/Travel Time</td>
<td>Income, Dwelling Type, Distance to public transport stop, Household Structure, Number of people with driver’s licences, Number of cars available in household</td>
</tr>
<tr>
<td>Transport System Quality</td>
<td>Reliability, Cost, Comfort, Safety</td>
</tr>
</tbody>
</table>

Sources: Sinn, Matthews & Guest, 1998; Vasconcellos, 2001 and M. Berenos Lecture Presentation (June 2004)
2.5. TRAFFIC ASSIGNMENT

Assignment is the process whereby trips are routed from their respective origins to their destinations through the travel network e.g. road, train routes and cycle ways (Sinn, Matthews & Guest, 1998). From the preceding step, the trips relevant to each zone have been distributed accordingly. Once these trips have been split up according to mode, the specific path that they use to travel from their origin to their destination can be found (Beimborn, 1995). This occurs in the last step of the classical four-step model.

These methods are all based on rational thinking theories, which state that a traveller chooses his/her route by taking into account the prevailing conditions of the route and other route attributes, such as distance, generalised cost of travel, safety and comfort. Depending on the existing transport infrastructure and its relative accessibility levels, the traveller chooses a route depending on the benefits expected to be accrued from choosing a particular route. The benefits that are often considered by travellers are time/cost savings, safety and transport mode service levels (Vasconcellos, 2001).

It is imperative to regard that not all of these factors are considered by the traveller at any given time. In fact, in most instances trade offs are often made between factors, in order to arrive at a decision that is the most favourable or beneficial at that particular time. Rational thinking theory implies that prior to an undertaking a trip; a traveller enacts with prior knowledge of the route characteristics. The latter statement is only true to an extent, as people are not perfect reasoning beings. Most travel decisions are never logically sought in this manner, but rather in an imperfect and humanistic way, which from an economic point of view is not sensible.

Three methods applied for the assigning the trips to their respective routes are “all or nothing”, “multiple routing” and “capacity restraint” methods. The “all or nothing” method, traffic is assigned to the shortest route irrespective of the route capacity. The method uses this approach on the assumption that the shortest route (Beimborn, 1995) and that the traveller utilising the route concerned, incurs the least cost. This method is relatively unrealistic because it represents an impractical scenario, which is it is generally
applied to small and un-congested networks. The method is easy to apply and as result. Nevertheless, the obtained results can be both unreliable and often inaccurate. For this reason, the above-mentioned approach is applied to external zones (i.e. outside the study area).

**Multiple routing**, involves the assignment of trips to routes, by taking route attributes such as distance, cost and safety into account. This method is applied to slightly larger networks. The method is more realistic in comparison to the “all or nothing method”. The major flaw with this method is that even though it considers route attributes, it implies that travellers at any given time consider the characteristics of each route, which is not correct.

<table>
<thead>
<tr>
<th>Table 5: Fundamental assumptions behind the three assignment methods</th>
</tr>
</thead>
</table>
| **All or nothing traffic assignment** | • Calculated trips are assigned to the shortest route  
• Method assumes that all travellers will take the shortest route  
• Assumption used is un-realistic in the sense that it does not take into considerations  
• Shortest route is not always the governing choice (depends on prevailing route conditions) |
| **Multiple routing traffic assignment** | • Trips are assigned to depending on route attractiveness  
• (not necessarily aesthetics) but: least cost, safety, short Travel time and degree of congestion are some of the factors that travellers consider |
| **Capacity Restraint traffic assignment (e.g. Wardrop’s equilibrium method)** | • Trips assigned to routes depending on the level of service  
• Capacities and other route attributes are considered  
• Traffic is distributed in such a way so as to eventually reach equilibrium within the network |

*Source: M. Vanderschuren Presentation (June 2004)*

Multiple Routing, assumes that some travellers make seemingly irrational choices. However, since people are all different, this means that chosen route attributes that one
individual might selected might not necessarily be important to another individual. In turn, it brings about a scenario where the humanistic and model attributes will be different.

The last method “capacity restraint traffic” is the most complex of the three. This method uses both route and other travel behaviour attributes to assign trips to their respective routes (see Table 5). The method takes, the non-perfect calculating humanistic nature into account, but simultaneously allows for traffic redistribution within the existing network, which occurs when the routes are congested (Beinborn, 1995). This method is the more representative of what actually occurs on a real network. The major disadvantage with this method is that it is laborious, as it requires many computations. The outputs from this step are in the form of traffic volumes by mode, for the routes within the existing transportation network. Each of the methods used in assigning trips have their respective advantages and disadvantages. Deciding on which method to use purely depends on the individual, of accuracy sought after, level of complexity of the transport network under investigation and the model objectives at hand.

2.6. CRITIQUES OF CLASSICAL FOUR-STEP MODELS

Literature contains numerous critiques that discuss the limitations and shortcomings of classical four step models. Publications by authors such as Atkins (1986) and Goodwin (1997) discuss these critiques in more details. The most commonly found critiques of the classical four-step modes are as follows:

- Predict and provide approaches of the 1950’s and 1960’s, where it was believed that the solution was to provide infrastructure to meet demand.
- Transport models, required large volumes of data to compile and calibrate, and as a result large scale studies had to be carried out to build up the required databanks.
- Forecasting horizons of these models ranged between fifteen to twenty years. These long analysis periods, were based on many assumptions, which are generally as follows:
  - It was possible to predict the future, with a high degree of accuracy.
• Travel behaviour was assumed to remain relatively constant
• It was possible to understand and predict travel behaviour in what has been observed at the transport area zones.
• Trip origins and destinations could be represented as originating and terminating at the zone centroids.

Despite these limitations, the classical four-step model still provides a useful and systematic approach to modelling transport. It is important to bear in mind that because of these critiques, the classical approach evolved, in an attempt to overcome the criticisms. In dealing with the raised criticisms, several adjustments in the modelling approach were made. The first adjustment to the modelling approach was the movement away from the predict and provide approach towards providing an exploratory tool that will enable practitioners to understand the present and perhaps future mobility patterns that are likely to occur as a result of current economic and socio-demographic trends.

The second adjustment made in the sketch-planning tool under discussion is, the model analysis period was reduced to multiples of five-year intervals. The third adjustment was the introduction of uncertainty envelopes. These envelopes were introduced in order to take cognisance of the fact that the future cannot be predicted with a high degree of accuracy. The last adjustment made to the modelling approach, was the bearing in mind that travel behaviour does not remain constant. As a result, it was decided to incorporate scenario analyses into the model, which will attempt to describe the expected as well the unexpected mobility trends.
2.7. MODIFIED FOUR-STEP MODEL

As discussed in the preceding sections, the simulation is a four-step process comprising of trip generation, distribution, modal split and assignment (Beimborn, 1995).

For the purposes of this case study, the focus will be on total trips generated per capita and the subsequent modal split that result thereof. The classical modelling approach thus need to be simplified as indicating in Figure 4, where the distribution and the assignment steps have been omitted.

Bearing in mind the objectives of the sketch-planning tool, the inclusion of the trip distribution and assignment steps would be redundant, as the model, does not have the ability to link the generated trip origins to their respective trips ends. In addition to the above, because of data availability issues, from a development perspective, it was not possible to incorporate a distribution and an assignment stage into the model. As a result, the omission of the steps would to some extent not only simplify the model, but also limit the model domain considerably.

2.7.1. TRIP GENERATION

This step will make use of the variables, which will be identified during the data correlation steps. Having established their respective correlation coefficients, an expression for the trip generation for the town can be obtained. The generated trips must be analysed based on the categories presented in the thesis.
2.7.2. MODAL SPLIT

The modal split step, will make use of the trips generated from the preceding step (trip generation) and utilising the existing modal split trends in the town (collected in the base year). The trips are to be proportionally distributed over the modes to establish the overall modal split trends in Windhoek in a particular year.
3. MODELLING VARIABLES

3.1. MODELLING, VARIABLES AND CASE STUDIES

This section deals with the determination of the variables that influence personal mobility. During the preliminary steps, a primary list was drawn up, which consists of “brainstormed variables” that according to literature affect mobility at a personal or at a household level (see Table 6).

Table 6: Preliminary modelling variables, which influences personal mobility

<table>
<thead>
<tr>
<th>Vehicle Ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Vehicles accessibility per household</td>
</tr>
<tr>
<td>• Number of licensed drivers per household</td>
</tr>
<tr>
<td>• Vehicle ownership</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Household Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Household Income (Hunt, 1994)</td>
</tr>
<tr>
<td>• Employment Status (Hunt, 1994)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Educational Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Education levels</td>
</tr>
<tr>
<td>• School Enrolments and matrix passing rate</td>
</tr>
<tr>
<td>• Tertiary institution enrolment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Household/Population Demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Household member age</td>
</tr>
<tr>
<td>• Zone population pyramid</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transportation Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Household trip generation rates</td>
</tr>
<tr>
<td>• Available transport modes</td>
</tr>
<tr>
<td>• Commonly used modes of transport</td>
</tr>
<tr>
<td>• Public transport fares</td>
</tr>
<tr>
<td>• Fuel prices</td>
</tr>
<tr>
<td>• Vehicle operating costs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level of Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Average total travel times</td>
</tr>
<tr>
<td>• State of the road network</td>
</tr>
<tr>
<td>• Public transport waiting times</td>
</tr>
<tr>
<td>• Transport mode diversity</td>
</tr>
<tr>
<td>• Safety/Aesthetics/Comfort/Air quality</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Economic Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Gross Domestic Product (GDP)</td>
</tr>
<tr>
<td>• Gross National Product (GNP)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Political Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Public Policy</td>
</tr>
</tbody>
</table>

Sources: Federal Highway Administration (FHWA) Sacramento Land/Use Transportation Model (Beimbom, 1995), (Lee, D, 1973), (Ono and Lee, 1989), (Vasconcellos, 2001), (Sinn, Matthews & Guest, 1998), M. Berenos Lecture Presentation (June 2004)

Once the preliminary list was compiled, a series of transport modelling case studies were consulted to determine the relevant mobility variables and hence eliminate the redundant variables in the list. Due to insufficient data available to the modelling team, some of the
initial compiled variables had to be omitted. The consequence of these omissions is that
the accuracy of the model is reduced. Despite the former, most inaccuracies that might
occur in the model will be compensated for during the model calibration step. The second
factor that led to the further elimination of more variables, was that to some of the
initially compiled variables are to some extent interrelated, which means that the effects
of one variable is equally expressed by another, thus making one of the variables
redundant.

3.2. MODELLING VARIABLES
In order to determine, from a theoretical and practical point of view, the variables
necessary to develop a model for Windhoek, a series of case studies were consulted for
this task. Of the consulted case studies, only three of these are presented here and are as
follows:

   I. Case study 1: The Dutch I-move (Section 3.2.1.)
   II. Case study 2: Sacramento’s MEPLAN (Section 3.2.2.)
   III. Case study 3: EMME2: a case study of Hiroshima (Section 3.2.3.)

The presented case studies were taken from leading countries as far as modelling
transport is concerned.

Despite the fact that the presented case studies all had their own objectives and goals in
mind, the governing principles, lessons learnt and their respective methodologies provide
useful information in the determining the relevant variables for the development of the
sketch-planning tool.
3.2.1. STUDY 1: I-MOVE

BACKGROUND
Mobility in modern cities forms an important part of the function of our cities. The resulting movements of goods and people around the city, accrues significant benefits for both the economy and the job market. However, there are negative side effects associated with these movements, especially when they occur on a high scale as is the case with many cities around the world.

The general effects occur usually in the form of traffic accident victims, noise and air pollution (Demis: www.demis.nl/home). One way to reduce the negative impacts is to implement measures which reduce the number of kilometers traveled by car and hence to consider the use of alternative transport modes; bus, train and bicycle. Often though, the use of a combination of different transport modes is attractive enough to form a realistic alternative for utilising the car. The preceding statements and considerations are what led to the development of the “I-move”, which is a strategic multimodal transportation model, developed to model mobility at a strategic level.

The model was developed by Demis in collaboration with the Technical University of Delft, for the Dutch Ministry if Public Works and Transport. For Holland, being a generally multi-modal society, this meant that the developed tool, needed to model freight, personal travel and people on roads, railways and water. An additional module for the I-Move was later added, which was able to estimate the mobility effects in terms of road safety, noise and air pollution (Demis: www.demis.nl/home).

One of the first hurdles that faced by the modelling team was to define a trip chain. Eventually it was decided to define a trip chain as a trip where two or more transportation modes are used. The aim of the model was to analyse personal travel and transit.

MODELLING APPROACH
In the Netherlands, where the availability of open space is becoming an ever-increasing problem, local authorities constantly seek ways to optimize the existing transport infrastructure in order to meet rising transport demand.
The rising popularity in analysing multi modal trips was prompted by the following. Firstly multimodal trips, present the opportunity to reduce long distance car trips (Demis: www.demis.nl/home). The second reason is that they present the opportunity to reduce personal motor vehicle trips. Hence increasing transit patronage, this in turn would lead to an improved utilisation of scarce public space and fiscal resources. A study conducted in the Netherlands, revealed that nearly 3% of all trips in the country are classified as multi-modal trips. For longer distance trips (city to city), multi-modal trips make up a greater share, ranging between, 15%, and 20% of trips.

In order to realise the dream of a multi-modal society, the local authorities have recognised that they would be required to provide infrastructure that will both facilitate this and enable commuters to change from one mode to the other with relative ease through the provision of transport interchange facilities. The former will only be achieved by providing high quality transfer points, which need to offer high quality public transport services and sufficient parking facilities for cars and bicycles (Demis: www.demis.nl/home).

The I-Move like most strategic transport models is static. This means that for each time in the model the calculated traffic intensities represent the average situation of the whole period (Demis: www.demis.nl/home).

The generation step, involves the calculation of trip productions and attractions for each zone by purpose. The distribution step, involves the distributed and balancing of trips across the study area. This leads to the derivation of the origin-destination table per trip purpose.

The trip assignment model uses an integrated route choice model that is used to generate multimodal routes and assign trips based on a generalized cost of the route per category of traveller (Demis: www.demis.nl/home). The generalized cost of travel is based on distance, travel time and actual vehicle operating costs. For multimodal routes, the cost of switching modes is also taken into account, e.g. parking costs and transfer time.
The assignment step uses three methods to assign traffic to their respective routes. These are as follows: All or nothing, multinomial logit model (MNL) and the paired combinatorial logit model (Demis: www.demis.nl/home). The effects of congestion on the links are and corrected by the application of the generalized cost of transport.

**MODEL INPUTS**

The first step is to define the nature of interest of study area concerned. Within that study area, nodes and links (i.e. routes) are identified. The user utilizing the system is free to choose the level at which the modeling will be carried out as well as the variables to be utilized in the analysis. Common inputs are as follows:

a) Node data (population, income levels...etc)

b) Link attributes-roads, railway link data(length, travel time, cost)

c) Trip productions and attractions for each node;

d) Origin/Destination trips for the zones concerned;

e) Trip purposes for each undertaken trip;

f) Transfer time when more than one transport mode is involved and

g) Multimodal Trip chains consisting of two or more vehicular modes.

**MODEL OUTPUTS**

The outputs of the I-Move are in the form of an integrated route choice model, which is used to generate multimodal route choices. The subsequent assignation of trips to their respective routes was carried out utilising a generalised cost of utilising each route, travel time and actual cost of choosing that particular route (Demis: www.demis.nl/home). The I-Move the user can select as route choice model (1) All or nothing, (2) Multinomial Logit model and (3) Paired Combinatorial Logit model (Demis). An iterative loop is used to correct the generalised cost of transport on the links for any congestion effects. The user is able to define the maximum number of iterations in this loop. The model is also able to correct the generalised costs of travel by taking into account congestion effects that can occur on a chosen route.
The output from the model exists in the form of standardised tables, which indicates relevant zone nodes, route links, and origin/destination matrices, as well as other their associated computations. The computed data can also be represented in the form of figures, charts, and schematic diagrams (Demis: www.demis.nl/home).

**MODEL SCALE**
The developed model is not restricted to a specific level as far as modelling is concerned. The model is able to operate at any level (i.e. macro, meso and micro levels), that was required. Deciding on the modelling scale is at the discretion of the user, which again is dependant on the modelling objectives, user specifications and other goals (Demis: www.demis.nl/home).

**TRANSPORT MODES**
The model focused on the analysis of the following transport modes: car, transit (bus and train) and non-motorised transport (cyclists and pedestrians).

**MODEL FEATURES**
One of the features of the I-Move is that it boasts a user-friendly digital map, which provides a comprehensive list of multi-modal route choices, consisting of an origin and destination pair, to the traveller (Demis: www.demis.nl/home). The comprehensive customer oriented map, enables the traveller, to consider different route choices and hence decide upon the best route to take in order to reach the destination of their choice. The planning of a personal trip was facilitated by means of a digital map. This means that the traveller can plan movements more effectively, hence reduce their respective travel times or trip frequencies. The reduction in travel time because of a better-planned route can have positive effects in reducing commuter volumes during transit peaks (Demis: www.demis.nl/home).

**MODEL LIMITATIONS**
From the collected information about the mode, insufficient data exists that critically assess the shortcomings of the I-Move model. In addition to the above, no detailed
explanation of the modelling methodology was executed thus making it extremely difficult to assess the utilised approaches.

3.2.2 STUDY 2: SACRAMENTO’S MEPLAN

BACKGROUND
The Sacramento metropolitan area is a mid-size urban area, when compared to other North American towns. The town has an estimated 1995 population of 1.8 million. It was estimated that, at the current rate, the population and employment levels could be expected to grow at annual rates of 1.9 and 2.2 percent, respectively, through 2015. In the past, the employment base of the Sacramento region has been largely government and agriculture. However, more recently there was a rapid expansion of high-technology manufacturing. The residential and employment densities of the region can be characterized as medium to low. The modal split in the town is largely in favour of the automobile. Private vehicles constitute approximately 76% of the total split. 17% of the population carpool, 3% use transit, 2% walk, and the remaining 2% cycle (FHWA: www.ucalgary.ca).

MODELLING APPROACH
The modelling approach for this case study was not discussed in great depth, therefore the actual procedures used and approach remain somewhat unclear. The MEPLAN model is a land use/transportation interaction model, which has taken the experiences and lessons learnt from modelling experiences in Naples and Bilbao to develop a model, which combines both land use and transportation effects. The model comprises of two components, transportation, and a land use module. The two models works are in essence two entities, which interact with one another in a recursive manner.

Standard travel demand models are generally capable of measuring the transportation impacts of alternative land development patterns. In the case of a land use and transport interaction models such as MEPLAN, TRANUS, or UrbanSim the following modelling objectives can be achieved:
1. Measuring the effect of alternative transportation investments and policies on land use patterns (FHWA: www.ucalgary.ca);
2. Analyzing and consider the impacts of the outputs from the land use module on the transportation performance of the area concerned (FHWA: www.ucalgary.ca);
3. Measuring the effect of alternative land use policies e.g. zoning or tax incentives on land use patterns and the resulting transportation impacts (FHWA: www.ucalgary.ca).

Given the existing land use and the existing activities occurring on them, it is then possible to generate a matrix for any origin/destination pair. The generated and the arriving trips are therefore assigned to specific routes by utilising the utility functions, utilising capacity restraint method to obtain a realistic representation of the traffic flows on the routes. Since the resultant network times affect the attractiveness of the zones and its subsequent land use activities, these results are “fed back” into the model (negative feedback) until the steady state equilibrium is reached. The analysis is carried out in a series of time steps, which makes this framework model quasi-dynamic (Hunt, 1994). The former implies that at any given time period, the model’s the land use patterns are used to generate trips, which in turn generate new land use patterns whose results forms the input of the next time step of the analysis (Hunt, 1994).

The effects of each module were measured for the years 2005 and 2015 on travel, emissions, user benefits, and the spatial distribution of population and employment. The findings indicated that the results of the modeling are not always intuitive. Some of the major findings for the Sacramento region including an accounting for land use effects can have significant impacts on forecast vehicle-trips; vehicle miles traveled (VMT), congestion, and emissions.

The trip generation step of this strategic framework, involved the estimation of trips using the existing land use patterns found in the zones. The model data bank contained detailed information concerning each land use pattern, as well its trip generating potential. Given the former data, the model was able to estimate the trip productions and attractions for each zone (by trip purpose). Since the land use and transport models interact with each
other in a recursive manner, the generated trips (origin destination pair) are fed back into to the land use model to produce a land use pattern for the proceeding time step.

The distribution of generated trips was carried out by using the computed trips attractions, which in turn were estimated using the available land use data. The modal split stage, was not discussed in detail, however, it is known that, the generated trips were categorised by transit and private transport respectively.

The trips assignment stage, involved the assigning of generated trips to their respective zones by using utility functions, with capacity restraint, to obtain a realistic representation of the traffic flows on the routes linking the zones. Since the resultant network times affect the attractiveness of the zones and hence the land use activities, these results were fed back into the model again (negative feedback) until steady state equilibrium was reached. The analysis is carried out in a series of time steps, which makes this framework model quasi-dynamic (Hunt, 1994).

The model was calibrated using the “sequential time step” approach. This process involves the incremental loading of data into the model in a series of steps until the required has been successfully incorporated into the time step concerned. The modelling team automated this process such that once the land use model has completed its analysis; the results are automatically fed into the transportation model for the same analysis period. This procedure is repeated until such a time when equilibrium has been reached.

The MEPLAN model has the additional ability of perform scenario analyses. In total four scenario analyses were considered and are as follows: Minimal Construction (Trend Scenario), Extensive Highway Construction (Beltway Scenario), LRT Construction (Rail Scenario) and the Transit Oriented Development (TOD Scenario). The analysed scenarios represent a case whose probability of occurrence is high because the listed developments are in line with the City of Sacramento’s strategic plan. By exploring the available options, and hence the determining the likely effects, for both land use and mobility, a
well informed decision can be made concerning the type and level of development that
the municipality is likely to implement.

**MODEL INPUTS**
The model under discussion is a data hungry model in the sense that large amounts of
data had to be collected. The following inputs were needed for the modelling process:

a) Household income and zones;
b) Employment and industry data;
c) Supply of zoned land;
d) Social accounting matrices;
e) Transportation networks by mode utilisation;
f) Trips aggregated by category;
g) Distribution travel distances;
h) Origin/destination matrix of total trips made (at the household level); and
i) Floor space data (indicating the impacts of different land use).

*Source:* Federal Highway Administration (FHWA): *Sacramento Land/Use Transportation Model*

The model was calibrated by utilising the “sequential time step” approach (Hunt, 1994). This process involves the incremental loading of data into the model in a series of steps until the required criterion is successfully incorporated into the time step concerned (Hunt, 1994). The modelling team automated this process so that, once the land use model has completed its analysis, the results are used as inputs into the transportation model for the same time-period. This procedure is repeated, until steady state equilibrium for land use activities and demand for travel is reached.

**MODEL OUTPUTS**
The following data outputs are obtainable from the model: total aggregated vehicle-trips, vehicle miles traveled (VMT), congestion computations, vehicle emissions, and the resultant transport modal split (both private and transit).
**MODEL SCALE**

From the discussions covered so far, it has become apparent that the model is relatively coarse in the sense that its approach is strategic i.e. it can be classified as a macro and/or meso level model. In Sacramento’s case study, there were 32 zones in total, therefore obtaining all the required data was relatively cumbersome, time consuming and extremely expensive.

**TRANSPORT MODES**

The following transportation modes were analysed during the case study: automobile, light rail transit and other forms of transit. There is no mention of non-motorised transport in the case study concerned. For this reason, it is relatively unclear whether these modes were included or not. From the generated analysis outputs, such as vehicle miles travelled and fuel emissions, it is likely that the above modes received little or no consideration.

**MODEL FEATURES**

A feature of the MEPLAN is that it consists of a social accounting matrix (SAM), which exists in the form of an input/output table. The table has been greatly expanded to include attributes, such as households, building floor space and land availability (Hunt, 1994). The model also goes further to make use of eleven industry and service categories, aggregated to match the employment and location of the area. Household incomes are categorised into low, middle, and high-income households, thus enabling the output analyses to indicate the stratified trends exhibited by the three groups (Hunt, 1994).

The MEPLAN model provides a number of advantages for assessing regional transportation and land use policies. The inclusion of land use effects, generally, leads to higher travel impacts (positive or negative) for comparable policy scenarios (FHWA: www.ucalgary.ca). Models, such as the MEPLAN are based on a strong economic foundation. Business and residential location decisions are based on the range of factors available. Therefore, the results produced might not necessarily reflect a realistic picture.
However, from an economic standpoint, the model will generate results consistent with the conventional forms of transport analysis approaches.

Since interest in transit-oriented development is growing, a number of regions in the United States have modeled the travel impacts of concentrating development in transit station areas. A land use model, such as MEPLAN, which simulates land markets, can be used to test different policy mechanisms for achieving development objectives.

**MODEL LIMITATIONS**

One of the biggest problems experienced by modelling staff in this case study was the shortage of data to compile and calibrate the model. In Sacramento’s case, it was desired for freight to be modelled as well. However, due to an insufficient data pool, it was not possible. Therefore, this part of the analysis was omitted. Other difficulties faced by the modelling team was that even though the model considered the interactions between transport and land use, inconsistencies in the collected data produced undesirable effects in the model thus making some of the computed results inaccurate (Hunt, 1994).

As most transportation-land use models, the MEPLAN uses large zones and sketch networks. The simplification of the actual networks often leads to different travel and emission results, which are significantly different when compared to the city of Sacramento’s detailed model. Inconsistencies in the results, due to the inaccuracies in the representation of the zones surfaced during the estimation projected vehicle volumes, speeds, distances, and emissions (FHWA: www.ucalgary.ca).

The trade-off, for a detailed representation of land markets and inter-industry interactions, is that a large amount of data is required to develop and calibrate the model. While MEPLAN can be customized based on locally available data, many regions will not have adequate data to take full advantage of the modelling capabilities offered. The application of the model in Sacramento, as a result of inadequate data, would have been strengthened through the availability of floor space data as well as data, from multiple years (FHWA: www.ucalgary.ca).
In addition to the above, MEPLAN’s modelling staff expressed concern over utilising two different models since each one produces different results. If the land use feedback is to be incorporated into travel modelling module for regional planning purposes, an approach will be required that uses a land use model in combination with a travel model that includes a detailed network and zone system (FHWA: www.ucalgary.ca).

Lastly, since travel behaviour is modelled at an aggregate level, the travel behaviour of a certain groups or individuals is masked. The large-scale aggregation does not allow the differences in behaviour between individuals or subsets of the population to be distinguished. While the aggregate approach is less realistic, it is much simpler than modelling an entire heterogeneous market.

Throughout the entire model review, there is no mention of how non-motorised transport was included in the analysis. The exclusion implies that the modelling was primarily focused on motorised transport. The review also fails to clarify a systematic modelling approach that was used thus making it particularly difficulty to assess the methodology used by the modelling staff.

3.2.3. STUDY 3: EMME2, A CASE STUDY OF HIROSHIMA

BACKGROUND

Hiroshima is one of Japan’s fast growing cities and it is located on the western corner of the island of Japan. The city has an estimated population of 1.5 million inhabitants (Ono, China and Lee, 1989). The island is relatively small and the availability of space has become an even increasing concern in the city. Since the 1970’s, Japanese cities, populations often exceed one million. These cities have taken it upon themselves to carry out transportation master plan studies in order to gain a better understanding of the personal and household mobility patterns occurring within such cities (Ono, China and Lee, 1989).

To assess citywide mobility patterns, Japanese local authorities used “in house” developed software (Ono, China and Lee, 1989). This meant that the packages were only
applicable to specific situations. In certain instances, packages were developed by foreign consultants, which meant that they lacked transparency and user friendliness (Ono, China and Lee, 1989), as the recipients of the modelling package did not fully understand the full functionality of the model concerned. Existing software packages were often incompatible with each other, as their output results could not be shared easily among other planning professionals. This was primarily because it was always difficult to decipher the steps that the developed model was performing. An additional problem encountered by Japanese consultants, was that transportation related data was never collected in a standard and consistent format. This meant that the linking of the different database tables was difficult because of the inconsistencies in the data pools compiled on different transport surveys.

Despite the many hurdles faced by the modelling staff, cognisance was taken of the fact that the successful compilation of the data bank, depends on the clear establishment of objectives and goals of the model to be developed (Ono, China and Lee, 1989).

**MODELLING APPROACH**

The modelling approach was similar classical four-step transport model. The modelling steps consisted of trip generation, trip distribution, modal split step and the assignment steps respectively. To generate trips for the zones concerned, regression models were used. Zone attribute data, was utilised in the regression analysis to determine their relative impact on trip generation (Ono, China and Lee, 1989). The derived trip generation equation was of the form:

\[
O_i = 1.36832X_{i1} + 0.70039X_{i2} + 1.16410X_{i3} + 3.02837X_{i4} + 0.82671X_{i5} \\
D_j = 1.40447X_{j1} + 0.67486X_{j2} + 1.19761X_{j3} + 0.92853X_{j4}
\]

Where:
- \(O_i\) = Trip production in zone \(i\)
- \(D_j\) = Trip production in zone \(j\)
- \(X_{i1}\) = Population in zone \(i\)
- \(X_{i2}\) = Employee of agriculture in zone \(i\)
- \(X_{i3}\) = Employee in manufacturing in zone \(i\)
- \(X_{i4}\) = Employee of commerce in zone \(i\)
- \(X_{i5}\) = School enrolment in zone \(i\)
- \(X_{j1}\) = Population in zone \(j\)
- \(X_{j2}\) = Employee of agriculture in zone \(j\)
- \(X_{j3}\) = Employee in manufacturing in zone \(j\)
- \(X_{j4}\) = Employee of commerce in zone \(j\)
- \(X_{j5}\) = School enrolment in zone \(j\)

*Source: Ono, China & Lee, 1989*
To ensure that the model predictions were consistent with those observed in reality, trips generation model calibration was performed. During this analysis, base year trips generated by the model were compared against the existing base year data to determine the root means square.

The trip distribution model used was a doubly constrained gravity model (Ono, China and Lee, 1989). By utilising the base data collected from the surveys, volume-speed tables were generated to calculate the flows on the identified links within the defined transport system. The generated flow/speed tables were used to represent the relationship between the actual volumes of traffic on roads versus the design traffic (Ono, China and Lee, 1989). The relationship obtained was of the form:

\[
T_{ij} = A_i \times B_j \times O_i \times D_j \times t_{ij}
\]

\[
D_j = 1.40447X1j+0.067486X2j+1.19761X3j+0.92853X5j
\]

Where:
- \(T_{ij}\): Trip distribution from zone i to j
- \(O_i\): Trip production from zone i
- \(D_j\): Trip attraction from zone j
- \(t_{ij}\): Travel time from i to j
- \(A_i, B_j\): Balancing Factor

Source: Ono, China & Lee, 1989

The desired vehicles travel times were computed from the collected flow versus speed tables (Ono, China and Lee, 1989). The subdivision of generated traffic volumes into their respective transport mode categories, was achieved by utilising a series utility functions for waiting times, in vehicle time, transfer time and egress time components, travel cost and vehicle availability (Ono, China and Lee, 1989). The travel time computation was iterated and the output from this step was used as an input for the proceeding steps of the analyses, whereby the average travel times by car and transit were eventually computed.

The modal split step was divided into two steps. The first step comprised of walking, cycling and transit. The expressions used were derived from the transit curve used by the
Hiroshima Area Transportation Study (HATS) model. The second step entailed the further sub-division of the other transport modes into their respective categories i.e. car, bus and tram. The former was achieved by utilising a multi-modal logit model (Ono, China and Lee, 1989).

To assign vehicles to their respective routes, a capacity constrained equilibrium assignment method was used. The capacity-constrained method was only used for the assignation of private automobiles and non-motorised transport modes. To assign transit vehicles to the respective routes taken, a separate transit model was developed for that task (Ono, China and Lee, 1989).

\[
\begin{align*}
U_{auto} &= -0.018 \times t_{autoij} - 0.014 \times C_{autoij} + 0.032 \times Y_{1i} - 0.0028 \times Y_{2j} \\
U_{bus} &= -0.018 \times t_{busij} - 0.070W_{busij} - 0.014 \times C_{busij} + 0.20 \\
U_{tram} &= -0.018 \times t_{tramij} - 0.070W_{tramij} - 0.014 \times C_{tramij} + 0.22
\end{align*}
\]

Where:
- \( t_{ij} \): In vehicle, access and egress time from zone i to zone j (in minutes)
- \( W_{ij} \): Waiting time and transfer time from zone i to zone j (in minutes)
- \( C_{ij} \): Travel cost from zone i to zone j (yen/km)
- \( Y_{1i} \): Car availability (vehicles/1000person) [car availability]
- \( Y_{2j} \): employment density in destination zone j (per/ha) [parking availability]

Source: Ono, China & Lee, 1989

MODEL INPUTS

To ensure the adequate modelling of the existing mobility patterns, both public and private transport had to be defined. Hiroshima, such as other cities in Japan, has successfully implemented the use of a citywide coordinated digital roadmap, indicating all the transportation links and nodes. The existing digital route map was developed for nationwide usage, and it has been successfully utilise to aid in many planning sectors. Given the fact that some of the required data was already captured in the city’s digital map, which has well over 1,000 nodes together with 2,700 directionals as well as other transport related information (Ono, China and Lee, 1989). Large volumes of data could be retrieved from the city’s digital map; this meant that the data collection efforts that needed to be carried out were greatly reduced.
As a result, the only data that needed to be collected was information describing the attributes of the population, economy and the study zones. Thus, the data that needed to be gathered for the above purpose are follows: area and social and economic attributes, age/sex population structure, employment status, travel demand matrices by mode and activity.

MODEL OUTPUTS
By utilising the data collected during the field survey, the trip generation and distribution steps, the model was able to estimate an origin/destination pair for the zones concerned. Utilising the modal split module of the model, an estimate of the modal split was made for the following transport modes: automobile, transit, non-motorised transport. The assignment of trips was carried out by utilising the methods outlined earlier. Hence, a graphical representation (in the form of a map) of the traffic volumes on each link in the study area was obtained.

MODEL SCALE
From the procedures applied and the modelling methodology used, the modelling level for this case study can be classified as a composite of a macro and/or meso level model.

TRANSPORT MODES
The modelled transportation modes were as follows: non-motorised transport modes, automobile, and transit.

MODEL FEATURES
After the EMME2 modelling experience, it was established that, as a result of the output format results produced by the EMME2 model, it was now possibly to easily unify the output and matrix tables from the EMME2 model into the HATS model. The former is due to the manner in which EMME2 output tables were written (Ono, China and Lee, 1989). The simplicity and relative transparency of the model has made it easier for practitioners using both the EMME2 and the HATS models to exchange data from the one software to the other without difficulty.
MODEL LIMITATIONS

One of the greatest challenges that faced the modelling team was the shortage of data. The second problem was encountered during the model calibration steps, where the modelling team battled to simulate the collected data in order to suit the observed trends. During the model calibration step, every effort was made in order to ensure that every output produced by the EMME2 model was consistent with the observed trends recorded by the Japanese HATS model. The relative differences between the two models are indicating in Table 7.

Table 7: Differences between the EMME2 model and the HATS model

<table>
<thead>
<tr>
<th>Modelling type</th>
<th>Developed Models in the Study</th>
<th>Hiroshima Project Models [HATS, 1989]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trip Generation (Trip Production)</td>
<td>R-Squared = 0.9704</td>
<td>R Squared = 0.9704</td>
</tr>
<tr>
<td></td>
<td>RMS Rate = 14%</td>
<td>RMS Rate = unknown</td>
</tr>
<tr>
<td>Trip Generation (Trip Attraction)</td>
<td>R-Squared = 0.9713</td>
<td>R Squared = 0.9713</td>
</tr>
<tr>
<td></td>
<td>RMS Rate = 14%</td>
<td>RMS Rate = unknown</td>
</tr>
<tr>
<td>Trip Distribution</td>
<td>R-Squared = 0.9889</td>
<td>R Squared = 0.9652</td>
</tr>
<tr>
<td></td>
<td>RMS Rate = 16%</td>
<td>RMS Rate = unknown</td>
</tr>
<tr>
<td>Modal Split 1 (Diversion Curve)</td>
<td>R-Squared = 0.9907</td>
<td>R Squared = 0.9957</td>
</tr>
<tr>
<td></td>
<td>RMS Rate = 49%</td>
<td>RMS Rate = unknown</td>
</tr>
<tr>
<td>Modal Split (Multi-Modal Logit)</td>
<td>R-Squared = 0.8331</td>
<td>R Squared = 0.8875</td>
</tr>
<tr>
<td></td>
<td>RMS Rate = 18%</td>
<td>RMS Rate = unknown</td>
</tr>
<tr>
<td>Car Assignment</td>
<td>R-Squared = 0.5865</td>
<td>R Squared = unknown</td>
</tr>
<tr>
<td></td>
<td>RMS Rate = 34%</td>
<td>RMS Rate = unknown</td>
</tr>
<tr>
<td>Transit Assignment</td>
<td>R-Squared = 0.9268</td>
<td>R Squared = unknown</td>
</tr>
<tr>
<td></td>
<td>RMS Rate = 38%</td>
<td>RMS Rate = unknown</td>
</tr>
</tbody>
</table>

Source: Ona, China and Lee, 1989

3.2.5. CASE STUDY SELECTION DISCUSSION

In selecting transport-modelling case studies, initially it was very difficult as literature contains many journals discussing the subject matter. One of the criteria used in selecting these case studies, was to try to envelop a wide spectre of modelling approaches as possible and then at a later stage decide on the approach that can be applied to
Windhoek’s context. This requirement was necessary in order to gain a broad on the available modelling approaches that are available internationally.

The first case study, the I-Move, is a multi-modal model, models freight, personal travel and people on roads, railways and water. The ability of the tool to model multi-modal trips sheds light on how to tackle trips that involve more than one transport mode.

The MEPLAN case study was chosen, as it is one of the few models that has the ability to model the recursive relationship between land use and trip generation. Sacramento, being a relatively motorcar dependent city, this case study can be applied in Windhoek’s context, given that motorcar dependencies are also high.

The last case study, (EMME2: A case study of urban Hiroshima), was chosen on the merits that it presented a scenario, which discussed the disadvantages of developing in-house software packages that are incompatible with other readily available software packages. In addition, to the above, the case study provided alternative methods of overcoming the modelling hurdles.
3.2.6. CASE STUDY COMPARISONS

This section of the thesis compares the presented case studies and assesses them in recognising their merits and respective shortcoming (see Table 8). The respective advantages and disadvantages of each model will be described.

Table 8: Comparison of strengths and weaknesses between the models

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
</table>
| I-Move             | • Ability to operate on many modelling levels  
• Estimate the effects of mobility: traffic accidents, air and noise pollution  
• User defined method of trip assignment  
• Visual aids makes data easy to interpret  
• Models both motorised and non-motorised transport | • Model is data hungry  
• The model was compiled for a specific purpose: to explore the use more than one transport mode on a trip  
• Model does not consider the effects of land use on the resultant movement patterns |
| Sacramento’s MEPLAN | • Asses both regional and urban land use policies and transit oriented developments  
• Estimate the effects of alternative transportation investments and policies on land use patterns  
• Quasi-dynamic modeling  
• Estimate the effects of traffic e.g. gas emissions  
• A highly detailed social accounting matrix (SAM), which includes attributes, such as household incomes, land use, building floor space and land availability  
• Recursive relationships between land use and resultant movement patterns | • No consideration to non-motorised transport modes  
• Founded on strong economic principles which sometimes in reality do not reflect a realistic picture  
• Large volumes of data needed to compile and calibrate  
• Modeling simplifications lead to discrepancies between calculated and observed trends  
• Travel behavior is modeled at an aggregate level therefore the behavior of certain groups are masked, thus making it unrealistic  
• Land use and transport models are two independent entities |
| EMME2 (Urban Hiroshima) | • Model output formats are compatible with other software packages  
• Ability to analyse both motorised and non-motorised transport  
• Visual model aids enable users to interpret data with ease | • Large volumes of data are needed to compile and calibrate the model |
3.3. WINDHOEK’S MOBILITY EXPLORATION TOOL

BACKGROUND

Windhoek, the capital city of Namibia, is situated central area of Namibia and has an estimated population of 268,000 people. The town’s population has been growing at an annual growth rate 1.52%. In addition to the natural growth, the town has been receiving a high influx of immigrants, which has accelerated the city’s population growth. 80% of the city’s population can be categorised as low-income, whereas the remaining 15% and 5% can be categorised as middle and high-income respectively.

Private motorised modes constitute approximately 24.7% of the total split. 12.1% of the population use lifts, 3% use busses, 30.2% use taxi, 0.9% cycle, 0.2% use motorcycles and the remaining 29.0% are pedestrians (Central Bureau of Statistics, Namibia-2001 Report).

MODELLING APPROACH

The model consists of three steps: population estimation step, trip generation and lastly the modal split part. The population growth model consists of a model that was derived by fitting a series of trend lines to existing census data, to obtain an equation, which fits the data the best. This was achieved through forward and back-casting techniques, where estimated population figures were compared to the census data in 1981, 1985, 2001 and 2005 respectively. The trend line that yielded the lowest error was chosen.

Using the results of the correlation analysis, performed on available variables, a generalised equation for trip generation was derived and calibrated using 2005, base year data. The derived model is as follows:

\[
GT_{\text{year n}} = 9.8602 \times (VAH_{\text{year n}}) + 7.9576 \times (LDH_{\text{year n}}) + 0.1107 \times (VOZ_{\text{year n}}) + 0.0191 \times TGI_{\text{year n}}
\]

Where:
- VAH = Aggregated Vehicle Access/Household
- LDH = Aggregated number of licensed drivers/household
- VOZ = Aggregated vehicle ownership/zone
- HTGI = aggregated household trip generation rates by income category
Utilising the derived trip generation model, an estimate of trips for each year between 2005 and 2014 was made. Using zone apportionment factors, the aggregated trips were apportioned to their respective zones, hence obtaining a summary of trips generated by each zone.

The last step, modal split, the utilisation of generated trips from the trip generation step, using the derived modal split, obtained using existing base year modal split trends, trips were proportionally distributed by mode to determine the modal split trends for the required year.

**MODEL INPUTS (WHK)**

The model under discussion is a data hungry model in the sense that large amounts of data had to be collected. The following inputs were needed for the modelling process:

- Household income/zones,
- Vehicle access/household,
- number of licensed drivers/household,
- Vehicle ownership/zone,
- and Household trip generation rates by income category.

*Source: Central Bureau of Statistics, Namibia-2001 Report*

**MODEL OUTPUTS (WHK)**

The following data outputs are obtainable from the model: total aggregated vehicle-trips, vehicle miles traveled (VMT), congestion computations, vehicle emissions, and the resultant transport modal split (both private and transit).

**MODEL SCALE (WHK)**

The developed model can be categorised as macro model, as it is concerned with the aggregated trip generation and the resultant modal split for Windhoek. The performed analyses are focused at city wide as opposed to zone levels. This makes the model output data relatively coarse, in the sense that certain mobility and socio-demographic trends are masked by the presence of more pronounced trends.
TRANSPORT MODES (WHK)
The following transportation modes were analysed during the case study: car, lifts, bus, taxi, motor cycle, bicycle and pedestrians

MODEL LIMITATIONS (WHK)
The biggest problems faced, was the shortage of reliable and well-documented data that could be used to develop the model. Due to the problems faced during data gathering stages, this can have significant effects on the model’s accuracy. The second limitation of Windhoek’s model is that since not enough data was available to calibrate the model. Generally, to develop a reliable and accurate model, data banks stretching as far back as fifteen years are required. As a result, of the data shortages, errors contained in the collected data could propagate throughout the model thus magnifying the errors within the model.

The last two domain limitations regarding the sketch-planning tool are concerned with the simplification of the classical four-step model and the specification of the scenario analyses. The simplification of the classical four-step model, by the omission of the trip distribution and assignment stages, meant that the developed, tool is unable to generated an origin destination pair, the step where trip origins are linked to their respective trip ends has been omitted. The last limitation of the developed model is that it is unable to incorporate the effects of infrastructural interventions on the resultant mobility patterns. Therefore, the tool cannot be used to assess such scenarios.

3.3.1. MODEL COMPARISONS
A comparative analysis of the presented models was carried, to determine the strengths and weakness of the identified models. From Table 9, it can be seen on of the greatest strengths that the presented models were that they were able to perform traffic modelling analyses on more than one level. The I-Move Case study and the Hiroshima’s EMME2 models are able to analyse both motorised and non-motorised transport, which is an important merit because the model recognises the importance of including all the
available modes of transport in the study area concerned. For this reason, it makes the modelling rationale complete, from a transport mode point of view.

Table 9: Similarities and differences between Windhoek’s mobility explorer models and the presented case studies

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Similarities</th>
<th>Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windhoek Mobility Sketch Planning Tool versus the I-Move</td>
<td>• Analyses both motorised and non-motorised transport • Model is a strategic model that operates on a macro modelling level • Model follows the conventional four step modelling approach</td>
<td>• Inability to operate on different modelling levels • Does not consider multi-modal trip making • Model does not have a trips distribution and assignment steps</td>
</tr>
<tr>
<td>Windhoek Mobility Sketch Planning Tool versus Sacramento’s MEPLAN</td>
<td>• Model is a strategic model that operates on a macro modelling level • Model follows the conventional four step modelling approach</td>
<td>• Does not consider the effect of land use on the resultant mobility patterns • Model not able to assess both regional and urban land use policies and transit oriented developments</td>
</tr>
<tr>
<td>Windhoek Mobility Sketch Planning Tool versus EMME2 (Urban Hiroshima)</td>
<td>• Analyses both motorised and non-motorised transport • Model follows the conventional four step approach</td>
<td>• Model does not have a trips distribution and assignment steps • Outputs from Windhoek’s mobility explorer model is in tabular form, which is not necessarily easy to apply to other software packages</td>
</tr>
</tbody>
</table>

A general disadvantage with all the models (see Table 8) was that they required large volumes of data to compile and calibrate thus necessitating a large data collection effort during the preliminary steps of the model compilation.

In determining the similarities and differences between the Windhoek’s mobility explorer and the presented case studies (see Table 9), cognisance was taken of the fact that in the three models, the conventional four step approach to modelling was utilised.
3.4. COMPILATION OF PRELIMINARY VARIABLES

The proceeding section of the report (section 3.3.), is going to discuss the variable correlation analyses that were performed on the compiled data in order to determine the influence that each variable has on the overall trip generation potential. The variables used in the three case studies will be used as guide, to indicate the type and nature of variables that are used in the development of a mobility sketch-planning tool. From the case studies, it became evident that the common variables needed to develop a model are as follows:

The variables identified from The I-Move, were as follows: Node and link attributes data, trip productions and attractions for each node, origin/destination trips/per zone, trip purposes and transfer time.

The variables identified from Sacramento’s MEPLAN, were as follows: household income/zones, employment and industry data, supply of zoned land, social accounting matrices, transportation mode utilisation, trips purpose, origin/destination matrix and building floor space data.

The variables identified from EMME2 (A case study of urban Hiroshima), were as follows: Area and social and economic attributes, age/sex population structure, employment status, travel demand matrices by mode and activity.

Depending on data availability, variables similar to those presented case studies in combination with the data obtained from the Central Bureau of Statistics, were used to compile a preliminary list of variables, which will be correlated against each other to determine the relative strengths and nature of the relationships that exist between them.

The compiled list of preliminary variables, to undergo the Pearson correlation analysis, in section 3.3, was as follows:

- Number of licensed drivers per household,
- Vehicle ownership/household income,
Vehicle ownership/zone,
Employment status by sub-region,
and Household trip generation rates by income category.

3.5. PEARSON CORRELATION

3.5.1. PEARSON VARIABLE CORRELATION
To determine, the variables needed for the development of the model, as far as trip generation and modal split modelling is concerned, a correlation analysis had to be performed. The analysis is able to identify the important variables for the compilation of the model, hence eliminate the redundant variables. The method used to achieve this is called the **Pearson Correlation** method. To determine whether a certain variable need to be included in the model or not, a correlation coefficient (r) variable is used (see figure 4a). The coefficient measures the existing relationship between two variables, as well as the strength of the relationship, between them (Key, 1997).

![Pearson Product Moment Correlation](image)

**Pearson product-moment correlation formula**

Source: Key, (1997)

Using the presented case studies and available census data, a preliminary list of variables was compiled and correlation analyses performed. The preliminary list, consisted of the following variables: accessibility to a motorised mode of transport, vehicle ownership per household, licensed drivers/household, vehicle ownership/income, vehicle ownership/zone, income category, employment status (by sub-region), household trip
generation rate/income group, departure times by trip purpose and transport mode utilisation levels.

The compilation of the above-mentioned list was carried out in consultation with the presented case studies. Since the presented studies offered a wide range of modelling techniques and approaches which were similar to those used in developing sketch planning tool under discussion.

The second reason was due to the fact not all the required variables were available during the model compilation and calibration steps. Therefore, the only option left was to utilise the available data, which in some cases lacked important information. As a result of the above action, important variables that could have potentially improved the model’s accuracy could have been omitted. These omissions however, should not affect the model’s accuracy in any way, as these omissions will be accounted for by the high calibration factors (k) that will stem out during the model calibration step.
3.5.2. CORRELATION ASSESSMENT

To ensure that a consistent method of assessing the correlation was consistent, a Pearson correlation assessment scale needed to be used. Table 10 shows an extract of such a scale, which describes the nature and the strength of the relationship between any variables.

Table 10: Pearson correlation coefficient assessment scale (Key, 1997)

<table>
<thead>
<tr>
<th>CORRELATION COEFFICIENT (r)</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>If: $r = +1.0$</td>
<td>Relationship is positive and strong.</td>
</tr>
<tr>
<td>If: $r = -1.0$</td>
<td>Relationship between X and Y is negative and strong.</td>
</tr>
<tr>
<td>If: $0 \leq r \leq +0.5$</td>
<td>Relationship between X and Y is positive and weak.</td>
</tr>
<tr>
<td>If: $-0.5 \leq r \leq 0$</td>
<td>Relationship between X and Y is negative and weak.</td>
</tr>
<tr>
<td>If: $0.75 \leq r \leq +1.0$</td>
<td>Relationship between X and Y is positive/fairly strong.</td>
</tr>
<tr>
<td>If: $0.75 \leq r \leq -1.0$</td>
<td>Relationship between X and Y is negative/fairly strong.</td>
</tr>
<tr>
<td>If: $r = 0$ or close to zero</td>
<td>Relationship between variables X and Y is very weak</td>
</tr>
</tbody>
</table>

3.5.3. PEARSON CORRELATION RESULTS

The correlation analyses yielded the results presented Table 11. The overall correlation analysis yielded interesting, yet surprising results.

Table 11: Results of the Pearson Correlation analysis

<table>
<thead>
<tr>
<th>Variable Title</th>
<th>Variables</th>
<th>Coefficient (r)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of licensed drivers</td>
<td>X: Licensed drivers/ Household</td>
<td>$r_{XY1} = -0.825$</td>
<td>Strong and negative</td>
</tr>
<tr>
<td>Vehicle ownership/ household</td>
<td>Y: No. of Households</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle ownership/ zone</td>
<td>X: Zone Number</td>
<td>$r_{XY1} = 0.970$</td>
<td>Very strong and negative</td>
</tr>
<tr>
<td>Vehicle ownership/ household</td>
<td>Y: No. Households</td>
<td>$r_{XY2} = -0.619$</td>
<td></td>
</tr>
<tr>
<td>Vehicle ownership/ household</td>
<td>Y: Vehicle/ Household</td>
<td>$r_{XY3} = -0.654$</td>
<td>Correlation inconclusive.</td>
</tr>
<tr>
<td>Employment status by sub-region</td>
<td>X: Zone Number</td>
<td>$r_{X1} = 0.011$</td>
<td>Weak and Positive</td>
</tr>
<tr>
<td></td>
<td>Y: Employed pers./house</td>
<td>$r_{X2} = 0.274$</td>
<td></td>
</tr>
<tr>
<td>Household trip generation rates</td>
<td>X: Income Category</td>
<td>$r_{X1} = 0.494$</td>
<td>Average and Positive</td>
</tr>
<tr>
<td>rates by income category</td>
<td>Y: Avg. Trips, Y: Work Trips, Y: School trips,</td>
<td>$r_{X2} = 0.555$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Y: Serv. Pass. Trips</td>
<td>$r_{X3} = 0.480$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$r_{X4} = 0.550$</td>
<td></td>
</tr>
</tbody>
</table>
The proceeding sections will discuss each of the correlated variables in turn, and depending on the obtained correlation coefficients, a decision was made whether to include or to eliminate variable from the model.

From Table 11, it can be seen that the results of the correlation of the correlated variables in turn, and depending on the established relationship between variables, a decision was made whether to include or to eliminate variable from the model.

### 3.5.4. CORRELATION RESULTS DISCUSSION

**LICENSED DRIVERS/HOUSEHOLD**

The licensed driver per household as a variable is important because, by law, all citizens wishing to operate a motorised motor vehicle must be in possession of a valid driver’s license. The former policy plays a significant role in deterring or encouraging people to acquire a driver’s licenses.

When a correlation analysis was performed on the above-mentioned variable, the analysis yielded a correlation coefficient \( r \) of -0.825. This coefficient, suggests that as the number of licensed drivers in a household increase, the number of corresponding households decreases. The obtained relationship could be explained by the fact that as household income levels increase, so does the tendency for the household concerned to have more than one eligible driver.

The above finding could also be interpreted as follows; that as a household’s income increases, there is a greater tendency for the household to have more than one eligible driver. This finding can be debated and is applicable to middle and high-income households respectively. The lower-income households on the other hand, who in most cannot afford a motorcar, having more than one eligible driver, cause any additional drivers to be redundant.
ZONE VEHICLE OWNERSHIPS
The correlation analysis yielded a correlation coefficient of +0.970. The obtained result indicates that the relationship between zone and vehicle ownership is strong and positive. The result confirms the fact that residence location, which in turn is related to personal or household income levels, plays a role in influencing household vehicle ownerships.

In addition to the above, additional information was gathered in order to validate the above-mentioned findings (vehicle ownership by zone). When information regarding the spatial distribution of motorised modes of transport was analysed, it confirmed that residence location does play a role in influencing household vehicle ownership rates and to some extent the financial status of the households residing in the area concerned.

ZONE VEHICLE OWNERSHIPS
The correlation analysis results, suggested that as the zone number (a number assigned to each zone depending on its relative distance from the Central Business District (CBD) increases, the likelihood of a household owning a motorised mode of transport decreases. The obtained correlation coefficients for the three variables $Y_1$, $Y_2$ and $Y_3$ were -0.748, -0.619 and -0.654 respectively (see Table 11). The nature of the relationship is fairly strong; therefore the subsequent inclusion of this variable might be necessary.

EMPLOYMENT STATUS BY SUB-REGION
When employment status by sub-region was correlated against the zone number, correlation coefficients +0.011 and +0.274 were obtained. The results suggest there is a relatively weak relationship between the correlated variables. From the obtained correlation coefficients one can deduce that as the zone number increases, then the number of employed persons per household decreases.

HOUSEHOLD TRIP GENERATION RATES/INCOME
The trips generation rate versus household income correlation analysis was performed for four different trip purposes, which were as follows: average trips ($Y_1$), work trips ($Y_2$), school trips ($Y_3$) and serving-passenger trips ($Y_4$). The resultant correlation coefficients
indicated that there is a strong relationship between the correlated variables. The obtained correlation coefficients $r_1$, $r_2$, $r_3$ and $r_4$ were +0.494, +0.555, +0.480 and +0.550 respectively (see Table 11). From the obtained coefficients, it can be deduced that the nature of the relationship between variables and household income is positive and of average strength.

3.6. VARIABLE SELECTION PROCESS

From the correlation analysis findings, it was possible to eliminate the redundant variables and hence selected variables that will be used in the estimation of the trip generation. The chosen variables (see Table 12), were chosen depending on the strength of the correlation coefficient obtained.

To ensure that the selection criterion was applied consistently throughout the variable selection process, it was decided to eliminate all variables that yielded correlation coefficients ($r$) of less than 0.4 (positive or negative).

Table 12: Variables to be utilized in the mobility exploratory tool

<table>
<thead>
<tr>
<th>VARIABLE TITLE</th>
<th>VARIABLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Access/Household</td>
<td>$X_1$: Vehicles/household, $Y_1$: Vehicle, $Y_2$: Number of persons</td>
</tr>
<tr>
<td>Number of licensed drivers/household</td>
<td>$X_1$: Licensed drivers/household, $Y_1$: Number of Households</td>
</tr>
<tr>
<td>Vehicle ownership/zone</td>
<td>$X_1$: Zone Number, $Y_1$: Number of Households, $Y_2$: Number of households owning a vehicle, $Y_3$: Number of licensed drivers/household</td>
</tr>
<tr>
<td>Household trip generation rates by income category</td>
<td>$X_1$: Income Category, $Y_1$: Average number of trips, $Y_2$: Average number of works trips, $Y_3$: Average number of school trips, $Y_4$: Average number serving passengers</td>
</tr>
</tbody>
</table>

In applying the criterion, two variables were eliminated from the model as their relative influence on trip generation, was considered to be small and hence negligible in comparison to the variables shown in Table 12. The eliminated variables were as follows: “Employment status by sub-region” and “Utilisation of existing transport modes.” The correlated variables, yielded correlation coefficients ($r$), lower than the specified value of 0.4 (absolute).
In addition to the above, two additional variables were eliminated because when correlated against the other variables, in Table 11, the obtained correlation coefficients were very high. The obtained result suggests that the correlated variables are in essence the same variable, but represented in a different form. The inclusion of both variables into the trip generation model would be double counting and therefore, the elimination of one of the variables is necessary.

3.7. TRIP GENERATION MODEL: THE DERIVATION

The trip generation was derived utilizing the chosen variables from section 3.6. Since the collected data did not contain information regarding the trip generation rates for the different zones (see Table 11), it was necessary to derive a means of incorporating the available income data into the trip generation model. This was achieved by calculating the number of households that could be categorised as low, middle, and high-income households respectively. Having known the trip generation rates for the different income groups it was possible to estimate the aggregated person trips generated by each income category for a specific analysis year.

Each variable contained in the model expression, contributes in some way to the generated person-trips, therefore a theoretical equation combining all the variables was used to estimate the aggregated person-trips generated in each year. Therefore the model derived model is a generalised equation that estimates the aggregated person-trip making for the city as a whole. It needs to be born in mind, that the derived generalized does not 100% accurately represent the zonal trip generating capacities of each zone individually; therefore an error always needs to be accepted when developing a prediction model of this nature.
The derived trip generation model is of the form shown below:

\[ GT_{year} = k_1 \times (VAH_{year}) + k_2 \times (LDH_{year}) + k_3 \times (VOZ_{year}) + k_4 \times (HTGI_{year}) \]

Where: 
- VAH = Aggregated Vehicle Access/Household 
- LDH = Aggregated number of licensed drivers/household 
- VOZ = Aggregated vehicle ownership/zone 
- HTGI = aggregated household trip generation rates by income category 

And \( k_1, k_2, k_3 \) and \( k_4 \) are calibration factors for terms VAH, LDH, VOZ and HTGI.

<table>
<thead>
<tr>
<th>TRIP PURPOSE</th>
<th>RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average number of trips</td>
<td>0.542</td>
</tr>
<tr>
<td>Average number of trips to work</td>
<td>0.238</td>
</tr>
<tr>
<td>Average number of trips to school</td>
<td>0.153</td>
</tr>
<tr>
<td>Average number of serving passengers</td>
<td>0.066</td>
</tr>
</tbody>
</table>

From the equation, it was possible to estimate the total person-trips generated from 2005 to 2014. The distribution of these trips by trip purpose was carried out utilizing the distribution factors indicating in Table 13. The table indicates the ratios of zonal person-trip making by purpose versus the aggregated total person for all trip purposes. Utilizing the ratios it became possible to determine the aggregated person-trip for all the zones, as well by each individual zone.

### 3.7.1. CALIBRATION OF THE TRIP GENERATION MODEL

To ensure that the generated model yields results are consistent with the observed trends during the base year (in 2005), a model calibration needed to be carried out. Initially, the values of \( k_1, k_2, k_3 \) and \( k_4 \) were not known and thus had to be determined. The first step involved the determination if the four unknowns. This was achieved by determining the percentage of trips that each term in the equation contributed to the total trip generation. The obtained percentage was then used to assess the relative impact or “weight” that each term had on the overall trip generation.

The second step was to assign arbitrary values for \( k_1, k_2, k_3 \) and \( k_4 \) respectively. The preliminary values of \( k_1, k_2, k_3 \) and \( k_4 \) were determined by first calculating the relative...
weights that each term contributed to the total trip generation (expressed as a percentage). The third step, involved the calculation of aggregated person trips generated in 2001, using the available data. This was achieved by first determining the number of households residing in each zone then using the trip generation.

Using the appropriate household trip generation rate (by income), an estimate of the trips generated by a specific income group residing in a specific zone could be determined. These trips were at a later stage summed to yield the aggregated trip generating potential of the town’s population as a whole. Having determined the generated in 2001, using 1.52% (annual natural growth) and 3.75% (annual rate of urbanisation), it was possible to update the generated trips to the required base year in 2005.

Using the calculated values of \(k_1\), \(k_2\), \(k_3\) and \(k_4\), they were increased or decreased incrementally (by equal amounts) the model generated trips, matched the trips generation data obtained during the base year (2005).

\[
\text{GT}_{\text{year n}} = 9.8602 \times (\text{VAH}_{\text{year n}}) + 7.9576 \times (\text{LDH}_{\text{year n}}) + 0.1107 \times (\text{VOZ}_{\text{year n}}) + 0.0191 \times (\text{HTGI}_{\text{year n}})
\]

Where: \(\text{VAH}\) = Aggregated Vehicle Access/Household
\(\text{LDH}\) = Aggregated number of licensed drivers/household
\(\text{VOZ}\) = Aggregated vehicle ownership/zone
\(\text{HTGI}\) = aggregated household trip generation rates by income category

The iteration process yielded the above expression, which was going to form the basis of the trip generation model. Once the values of \(k_1\), \(k_2\), \(k_3\) and \(k_4\) were calculated, the obtained trip generation model was compared to the 2005 base year data in order to determine the error between the model and the observed 2005 base year data.

From Table 14, it can be observed that the derived model correlates closely with the projected data observed during the base year in 2005. The data also appears to suggest that as the analysis is period increases the percentage error also increases (see Table 14). In 2005, the percentage error between the projected base data and the mode was almost
zero (-0.01%), by 2008, the error increased to -6.97%. Over the next six years, the percentage error between the two data sets increased to -21.2%.

Table 14: Trip generation calibration results

<table>
<thead>
<tr>
<th>YEARS</th>
<th>PROJECTED PERSON TRIP DATA</th>
<th>MODEL ESTIMATE (PERS.-TRIPS)</th>
<th>ERROR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>458118</td>
<td>458175</td>
<td>-0.01</td>
</tr>
<tr>
<td>2006</td>
<td>483589</td>
<td>472534</td>
<td>-2.29</td>
</tr>
<tr>
<td>2007</td>
<td>510476</td>
<td>486893</td>
<td>-4.62</td>
</tr>
<tr>
<td>2008</td>
<td>538859</td>
<td>501253</td>
<td>-6.98</td>
</tr>
<tr>
<td>2009</td>
<td>568820</td>
<td>515612</td>
<td>-9.35</td>
</tr>
<tr>
<td>2010</td>
<td>600446</td>
<td>529973</td>
<td>-11.74</td>
</tr>
<tr>
<td>2011</td>
<td>633831</td>
<td>544330</td>
<td>-14.12</td>
</tr>
<tr>
<td>2012</td>
<td>669072</td>
<td>558690</td>
<td>-16.50</td>
</tr>
<tr>
<td>2013</td>
<td>706272</td>
<td>573049</td>
<td>-18.86</td>
</tr>
<tr>
<td>2014</td>
<td>745541</td>
<td>587408</td>
<td>-21.21</td>
</tr>
</tbody>
</table>

The progressively increasing percentage error, is consistent with findings by Atkins (1986), which suggested that, as the modelling analysis period is increased, the generated results become progressively more inaccurate and unreliable (Atkins, 1986).

3.8. MODAL SPLIT MODEL: THE DERIVATION

The modal split model was derived by using the base year data collected by the National Planning Commission 2001 Census (see Table 15). In the initial data collection steps, seven transport modes were identified. The chosen categorization was also used in the assessment of the zonal and the aggregated city-wide modal split. Of the seven identified transport modes, four are motorised (car, lift, bus and taxi) and the last three are non-motorised (bicycle and walking). The collected data also included as small proportion of trips that could not be categorized, therefore these trips were categorized as being made by an unknown mode. However, these trips constitute such a small percentage, that they will be ignored.
Table 15: Modal split data, by zone for Windhoek.

<table>
<thead>
<tr>
<th>Zone Name</th>
<th>Car (%)</th>
<th>Lift (%)</th>
<th>Bus (%)</th>
<th>Taxi (%)</th>
<th>Bicycle (%)</th>
<th>Motorcycle (%)</th>
<th>Walk (%)</th>
<th>Unknown (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.4</td>
<td>9.3</td>
<td>5.5</td>
<td>24.7</td>
<td>0.8</td>
<td>0.0</td>
<td>49.3</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>1.7</td>
<td>10.3</td>
<td>7.2</td>
<td>31.3</td>
<td>0.0</td>
<td>0.0</td>
<td>49.1</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>14.9</td>
<td>7.4</td>
<td>6.2</td>
<td>40.4</td>
<td>0.6</td>
<td>0.1</td>
<td>30.2</td>
<td>0.1</td>
</tr>
<tr>
<td>4</td>
<td>36.7</td>
<td>6.0</td>
<td>1.7</td>
<td>39.3</td>
<td>0.4</td>
<td>0.1</td>
<td>15.2</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>67.7</td>
<td>4.5</td>
<td>1.9</td>
<td>16.4</td>
<td>0.5</td>
<td>1.6</td>
<td>6.6</td>
<td>0.8</td>
</tr>
<tr>
<td>6</td>
<td>65.7</td>
<td>6.0</td>
<td>1.6</td>
<td>14</td>
<td>0.5</td>
<td>0.5</td>
<td>10.7</td>
<td>1.0</td>
</tr>
<tr>
<td>7</td>
<td>0.0</td>
<td>0.0</td>
<td>7.7</td>
<td>7.7</td>
<td>7.7</td>
<td>0.0</td>
<td>76.9</td>
<td>0.0</td>
</tr>
<tr>
<td>8</td>
<td>59.3</td>
<td>5.8</td>
<td>1.2</td>
<td>22.1</td>
<td>1.2</td>
<td>0.0</td>
<td>10.5</td>
<td>0.0</td>
</tr>
<tr>
<td>9</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>88.9</td>
<td>0.0</td>
<td>0.0</td>
<td>11.1</td>
<td>0.0</td>
</tr>
<tr>
<td>10</td>
<td>6.3</td>
<td>0.0</td>
<td>0.0</td>
<td>18.8</td>
<td>0.0</td>
<td>0.0</td>
<td>75.0</td>
<td>0.0</td>
</tr>
<tr>
<td>11</td>
<td>0.0</td>
<td>33.3</td>
<td>0.0</td>
<td>66.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>12</td>
<td>31.3</td>
<td>0.0</td>
<td>6.3</td>
<td>18.8</td>
<td>0.0</td>
<td>0.0</td>
<td>43.8</td>
<td>0.0</td>
</tr>
<tr>
<td>13</td>
<td>16.7</td>
<td>77.8</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>5.6</td>
</tr>
<tr>
<td>14</td>
<td>34.9</td>
<td>8.9</td>
<td>2.6</td>
<td>33.3</td>
<td>0.5</td>
<td>0.5</td>
<td>19.3</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Source: National Planning Commission 1995 Census Data

Table 15, could be re-written in matrix form as indicating in Figure 5. The matrix form offers many advantages in the sense that it allows the data to be easily updated and managed. By making use of the trip generation matrix, generated in the trip generation step, trips can be distributed to their respective zones and by the mode concerned. Small changes can be expected in the categorized by mode and produced data in Table 15. It was possible to derive a modal split matrix to enable the model to calculate the resultant modal split given the total trips generated by each zone.

![Modal split model, presented in matrix form for Windhoek](image-url)
It was mentioned in the preceding sections of the report, that the modal split model is based on existing data that was collected by the Central Bureau of Statistics in 2001. Given the former, there is no need to calibrate the model since it already correlates with the observed trends. For analyses purposes, the modal split module will need to be updated to incorporate the mode switching that is anticipated for the upper and lower bound cases (see section 5.3.).
4. WINDHOEK: THE CASE STUDY

4.1. EXISTING MOBILITY TRENDS IN WINDHOEK

4.1.1. ACCESS TO MOTORISED TRANSPORT MODES

Access to a motorised mode of transport is an indicator that can be used to indicate the level of accessibility that a household has to a motorised mode of transport, hence ease of mobility. A household with a high levels of access to motorised mode transportation, (car, taxi or bus), will generally be better off, in terms of mobility, in comparison to a household with low levels of access. High degrees of accessibility to motorised transport modes will enable a household to move about with relative ease thus increasing the potential trip making frequencies. A household with low levels accessibility to motorised modes of transport will generally generate fewer trips.

In Windhoek, there are a significant number of households whose access to motorised transport modes is poor. These families are able to survive in a motorised world by making use of either the existing public transport system or family members that own cars. From Figure 6, it can be observed that more than 41% of Windhoek's population do not have access to a motor vehicle. The former result leads to the conclusion that more than majority of Windhoek's residents have no access to a motorised mode of transport. The remaining 30%, 17%, 5%, and 3% of the town's households have access to one, two, three and four motorised modes of transport.

Figure 6: Household access to motorised modes of transport in Windhoek

Source: Central Bureau of Statistics, Namibia, 2001 Report
respectively. Households with two or more vehicles can be categorised as falling into the more affluent income group, which make 25% of total households. An additional trend identified from the chart is, that as number of vehicle accessibility increases, the number of corresponding household numbers decreases. The nature of the relationship cannot be determined at this step.

4.1.2. VEHICLE OWNERSHIP

Vehicle ownership is an indicator of the number of cars available to a specific sector of the population. If the household vehicle ownership rates and the populations for each zone are known, then it is possible estimate the potential traffic volumes generated by a population group.

In Windhoek, the vehicle ownership data collected during the traffic survey indicated that approximately 53% Windhoek’s households do not own a motor vehicle (see Figure 7). This is a typical trend of a developing country, where motor vehicle ownership rates are low. The number of households owning one or two vehicles per household makes up 26% and 14% respectively. The more affluent sector of the population, which own more than two vehicles, constitutes the remaining 3%, 2%, and 5%. The number of vehicles owned by the remaining 5% of the population is unknown.
4.1.3. SPATIAL DISTRIBUTION OF OWNED VEHICLES

Figure 8, indicates the spatial distribution of vehicles in Windhoek. The map indicates that the highest concentration of vehicles is near the city centre. Moving away from the city centre to the suburbs e.g. Auasbick, Hochland Park, Pionerspark, Academia, Hochland Park, Kleine Kuppe, and Klein Windhoek vehicular concentrations decrease rapidly. The lower income areas, such as Havana, Okuryangava, and Hakahana, are situated on the fringes of the city. In these areas, motorised vehicle concentrations are low. Vehicle concentrations are low because the vehicle ownership on a household level is directly linked to the corresponding household income.

In these areas, residents are generally so poor that they are unable to afford to own a vehicle. The prospect of paying a month’s worth of taxi fare to get from home to work is...
also too expensive for many people. In most of these households, the predominant mode of transport is walking, often supplemented by a lift or other forms of transit. The average number of vehicles accessible to a household varies from as little as 0.04 to 0.13.

Areas, such as Katutura and Khomasdal, (the better off areas) have a vehicle ownership rate of 0.41 vehicles per household. The higher income areas are located on the southern and southeastern side of the city. These include Auasblick, Hochland Park, Pionierspark, Academia, Dorado Park, Hochland Park, Kleine Kuppe and Klein Windhoek. They have aggregated vehicle ownership ranging from 1.25 to 1.75 vehicles per household. The vehicle ownership rates in these areas are on average three to four times higher than the lower income areas of Windhoek. Vehicle ownership rates for all the zones in Windhoek have been summarised in Table 16. From the table, it is possible to conclude that households with high vehicle ownerships also have a higher number of registered drivers in their households.

![Table 16: Spatial distribution of vehicle ownership in Windhoek, 2001 Data](source: Central Bureau of Statistics, Namibia, 2001 Report)
4.1.4. LICENSED DRIVERS
In Windhoek, the number of vehicles owned by household is generally higher than the number of eligible drivers. The former is, however, only true among the affluent households. From the Figure 9, it can be observed that 32% of households in Windhoek do not have licensed driver.

Figure 9: Relative percentages of licensed drivers/household in Windhoek
Source: Central Bureau of Statistics, Namibia, 2001 Report

4.1.5. HOUSEHOLD INCOME
Household income is another variable that affects personal and household mobility patterns. In Windhoek’s case study, the effect of household income is expected to be more pronounced because of the high household income disparities that occur within the existing population. Since vehicle ownerships are to some extent directly proportional to household income, the probability of a household owning a motorised mode of transport should increase as well. Therefore, by analysing household expenditures on transport and expressed as a percentage of the household’s total income, it is possible to assess households and hence categorise households into their respective income categories. Table 17, indicates the household income categories for Windhoek. Analyzing the figures, it can be observed that the income per household varies from as little as N$1,00-N$6,000 (low-income) to N$360,000 per annum.
Table 17: Vehicle ownership by household income

<table>
<thead>
<tr>
<th>Annual Income per Household (N$)</th>
<th>No. of HH</th>
<th>No. of HH with no vehicle</th>
<th>No. of HH with a vehicle</th>
<th>% of HH owning a vehicle</th>
<th>Nr. of veh. per group</th>
<th>Mean No. of Veh./HH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>56</td>
<td>23</td>
<td>26</td>
<td>53.1</td>
<td>50</td>
<td>1.02</td>
</tr>
<tr>
<td>No income</td>
<td>120</td>
<td>93</td>
<td>10</td>
<td>9.7</td>
<td>17</td>
<td>0.17</td>
</tr>
<tr>
<td>N$1 - N$6,000</td>
<td>378</td>
<td>304</td>
<td>52</td>
<td>14.6</td>
<td>65</td>
<td>0.18</td>
</tr>
<tr>
<td>N$6,001 - N$18,000</td>
<td>519</td>
<td>380</td>
<td>118</td>
<td>23.7</td>
<td>195</td>
<td>0.39</td>
</tr>
<tr>
<td>N$18,001 - N$42,000</td>
<td>506</td>
<td>292</td>
<td>194</td>
<td>39.9</td>
<td>250</td>
<td>0.51</td>
</tr>
<tr>
<td>N$42,001 - N$72,000</td>
<td>337</td>
<td>126</td>
<td>191</td>
<td>60.3</td>
<td>266</td>
<td>0.84</td>
</tr>
<tr>
<td>N$72,001 - N$132,000</td>
<td>320</td>
<td>68</td>
<td>236</td>
<td>77.6</td>
<td>359</td>
<td>1.18</td>
</tr>
<tr>
<td>N$132,001 - N$360,000</td>
<td>186</td>
<td>22</td>
<td>160</td>
<td>87.9</td>
<td>312</td>
<td>1.71</td>
</tr>
<tr>
<td>N$360,001 or more</td>
<td>51</td>
<td>2</td>
<td>49</td>
<td>96.1</td>
<td>106</td>
<td>2.08</td>
</tr>
</tbody>
</table>

Source: Central Bureau of Statistics, Namibia-2001 Report

Of the households earning less than N$6000.00 per annum, only 21.6% of households own a motor vehicle. The middle-income group (N$18,001 to N$132,000), depending on the income category under consideration, vehicle ownership vary from 26.1% to 60.3%. The income categories, ranging from N$132,000 to N$360,001 and more, almost all the interviewed households own the vehicle. The stated observations confirm that household income does play an important role in affecting household vehicle ownerships. In addition to the above-mentioned analyses, a regression analysis was performed on the data in Table 17 to determine the nature of the relationship between household income and motor vehicle ownerships. The findings of the analysis suggest that as household income increases, then so does the likelihood of a household owning a motorcar.

4.1.6. EMPLOYMENT STATUS BY SUB-REGION

The highest employment levels in Windhoek are in areas with high household incomes, which are namely zones three, four and five (see Figure 10). When employment levels across all the zones are compared, it was found that they range from as low as 33%, in Okuryangava (an informal settlement) to a high of 86%, in the inner city areas.
Unemployment levels, which are in essence the reciprocal of employment levels, range from 14% to 18% between zones five and six, respectively. Informal settlements such as Okuryangava, Hakahana, and Havana were found to have low employment levels.

(see figure 11). The former trend is characteristic of low-income residential areas. Households residing in these areas generally earn very low salaries, which makes their livelihood in the city extremely difficult.

From Figure 11, it can be observed that the average employment levels in Windhoek are of the order of 55% on average in all the zones. It can be observed that Zone 9 has the lowest levels of employment. The former trend is because the concerned accommodates many students thus significantly lowering the potential work force.
4.1.7. WORK STATUS

The work status of a zone provides a useful insight into household employment levels in the zone concerned. Bearing in mind that not all members of a household contribute financially to the overall income of the household concerned. Therefore, an assessment needs to be conducted in order to determine household dependencies that might exist and hence compute a household’s disposable income that can be used for transport. In order to compute the percentage of household’s income that is spent on transport involves the consideration of numerous factors.

For the purpose of this case study, work status was considered in order to predict trip generation. From Figure 12, it can be observed that, of the household interviewed in 2001, 18% were found to be out of work.

Another 33% of household members were either students or learners (see Figure 12). The employment status of the remaining 12.5% of the interviewed households is unknown.

Figure 12: Employment status by sub region in Windhoek

Source: Central Bureau of Statistics, Namibia 2001 Report
4.1.8. POPULATION DEMOGRAPHICS

Population demographics forms an integral part of the mobility analysis. In Windhoek’s case study, both male and female population pyramids were analysed and their respective male/female ratios determined. The calculated ratios provided a useful way of representing the one variable in terms of the other. From the analysis, it was observed that Windhoek has considerably more females in comparison to the males. The approximate male/female ratio for the economically productive group is (18 to 44 years) is 0.85.

![Female age pyramid in Windhoek](Figure 13: Female age pyramid in Windhoek)
Source: Central Bureau of Statistics, Namibia-2001 Report

The above-mentioned trends lead to the deduction that for every male there are 1.17 women. The 45 to 59 age group indicates different trends to those exhibited in the 18 to 44 age category. In the above-mentioned age category, for every female there are 1.29 males.

The elderly age groups (namely 60-64 and the 65+ age groups), also have high ratios in favour of females. The calculated male to female ratio for the two age categories was 0.93.

From Figures 13 and 14, it can be observed that Windhoek has a relatively young population. The majority of Windhoek’s population falls into the working group, which is the 18 to 59 years age group. The youth alone, make up a combined 36.8% (Categories: 0-6; 7-12 and 13-17 years) of the total population. The working cluster, ages 18 to 59 years, constitutes 50.8% of the total male population.
In summary, from Figures 13 and 14, it can be deduced that the population pyramids for the males and females look similar. The existing differences can be found in the elderly groups, namely age 60-64 and 65+ year categories, where the females outnumber the males.

4.1.9. TRIP SUMMARIES BY ZONE

The trips generated by each zone in the study area were analysed and the most significant trends recorded.

From Figure 15, it can be observed that, when considering the overall trips generated by the population concerned, the majority of the generated trips (4,790) originate from zone three (Katutura, Khomasdal, Wanahebra and Goreangab).

In comparison, zones one, two, five, and six only generated 412, 389, 837, and 1580 trips, respectively. The high trip generation frequencies found in zone three, could be attributed to the high population densities found in that zone. The middle to high-income areas, namely Donaba Park, Hochland Park, Kleine Kuppe and Klein Windhoek only generate 7.7% of total trips recorded. Other zones, such as the University of Namibia, Ramaex
and Sports Fields generate few trips in comparison to zone three. Their aggregated total accounts for less than 1% of the generated trips.

From the observed trends, it is possible to conclude that low-income areas in Windhoek generate significantly more trips than the middle or high-income areas. The high trip frequencies found in some of the areas can be attributed to high dwelling densities and the respective household sizes found in these areas. Another reason why low-income households have higher trip frequencies is due to the fact that they do not own or have readily have access to a motorised mode of transport. As a result, the respective households are unable to combine their trips hence minimising the trip frequencies. Consequently, the number of trips required to carry out certain activities, remains high.

4.1.10. HOUSEHOLD TRIP GENERATION RATES

General observations suggest that the data trends collected by the Central Bureau of Statistics for generation rates are directly dependent on household income. From Figure 17, provide the trends that suggest that there exists a relationship between household income and trip generation rate. From the figure, it can be concluded that moving across the income categories from high to low income households, the associated trips generation rates (for average trips) decrease. Among high earning households the average trips generate rate was 2.9 trips per household.
The middle and lower income households for the same trip purpose had a trip generation rates of 2.4 (middle income) and finally 1.9 trips/household (low-income) respectively. Three trend lines were fitted to the observed data to determine the relationship between household income and trip generation rate. The equations produced are cubic models and are presented below:

The obtained theoretical expressions (see Figure 17) obtained are as follows:

\[
\begin{align*}
\text{TGR}_1 &= -0.18 \times I_3^3 + 1.75 \times I_3^2 - 5.85 \times I_3 + 7.15 \quad \text{middle income (2)} \\
\text{TGR}_2 &= -0.20 \times I_3^3 + 1.70 \times I_3^2 - 4.69 \times I_3 + 5.09 \quad \text{low income (3)}
\end{align*}
\]

Where: 
- \( I_3 \) Income category (low-income)
- \( I_2 \) Income category (middle-income)
- \( I_1 \) Income category (high-income)

Utilising the above model, it is possible, given a household income category, to estimate the expected trip generation rate.

### 4.1.12. AVAILABLE TRANSPORT MODES

In Windhoek, the most prevalent mode of transport is the taxi, followed by the car and then lastly the bus. The taxi is an important mode of transport, especially among low and middle-income households that have little or no access to private motorised modes of transport. From Table 18, it can be observed that areas, such as Hakanana and Okuryangava, which are categorised as low-income areas, taxis constitute approximately 56.2% of the total modal split. The use of taxis in these areas is high, because taxis
provide the most reliable means of transport, when compared to other transport modes such as transit.

Since most of the informal settlements in Windhoek are situated on the outskirts of city, the taxi has thus become the best-suited modal choice for many inhabitants. In other areas such as Katutura, Khomasdal, Windhoek West, University of Namibia, and the CBD (Central business district), the use of the taxi is also very high. In these areas, taxis constitute 68.8% of the total modal split. The next mode with high levels of utility is walking. Walking for many residents is a legitimate and genuine mode of transport.

Given the fact that the large proportion of Windhoek's residents are categorised as originating from low-income households, these persons are often left with no choice but to walk. The remaining portion of the population also makes use of walking. This application is used as a supplement to other modes of transport. Of the respondents that were interviewed during the data survey, 69% stated that they supplement other transport modes with walking. Areas, such as Kamalex and Okuryangavera, Hakahana and Otjomuise, where the majority of low-income families reside and work, 100% of them stated that they rely heavily on walking to move about.

The use of transit in Windhoek is generally low. From Table 18, it can be observed that transit utilisation is only high in low-income areas (i.e. Havara, Okuryangavera Katutura, Khomasdal, Wanaheda, and Goreangab). On average 9.7% of the population of Windhoek, uses transit.

Another area where transit level utilisation is high is the University of Namibia. The high utilisation in the area can be attributed to the high student population that commutes from and to the University every day.
Table 18: Transport mode available in Windhoek, 2001 Data

<table>
<thead>
<tr>
<th>Zone Name</th>
<th>Total (No.)</th>
<th>Car (%)</th>
<th>Lift (%)</th>
<th>Bus (%)</th>
<th>Taxi (%)</th>
<th>Bicycle (%)</th>
<th>Motor cycle (%)</th>
<th>Walk (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hartmann and Okuryangava</td>
<td>365</td>
<td>13.9</td>
<td>13.4</td>
<td>16.1</td>
<td>56.2</td>
<td>1.4</td>
<td>0.3</td>
<td>76.2</td>
</tr>
<tr>
<td>Hartmann and Okuryangava</td>
<td>348</td>
<td>13.9</td>
<td>13.5</td>
<td>9.8</td>
<td>56.3</td>
<td>0.6</td>
<td>0.0</td>
<td>74.0</td>
</tr>
<tr>
<td>Katutura, Kleinbean, Windhoek and Gobabeb</td>
<td>3601</td>
<td>26</td>
<td>13.9</td>
<td>9.3</td>
<td>67.4</td>
<td>1.2</td>
<td>0.1</td>
<td>58.4</td>
</tr>
<tr>
<td>Rodey Cres and Gimbavona</td>
<td>1272</td>
<td>39.9</td>
<td>10.7</td>
<td>3.3</td>
<td>53.3</td>
<td>1.6</td>
<td>1.1</td>
<td>33.9</td>
</tr>
<tr>
<td>Donato Park, Hochland Park, Kleine Kuppe, Klein Windhoek, Windhoek, Klein Windhoek, Olaviap, Amania, Hochland Park, Palmwag Park, and Academic</td>
<td>375</td>
<td>78.8</td>
<td>10.6</td>
<td>2.4</td>
<td>36.0</td>
<td>2.6</td>
<td>0.7</td>
<td>19.9</td>
</tr>
<tr>
<td>Okuryangava, Hahabu and Oijoma</td>
<td>510</td>
<td>77.4</td>
<td>14.7</td>
<td>1.7</td>
<td>20.5</td>
<td>6.8</td>
<td>0.0</td>
<td>41.4</td>
</tr>
<tr>
<td>Windhoek, next to CENTRAL BUSINESS DISTRICT</td>
<td>86</td>
<td>73.3</td>
<td>11.6</td>
<td>3.5</td>
<td>33.7</td>
<td>2.3</td>
<td>0.0</td>
<td>38.4</td>
</tr>
<tr>
<td>University of Namibia</td>
<td>9</td>
<td>22.2</td>
<td>0.0</td>
<td>33.3</td>
<td>66.9</td>
<td>11.1</td>
<td>0.0</td>
<td>55.6</td>
</tr>
<tr>
<td>Windhoek West</td>
<td>16</td>
<td>12.5</td>
<td>6.5</td>
<td>0.0</td>
<td>68.8</td>
<td>0.0</td>
<td>0.0</td>
<td>43.8</td>
</tr>
<tr>
<td>Ramatrice</td>
<td>2</td>
<td>66.7</td>
<td>33.3</td>
<td>0.0</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Sports Fields</td>
<td>16</td>
<td>62.5</td>
<td>0.0</td>
<td>6.3</td>
<td>37.5</td>
<td>0.0</td>
<td>0.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Havana and Okuryangava</td>
<td>18</td>
<td>33.3</td>
<td>94.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>66.7</td>
</tr>
<tr>
<td>Unknown</td>
<td>192</td>
<td>42.2</td>
<td>19.5</td>
<td>3.6</td>
<td>68.8</td>
<td>1.6</td>
<td>1.0</td>
<td>58.3</td>
</tr>
</tbody>
</table>

Source: Central Bureau of Statistics, Namibia 2001 Report

The utilisation rates of the private automobile are generally high. Its use is especially high in areas with middle to high-income households. In Windhoek, the middle to high-income areas are: Windhoek West, Donato Park, Hochland Park, Kleine Kuppe, and Klein Windhoek. In these areas, the automobile utility rates are on average of 78.8% of the population residing there.

Other transport modes, such as motorcycles and bicycles are rarely used in Windhoek. From the table it can be observed that the highest level of bicycle usage occurs in Okuryangava, the University of Namibia, Hahabu, and Oijoma. In these areas, between 6.8% and 11.1% of the population use bicycles. When comparing Windhoek to other developing cities in the world, the use of bicycles as a mode is generally low. One of the reasons is the stigma associated with their usage. Many people perceive cycling to be a luxury as opposed to being a genuine mode of transport.
The second stigma associated with cycling is the respective safety aspect. In Windhoek, many cyclists are killed annually, due to motor vehicle to cyclist collisions (Central Bureau of Statistics, Namibia-2001 Interim Report). Therefore, many people are scared to cycle, let alone allow their children to cycle to school, for example.

The last mode of transportation to be discussed here, are motorcar trips made by serving passengers. These are essentially commuters that rely on lifts from friends or family to get from and to their respective destinations. From Table 20, it can be observed that the highest reliance on lifts is in the lower income areas, such as Okuryangava and Havana, where 94.4% of serving passengers reside.

4.1.13. FREQUENTLY USED TRANSPORT MODES

This section is going to look at the existing utility levels for different transportation modes in Windhoek. Table 19, indicates the transport mode utility levels for zones 1 to 13. From the table, it can be observed that the private automobile is by far the most widely used mode of transport. The former statement is applicable to the middle and high-income sector of the population.

In the more affluent areas of Windhoek (near the CBD in comparison to other areas, which are situated even further away, Rocky Crest/Cimbebasia, Dorado Park, Hochland Park, Windhoek/Klein Windhoek), an average 57% of trips are made by motorcar. Considering the households that rely on lifts, it can be observed that this transport mode category is almost constant throughout the study zones. Serving passengers on the other make up an aggregated 5% and 10% of total trips made. The only exception is in Havana, where more than 77.8% of the trips can be categorised as having been made by serving passengers. It was previously stated that taxis and transit form an important modal choice for many low-earning households.

From Table 19, it can be observed that Windhoek has more taxis users than bus users. In zones one to three, 5.5%, 7.2% and 6.2% of people use the bus compared to 24.7%, 31.3%, and 40.4% that use taxis.
The existing trend can be attributed to the inflexibility, unreliability, inadequacy of the existing public transport system. Thus, many of Windhoek’s residents opt to use the taxi because it is better able to cater for their daily needs. The current use of motorcycles and bicycles in the city is very low. The highest level of bicycle usage is found in Okuryangava, Hakahana, and Otjomuise, where 7.7% of the population use them. In other areas, such as Windhoek, Klein Windhoek, Olympia, Aussicht, Hochland Park, Dorado Park, Hochland Park, Kleine Kuppe and Klein Windhoek, bicycle use ranges between 0% and 0.5%.

Table 19: Transport modes most often used in Windhoek, 2001 Data

<table>
<thead>
<tr>
<th>ZONE NAME</th>
<th>TOTAL</th>
<th>CAR (%)</th>
<th>LIFT (%)</th>
<th>BUS (%)</th>
<th>TAXI (%)</th>
<th>BICYCLE (%)</th>
<th>MOTOR CYCLE (%)</th>
<th>WALK (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Havana and Okuryangava</td>
<td>365</td>
<td>10.4</td>
<td>9.5</td>
<td>5.5</td>
<td>24.7</td>
<td>0.8</td>
<td>0.0</td>
<td>69.3</td>
</tr>
<tr>
<td>Havana and Okuryangava</td>
<td>348</td>
<td>1.7</td>
<td>10.3</td>
<td>7.2</td>
<td>21.3</td>
<td>0.0</td>
<td>0.0</td>
<td>49.1</td>
</tr>
<tr>
<td>Kaurima, Khomasdal,</td>
<td>1601</td>
<td>14.9</td>
<td>7.4</td>
<td>6.2</td>
<td>40.4</td>
<td>0.6</td>
<td>0.1</td>
<td>30.2</td>
</tr>
<tr>
<td>Windhoek and Gar Wantshola</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rocky Crest and Cinteharia</td>
<td>1273</td>
<td>46.7</td>
<td>6.0</td>
<td>1.7</td>
<td>39.3</td>
<td>0.4</td>
<td>0.1</td>
<td>15.2</td>
</tr>
<tr>
<td>Dorado Park, Hochland Park, Klein Kuppe, Klein Windhoek</td>
<td>378</td>
<td>67.7</td>
<td>4.5</td>
<td>1.9</td>
<td>16.4</td>
<td>0.5</td>
<td>1.6</td>
<td>6.6</td>
</tr>
<tr>
<td>Windhoek, Klein Windhoek, Olympia, Aussicht, Hochland Park</td>
<td>319</td>
<td>68.7</td>
<td>6.0</td>
<td>1.6</td>
<td>14.6</td>
<td>0.5</td>
<td>0.5</td>
<td>10.7</td>
</tr>
<tr>
<td>Pieter spark and Academy, Okuryangava, Hakahana and Otjomuise</td>
<td>13</td>
<td>0.0</td>
<td>0.0</td>
<td>7.7</td>
<td>7.7</td>
<td>7.7</td>
<td>0.0</td>
<td>76.9</td>
</tr>
<tr>
<td>Windhoek East to CDP</td>
<td>86</td>
<td>59.3</td>
<td>5.8</td>
<td>1.2</td>
<td>22.1</td>
<td>1.2</td>
<td>0.0</td>
<td>10.5</td>
</tr>
<tr>
<td>University of Namibia</td>
<td>9</td>
<td>0.0</td>
<td>6.0</td>
<td>0.0</td>
<td>38.8</td>
<td>0.0</td>
<td>0.0</td>
<td>41.1</td>
</tr>
<tr>
<td>Windhoek West</td>
<td>16</td>
<td>6.3</td>
<td>0.0</td>
<td>0.0</td>
<td>18.8</td>
<td>0.0</td>
<td>0.0</td>
<td>75.0</td>
</tr>
<tr>
<td>Rumatex</td>
<td>3</td>
<td>0.0</td>
<td>33.3</td>
<td>0.0</td>
<td>66.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sports Fields</td>
<td>16</td>
<td>31.3</td>
<td>0.0</td>
<td>6.3</td>
<td>18.8</td>
<td>0.0</td>
<td>0.0</td>
<td>43.8</td>
</tr>
<tr>
<td>Havana and Okuryangava</td>
<td>18</td>
<td>16.7</td>
<td>77.8</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Unknown</td>
<td>192</td>
<td>34.9</td>
<td>8.9</td>
<td>2.6</td>
<td>33.3</td>
<td>0.5</td>
<td>0.1</td>
<td>19.3</td>
</tr>
</tbody>
</table>

Source: Central Bureau of Statistics, Namibia-2001 Report
4.1.14. REASONS FOR USING PARTICULAR TRANSPORT MODES

This section looks at the different reasons which prompt commuters to choose specific modes of transport. In the conducted household survey, it was found that many commuters choose their transport modes depending on its affordability level. Of the respondents interviewed during the survey 41% (in zone one), 52% (in zone two), 27% (in zone three) and 54% (in zone seven) stated that they choose their transport mode depending on its affordability level (Table 20).

Table 20: Reasons for utilising transport mode in Windhoek, 2001 Data

<table>
<thead>
<tr>
<th>Zone Name</th>
<th>Total</th>
<th>Inability (%)</th>
<th>Affordability (%)</th>
<th>Quality (%)</th>
<th>Safety (%)</th>
<th>Status (%)</th>
<th>Ownership (%)</th>
<th>Accessibility (%)</th>
<th>No service Provided (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>365</td>
<td>10.0</td>
<td>41.0</td>
<td>9.0</td>
<td>2.0</td>
<td>1.0</td>
<td>5.0</td>
<td>39.0</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>348</td>
<td>2.0</td>
<td>52.0</td>
<td>9.0</td>
<td>1.0</td>
<td>2.0</td>
<td>5.0</td>
<td>33.0</td>
<td>2.0</td>
</tr>
<tr>
<td>3</td>
<td>360</td>
<td>3.0</td>
<td>27.0</td>
<td>13.0</td>
<td>5.0</td>
<td>1.0</td>
<td>8.0</td>
<td>47.0</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>273</td>
<td>2.0</td>
<td>33.0</td>
<td>9.0</td>
<td>4.0</td>
<td>1.0</td>
<td>24.0</td>
<td>59.0</td>
<td>3.0</td>
</tr>
<tr>
<td>5</td>
<td>378</td>
<td>3.0</td>
<td>3.0</td>
<td>27.0</td>
<td>8.0</td>
<td>1.0</td>
<td>25.0</td>
<td>46.0</td>
<td>1.0</td>
</tr>
<tr>
<td>6</td>
<td>819</td>
<td>8.0</td>
<td>7.0</td>
<td>22.0</td>
<td>11.0</td>
<td>1.0</td>
<td>28.0</td>
<td>37.0</td>
<td>0.0</td>
</tr>
<tr>
<td>7</td>
<td>12</td>
<td>1.0</td>
<td>55.0</td>
<td>8.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>31.0</td>
<td>8.0</td>
</tr>
<tr>
<td>8</td>
<td>86</td>
<td>6.0</td>
<td>1.0</td>
<td>10.0</td>
<td>0.0</td>
<td>0.0</td>
<td>24.0</td>
<td>35.0</td>
<td>0.0</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>0.0</td>
<td>6.0</td>
<td>7.0</td>
<td>3.0</td>
<td>0.0</td>
<td>3.0</td>
<td>33.0</td>
<td>100.0</td>
</tr>
<tr>
<td>10</td>
<td>18</td>
<td>9.0</td>
<td>0.0</td>
<td>0.0</td>
<td>6.0</td>
<td>0.0</td>
<td>15.0</td>
<td>81.0</td>
<td>9.0</td>
</tr>
<tr>
<td>11</td>
<td>3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>10.0</td>
<td>100.0</td>
<td>0.0</td>
</tr>
<tr>
<td>12</td>
<td>16</td>
<td>7.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>10.0</td>
<td>81.0</td>
<td>0.0</td>
</tr>
<tr>
<td>13</td>
<td>11</td>
<td>1.0</td>
<td>2.0</td>
<td>2.0</td>
<td>7.0</td>
<td>1.0</td>
<td>12.0</td>
<td>47.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Source: Central Bureau of Statistics, Namibia 2001 Report

Most respondents that consider affordability to be a governing reason behind choosing a mode of transport are generally from low-income areas. Thus, household's affordability would be a primary consideration when choosing a mode of transport. From the collected survey data, safety too was thought to be an important consideration as far as choosing transport is concerned, i.e. zone 9, where 33% of the inhabitants indicated that safety is one of their primary considerations when choosing a transport mode.

In every city, there are commuters that use a mode, simply because they have no other alternatives available to them. These types of commuters are often referred to as captive
commuters in the sense that they are captive to the transport mode that they are currently utilising. The percentage of persons that choose a transport mode because they are unable to choose anything else are few, however, they constitute on average 2.1% of commuters for zones, 1 to 10.

The quality of transport modes is an important consideration especially in the provision of public transportation. From the collected data, quality of transport was thought to be twice as important as safety (see Table 20). In zones 9, 78% of respondents interviewed stated that the transport mode quality is an important consideration when choosing a transport mode to use. In zones 5 and 6, 22% of respondents stated that transport mode quality is an important consideration.

Vehicle ownership is an important consideration as far as choosing a transport mode is concerned. In zones 5, 6 and 8, an average 22% of households stated that they choose to utilise a transport mode because they own it. In the above-mentioned zones, many households have their own motorcar. Therefore, it is of no surprise to find that these households consider ownership to be an important factor in choosing a mode of transport to use. Among the low-income earning households, an average of 6% households choose a motorcar because they own one (zones one, two and three respectively). In the middle to high-income households, 24.0% to 33.0% of respondents stated they choose the motorcar as they preferred mode of transport due to ownership reasons.

Accessibility, in this context refers to the degree of ease in which an individual can gain access to a specific transportation mode. From table 18, it can be observed that the highest accessibility are found in zones situated close to the central business district. Zones with the lowest levels accessibility, on the other hand, are found on the outskirts of the city where generally low-earning households reside (i.e. zones one, two and three). Medium levels of access can be found in zones four, five, six, and seven, where low to middle-income households reside. In these areas, household accessibility levels range between 31.0% and 46.0%.
5. **SCENARIO ANALYSES**

To be in a position to predict any changes in transport trends based on present trends, it is important to establish, and hence estimate, the effects of the identified factors have on mobility of the study area. Since it is virtually impossible to predict the future with a high degree of accuracy, scenario analyses will be utilised to take cognisance of the uncertainty factor. Utilising this approach, the upper bounds, and lower bounds of accuracy will be identified thus forming an uncertainty envelope where the expected variation is likely to occur.

The subsequent sections of this report will look at the anticipated trends in more detail. The identified limits of the analysis were as follows: Expected Case, Lower Bound Case, and the Upper Bound Case, which were used to determine the extents of the uncertainty envelope. The expected case represents a scenario where present transport, population demographic and economic trends remain virtually unchanged and continue to exhibit similar trends in the future. The latter of the three scenarios: the lower bound and upper bound case, on the other hand represent deviations from the expected trends.

The first trends to be analysed is the population growth trends (Section 5.1.), whose results were generated by using a regression analysis model extracted from the Census Data collected between 1990 and 2005. The population growth will predict the expected population for Windhoek for the analysis period 2005 to 2014. Since there are, certain levels of uncertainty involved in the predictions of upper bound and lower bound, analysis will be performed in order to determine the uncertainty margins to be expected.

Sections 5.2 will explore the expected economic trends to govern the population growth and transportation mobility trends respectively. In this section, scenarios regarding household income levels and employment levels will be portrayed. Since there is no way of determining the direction in which the economic trends will be heading, scenario analyses will also be utilised for this task. Three scenarios will be modelled as result, thus enabling any economic related uncertainties to be established and hence allowed for in the analyses.
Section 5.3 deals with the mobility trends that are likely to emanate from the population and economic trends described in section 5.1 and 5.2 respectively. An analysis of the expected trip generation trends will be made (categorised by income) for the analysis period starting in 2005 and 2014.

Generated trips for all three scenarios, expected, lower and upper bound cases will be outlined, as well as the anticipated changes in trends in each of the above-mentioned scenarios. The last part of this section, deals with changes in modal split trends that are expected to occur for the same scenarios (expected, lower and upper bound cases).

5.1. EXPECTED POPULATION TRENDS

Population changes in Windhoek were estimated utilising an exponential model that was produced generated by utilising national census data. First, a series of trend lines were fitted to the collected data to establish a relationship that would satisfactorily describe the existing data trends. The model trend line that yielded the most accurate results (utilising the root mean square as a measure of accuracy) was a combination of a power of the form:

\[ \text{Population at time } (t) = 92965 \times e^{0.034t} \]

Where \( t \) time in years

Note \( t = 0 \) (is the year 2005)

The calibration of the obtained model was carried out utilising census the 1985, 2001, and 2005 data. To ensure that the obtained model yielded the most accurate results possible, correction factors needed to be applied to the equation to derive the best possible fit. Upon the establishment of the model used to predict population growth, the root mean square error for the obtained model was determined. The results indicated the obtained model, is able to predict the future population growth within a 3.9% error margin for the year 2005. As the analysis period is increased, the error between the model estimate and the observed trends also increases.
In the limitations to the above approach the derived model does not take the various population factors into account, such as the effects of HIV aids pandemic, changes in birth rate and death rate. In addition, it is important to bear in mind that the population model is an aggregated model, which effectively means that the stratification of the various cultural and social income groups and the immigration of people from the rural areas were not considered. Windhoek currently has an estimated population of 233,530 inhabitants. According the city of Windhoek is planning department data, the present growth rate of the town's population has been estimated at 1.52% (projected figures from the 1995 census). The population increase in Windhoek has not only been attributed to existing population growth, but is largely accelerated by urbanisation. The rate of urbanisation is believed to be at an estimated rate of 3.75%. The combined effects of immigration and the natural growth rate of the population. As a result, the town's population has been increasing by an aggregated rate of 12,310 persons per annum, which is equivalent to 2,400 households.

Table 22, indicates the sequential anticipated population trends for three different scenarios. The Upper Bound Case represents a hypothetical situation where the expected trends, are expected to be exceeded. The stated trends were obtained from observed trends in other cities, which have undergone similar developmental patterns in comparison to Windhoek. Under this scenario, the city's population increases at a rate greater than 1% per annum. The expected trend patterns are listed in Table 21. The Expected Case represents a situation whereby the existing population is expected to grow under the same observed conditions (in 2001). The existing household income categories are also expected to remain in the proportions of 80% (low-income), 15% (middle-income) and 5% (high-income).

The Lower Bound Case represents a hypothetical situation that is least likely to occur. However, given the sensitive nature of the possible changes that could occur, due to economic and social pressures, the scenario cannot be ruled out.
Table 21: Demographic scenarios expected to affect Windhoek’s population growth

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>EXPECTED TRENDS</th>
</tr>
</thead>
</table>
| **UPPER BOUND CASE**   | 1. The population growth rate starts to increase at a rate greater than 1%.  
2. Immigrant levels decline and influx of low-income households reduces.  
3. Low income households increases drastically (95% of total population).  
4. 3% and 2% of population, recognised as middle/high-income.  
5. Unequal distribution of resources, causes low-income households not to have adequate access to basic services.  
6. Informal settlements grow in size, thus resulting in high un-employment levels.  
7. Low-income households are no longer able to afford land and hence illegal, squatter settlements form.  
8. Improved medical care, thus reducing the life of people.  
9. Elderly population increases.                                                                                           |
| **EXPECTED CASE**       | 1. Population of children to grow at a rate of 0.1cct (annual growth), with the added in-migration of 3%.  
2. Eighty-eight percent of population low in-income earning 10% middle-income bracket and the last 2% to into the high-income group.  
3. The city continues to provide even at the following rates:  
   2,600 houses = ultra low-income households  
   300 houses = middle-income households  
   50 houses = high-income households  
4. Improvised medical allow people live longer.  
5. Life expectancy of the elderly increases.  
6. Increased government support in terms of pension provision other special needs services e.g. Public transport especially in the urban areas (Coster 1997).                                                                 |
| **LOWER BOUND CASE**    | 1. Population of Windhoek begins to decline.  
2. A major part of the decline is migrants begin to move to other towns.  
3. Due to economic pressures (high costs of living, lack of employment and shortage of basic services), inhabitants decided to move out of Windhoek.  
4. The population starts to decline at a rate of 10% annually.  
5. In-migration halts, yet population continues to decrease.  
6. Low-income earning households find it hard to survive, hence move out of Windhoek.  
7. Middle and high earning begins to find life in the city is increasingly hard.  
8. High-income households remain relatively untouched.  
9. To adjust there is a realisation of fiscal resources (re-budgeting) by families.  
10. Due to accumulated savings per household, the economy will grow through accumulated household fiscal reserves. Through investment in healthcare, this will result in improving health within the population thus allowing people to participate longer in the labour force, thus increasing labour force productivity. |
5.2. EXPECTED ECONOMIC TRENDS

During the case study, the importance of including the economic factors that affect mobility was recognised. Table 22, lists the basic changes that are expected to occur. As in the preceding section, three scenarios are analysed. The economic variables discussed in Table 24 are economic productivity, literacy levels, expenditure on transport, fiscal savings per household and improved health and standard of living.

The problem faced was how to include the above-mentioned factors in the analysis. To avoid double counting, the expected changes in the variables were linked to the variables chosen in the preceding sections of the case study.

Table 22: Economic scenarios expected to affect mobility patterns

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>EXPECTED TRENDS</th>
</tr>
</thead>
</table>
| UPPER BOUND CASE  | 1. Increased motor vehicle usage among high-income households
|                   | 2. Increased usage of transit services by lower-income households due to reduced public transport fares
|                   | 3. Household income increases coupled by increased household savings
|                   | 4. Improved health and standard of living                                        |
| EXPECTED CASE     | 1. Increased number of health workers
|                   | 2. Increased access to high-paying jobs
|                   | 3. Increased employment levels lead to reduced levels of unemployment
|                   | 4. Increased life expectancy increases coupled with increased disposable income
|                   | 5. Improved healthcare amongst the young and elderly, thus increasing life expectancy and producing a healthier workforce
|                   | 6. Increased economic productivity                                              |
| LOWER BOUND CASE  | 1. A greater proportion of Windhoek's is well educated (tertiary education level)
|                   | 2. Increased proportion of persons with high earnings
|                   | 3. Improved transport infrastructure and service levels, thus lowering the total transport cost per capita
|                   | 4. Reduced congestion and travel time will yield greater fiscal savings per household
|                   | 5. Better access to public transport for all income categories
|                   | 6. Additional savings incurred to be used to invest in other activities e.g., land and houses |
5.3. EXPECTED MOBILITY TRENDS

Changes in mobility occur mainly due to the changes in different variables, such as transportation infrastructure, public transport fares and fuel price fluctuations. The above-mentioned factors alone do not cause any significant shifts in transportation modes. However, in combination with other social and household factors they can cause significant changes in travel behaviour and transport mode utilisation.

In the model, the explored changes are due to changes in population demographics, which in turn will cause transport mode ridership to change. The model also goes on further to explore the effect of a population change in affecting personal and household mobility patterns. The anticipated changes are expected to occur in the following categories: motor vehicle accessibility, licensed driver category, household trip generation, and trip category by purpose and modal split (see Tables 24 and 25).

Table 23: Trip generation rate trends, by income category for Windhoek

<table>
<thead>
<tr>
<th>Mode/Scenario</th>
<th>UPPER BOUND CASE</th>
<th>EXPECTED CASE</th>
<th>LOWER BOUND CASE</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOUSING</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOUSEHOLD TRIP</td>
<td>1. Trip generation rates among low-income households remain low</td>
<td>Trip generated by low-income households remain low</td>
<td>1. Trip generation for low, middle and high income households decreases</td>
</tr>
<tr>
<td>GENERATION RATE</td>
<td>2. Increase in trips among middle/high-income households</td>
<td>2. Middle and higher income households potentially generate more trips</td>
<td>2. Pedestrian trips/trips by low income households increase</td>
</tr>
<tr>
<td></td>
<td>3. Low and ultra high income households will remain</td>
<td>3. Decreasingly less time is spent at home than increasing the trips generated per capita</td>
<td></td>
</tr>
<tr>
<td></td>
<td>remaining</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 24: Modal split trends for Windhoek for the expected, upper and lower bound cases

| TRANSPORT MODES | MODES SCA
dario | UPPER BOUND CASE | EXPECTED CASE | LOWER BOUND CASE |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AUTOMOBILES</td>
<td>• Trips by automoble will continue to dominate the vehicular modal split.</td>
<td>• The automoble will continue to be the primary mode of transport as it is reliable and convenient.</td>
<td>• Increasing vehicle operating costs prompt many automoble users to switch to other modes, given that the existing public transport infrastructure has been upgraded to suitable standards.</td>
</tr>
<tr>
<td>TAKS</td>
<td>• Tax industry undergoes transformation due to increasing personal mobility levels.</td>
<td>• The tax industry continues to deliver its low level of service.</td>
<td>• Tax becomes the most popular mode of transport.</td>
</tr>
<tr>
<td>BUSES</td>
<td>• Public transit system undergoes a transformation, allowing present services to be greatly improved in attractiveness.</td>
<td>• Public transport the existing transit system continues to operate in its current inefficient mode.</td>
<td>• Existing transit service upgraded; thus increasing the number of commuters.</td>
</tr>
<tr>
<td>MOTORCYLISTS &amp; NON-MOTORISED TRANSPORT</td>
<td>• Low-income households increase, pedestrian activity increases.</td>
<td>• Pedestrians and cyclists constitute a small percentage of modal split.</td>
<td>• Due to the decline of the town’s population, the number of automoble decreases allowing non-motorised modes of transport to develop and flourish.</td>
</tr>
<tr>
<td>AUTOMOBILES</td>
<td>• Misible and high-income households are reluctant to abandon the automoble.</td>
<td>• Pedestrian and cyclists constitute a small percentage of modal split.</td>
<td>• Due to safety concerns, the use of a bicycle continues to occur on a small scale.</td>
</tr>
<tr>
<td>TAKS</td>
<td>• Number of households utilizing taxis increases.</td>
<td>• Pedestrian and cyclists constitute a small percentage of modal split.</td>
<td>• Due to safety concerns, the use of a bicycle continues to occur on a small scale.</td>
</tr>
<tr>
<td>BUSES</td>
<td>• Improved taxi system, permit commuters to start utilizing taxis.</td>
<td>• Pedestrian and cyclists constitute a small percentage of modal split.</td>
<td>• Due to safety concerns, the use of a bicycle continues to occur on a small scale.</td>
</tr>
</tbody>
</table>


Table 25: Trip generation by purpose in Windhoek

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>UPPER BOUND CASE</th>
<th>EXPECTED CASE</th>
<th>LOWER BOUND CASE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WORK TRIPS</strong></td>
<td>• Work related trips would decline in relation to the other trips as result of decreased employment opportunities</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Middle to high income households expected to contribute the majority of work trips made</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Social and informal sector trips (low/ultra-low income) continue to increase</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Advancements in telecommunications industry will reduce the number of generated work trips</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SCHOOL TRIPS</strong></td>
<td>• School related trips increase because of increasing work opportunities: more parents relocate to Windhoek in pursuit of work</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SHOPPING TRIPS</strong></td>
<td>• Increase population results in increased shopping trips</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Trip frequencies among low and ultra-low income households can be expected to be significantly when compared to higher income households</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MEDICAL TRIPS</strong></td>
<td>• Increased population results in a high demand for medical care, which will in turn result increased trip making</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Improvements in the number of medical facilities will result in increased trips to healthcare facilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Affordable healthcare, will encourage health related trip making</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Work trips expected to remain the same**

**Changes in modal split can be expected across the middle to high income categories**

**Upgrading of the existing public transport facilities will result in increased commuter trips, thus increasing the modal split in favour of other transport modes such as cycling, walking and transit.**

**Due to declining population growth, total aggregated school trips will decrease**

**Shopping trips**

**Low-income households and elderly will continue to have higher trip frequencies to shops via non-motorised modes of transport.**

**Medical trips**

**Improved healthcare and improved transportation facilities, will result in the increased frequency of trips to medical facilities**
6. MODEL FINDINGS

This section of the report deals with the reporting from the model output tables and charts. Section 6.1 will discuss the findings of the generated population growth model and discuss the errors found in the predicting the Windhoek’s population.

Section 6.2 deals with the person trip generation yielded by the derived model. The trips are analysed over nine-year analysis period. The trips generated by the model are further categorised by trip purpose, as well as by income in order to gain a better understanding of the differences in travel patterns expected between the low, middle and high-income households.

The last section, section 6.3 discusses the modal split results of the trips generated by the compiled model. In total (car, lift, bus, taxi, bicycle, motorcycle and walking) are discussed in turn, with particular attention being drawn to the most pronounced transport modes. The modal split analysis has been sub-divided into two sections. The first set of analyses looks at the modal split on an aggregated scale. The second set, looks at the resultant modal split on a zone scale, with attention being drawn the most prominent modes of transport.

6.1. POPULATION GROWTH MODEL

Utilising the derived population estimation model, both the upper and lower bound estimation of Windhoek’s population were determined. The uncertainty envelopes produced were calculated by increasing or decreasing the expected population growth. The pink and yellow lines in Figure 18, represent the upper and lower bound population estimates respectively. To ensure that the obtained model yielded with the observed trends, the error for each respective estimate value was computed.

From Table 26, it can be observed that, in 2005, the estimated population growth for the three scenarios correlate well with each other. During the analysis, the errors obtained for the upper, median and lower population growth estimates were less than 1%. As the
analysis progressed to year 2008, the obtained errors between the observed trends and the calculated estimates increased to +8.0% (overestimate) for the upper bound estimate and -13.4% (under-estimation) for the for the lower bound.

### Table 26: Population estimation model for Windhoek, 2005

<table>
<thead>
<tr>
<th>Year</th>
<th>Upper Bound Case</th>
<th>Expected Case</th>
<th>Lower Bound Case</th>
<th>% Difference in Upper Bound</th>
<th>% Difference in Expected Case</th>
<th>% Difference in Lower Bound Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>298,467</td>
<td>298,467</td>
<td>298,467</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2006</td>
<td>271,559</td>
<td>272,250</td>
<td>265,780</td>
<td>+2.6</td>
<td>0.1</td>
<td>4.7</td>
</tr>
<tr>
<td>2007</td>
<td>273,686</td>
<td>280,372</td>
<td>263,125</td>
<td>+5.4</td>
<td>0.3</td>
<td>-9.2</td>
</tr>
<tr>
<td>2008</td>
<td>278,602</td>
<td>304,889</td>
<td>260,494</td>
<td>-8.0</td>
<td>0.3</td>
<td>-23.4</td>
</tr>
<tr>
<td>2009</td>
<td>279,268</td>
<td>314,069</td>
<td>277,618</td>
<td>+7.0</td>
<td>0.7</td>
<td>-27.5</td>
</tr>
<tr>
<td>2010</td>
<td>282,162</td>
<td>276,552</td>
<td>255,518</td>
<td>+12.8</td>
<td>0.9</td>
<td>-21.2</td>
</tr>
<tr>
<td>2011</td>
<td>284,984</td>
<td>316,097</td>
<td>252,737</td>
<td>+15.1</td>
<td>1.2</td>
<td>-24.7</td>
</tr>
<tr>
<td>2012</td>
<td>287,333</td>
<td>333,283</td>
<td>270,236</td>
<td>+7.3</td>
<td>1.6</td>
<td>-36.1</td>
</tr>
<tr>
<td>2013</td>
<td>290,712</td>
<td>293,272</td>
<td>247,722</td>
<td>+12.5</td>
<td>1.8</td>
<td>-21.2</td>
</tr>
<tr>
<td>2014</td>
<td>293,619</td>
<td>322,318</td>
<td>245,286</td>
<td>+21.4</td>
<td>2.2</td>
<td>-34.1</td>
</tr>
<tr>
<td>2015</td>
<td>296,555</td>
<td>397,304</td>
<td>249,267</td>
<td>+52.4</td>
<td>3.7</td>
<td>-43.3</td>
</tr>
</tbody>
</table>

By the end of the analysis period, year 2015, the percentage error is +19.4% and -31.3% for the upper and lower bound estimates, respectively. The former trends suggest that as attempts to make predictions further into the future, the level of uncertainty involved increases.
6.2. TRIP GENERATION

In analysing the trips generation for Windhoek, from 2005 and 2014, it was necessary to categorise the trip analyses by income, as well as by trip purpose. Sections 6.2.1 and 6.2.2, describe the results yielded during the analyses and the most prominent trends expected in trip generation, based on the stated scenarios: lower bound, expected and upper bound cases. During the discussion, it is important to bear in mind that, the only case or scenario that was determined within reasonable accuracy limits was the expected case. The remaining cases or scenarios are mere representation of a hypothetical scenario.

6.2.2. TRIP GENERATION BY TRIP PURPOSE

The trips generated during the trips generation steps were categorised by trip purpose. In total five trip categories were identified. These are as follows: average trips (an aggregate of all combined trips), work trips (all work related trips), school trips and serving-passerenger trips (taking someone to their destination).

![Graph](image)

Figure 19: Person-trip generation for Windhoek, from 2005 to 2014
The limitations of the above categorisation was recognised during the early steps of the model compilation. However, as a result of data shortages, it was not possible to expand on the above-mentioned categorisation.

From Figure 19, it can be observed that in 2005, the aggregate person-trips were estimated at 458,175. By 2008, the figure is expected to increase to 501,253, which is the equivalent of a 9.4% increase in person-trips. These trips are expected to increase to 544,336 by 2011, and further increase by an additional 43,078 (aggregate growth of 7.91%) trips to 587,408 by 2014.

For the expected case, in 2005, work and school related trips were estimated at 110,000 and 7,000 trips respectively. By 2010, the figure is expected to increase by 6.3% to 117,000 and 7,450 trips respectively. By 2014 the aggregated person-trips can be expected to increase to almost 140,000. The former figure represents an average increase of 19.7% over the nine year period. Similar trends were noted for the school, work, and serving-passenger trips. The only differences are in the magnitude of the trips generated (see Figures 20 and 21). Work related trips generate on aggregate 23.8% of the total generated trips, whereas school and serving-passenger trips generate the remaining 15.3 and 14.3% of the total trips categorized by trips purpose. In 2005, the work, school, and serving-passenger trips were estimated at 109,239; 70,316 and 30,184 person-trips respectively.

![Figure 20: Trip generation by purpose for Windhoek, (Expected Case)](image-url)
By 2010, trips are expected to increase to 126,358 (work trips); 81,335 (school trips) and 34,914 (serving-passenger trips), where the equivalent of 15.6% growth over the five years. By 2014, the same trip purpose categories can be expected to increase by an additional 12.5% to 140,051 (work trips); 90,149 (school trips) and 38,697 (serving-passenger trips) respectively.

In 2010, for the upper and lower bound cases, the total average person-trips are estimated to be around 261,109 for the upper and 255,939 person-trips respectively. By 2014, the former figure is expected to increase to 271,711 and 266,311 for the above-mentioned scenarios. The above finding indicates that the upper and lower bound limits of the analysis are +9.1% and -10.9% above and below the expected average respectively.

Figure 21: Trip generation by purpose for Windhoek. (Upper Bound Case)

Analysing the remaining trip purposes, the findings revealed that between 2010 and 2014, an aggregated increase ranging between 10.1% and 12.7% for the upper bound case, could be expected for work, school and serving-passenger trips.

In 2010, for the lower bound case, the average trips, work, school and serving-passenger trips were estimated at 255,939; 105,735; 69,615 and 29,958 person-trips. By the end of the analysis period, in 2014 the person-trips for the same trip purpose categories can be expected to increase to 266,331; 101,012; 69,060 and 29,779 person-trips respectively.
The above-mentioned changes in person-trips is representative of an aggregate growth of 2.20% for all trip purposes; average, work, school and serving passenger trips respectively.

Figure 22: Trip generation by purpose for Windhoek, (Lower Bound Case)

6.2.3. TRIP GENERATION BY INCOME

From Figure 23, it can be observed that the highest person-trip generation per capita, would be from the high and middle-income households respectively. Despite the fact that Windhoek’s population comprises of medium to low-income households, their respective household trip generating capacities are considerably lower compared to the more affluent sector of the population. Figure 24 (expected case), indicates that, in 2005, the aggregated person-trips, for the expected case, was estimated at 61,213; 83,647 and 103,576 person-trips for the low, middle and high-income households respectively.

The same trip category is expected to increase steadily to 78,479 (low-income); 107,241 (middle-income) and 132,790 (high-income) person-trips by 2014 respectively. The former growth is equivalent to a growth of 18.8% over the nine year analysis period. In analysing the work-person-trips generated by the three income categories, it was observed that the highest trip-generating group was the middle-income group. In 2005, the total number of work-trips generated by the middle-income group was estimated to be 40,255 trips.
Figure 23: Trip generation by income for Windhoek, (Expected Case)

By 2014, the figure is expected to increase to 51,609 work trips. The low-income households yielded significantly lower work-person-trips in comparison to their higher income counterparts. The former trend was expected, since the employment levels among these low earning households tends to be low.

In 2005 the work trips for the income category concerned was estimated at 22,515 work trips and by 2014; the figure is expected to increase to 28,866 work trips. The high-income households generated a similar magnitude of work trips in comparison to their middle-income counterparts. In 2005, work trips were estimated at 46,469 work-person-trips. By 2014, the figure is expected to rise to 59,576 work-person-trips.

Trips to school, for the expected scenario can be expected to increase by 28.2% for all income categories. In 2005, the total person-trips to school generated by low, middle, and high-income groups were estimated 20,912; 23,787 and 25,617 respectively.
In 2010, the figure is expected to increase by 16.0% to 24,189, 27,515 and 29,631 respectively. By 2014, these trips for all income categories are expected to increase by an additional 12.2% to 26,810, 30,496 and 32,842 school trips respectively.

The upper and lower bound cases, for generated trips by income, yielded results similar to the expected case. The observed trends seem to suggest that slight variations in trip making by category can be expected, provided that the stipulated scenarios are realised. From Figures 24 and 25, an estimate of the 2010 person-trips was made. In the year concerned, the average person-trips for the low, middle, and high-income households are 59,389, 85,760 and 106,191 for the upper bound case. The former findings represent a difference in average trips making between the expected and the upper bound case to be well in excess of -12.9%.

The remaining case (lower bound) for the same period, the generated person-trips for the above trip category is estimated at 71,513, 81,577 and 101,012 respectively. The estimated person-trip for the expected case is on aggregate 10.1% higher in comparison to the trips generated for the expected case. The average growth in person-trips between 2010 and 2014 for the upper bound case, is 3.94% for is low income and by 2.02% for the middle and high income households respectively. For the lower bound case (for the same analysis period), between 2010 and 2014, the aggregated person-trips are expected to increase by no less than +10.8% (for the low income) and decrease by 1.9% for the middle and high-income categories respectively. In analysing the trips made to school and work, the following observations were made.

Figure 24: Trip generation by income for Windhoek: (Lower Bound Case)
For the upper bound case, the aggregated person-trips to work, school and serving passenger trips, are expected to be on average 11.2% lower in comparison to the same trip category for the expected case.

For the lower bound case, the total person-trips made to work, school and serving passenger trips are expected to be on aggregate 10.1% for all three-income categories.

6.3. MODAL SPLIT

Figure 27. indicates the expected modal split trends for Windhoek, from 2005 to 2014. It can be observed that Windhoek modal split will continue to be motor vehicle dominated, because both the taxi and the private motorcar are expected to continue serving the middle and high-income households respectively. In terms of transport mode utilisation, walking is still expected to continue to be the second most popular mode of transport. The former trend is particularly pronounced among the low and ultra-low income households, whom most often are captive to the transport mode concerned.

Bicycle usage in Windhoek is expected to gain popularity, particularly as result of anticipated increases in petrol/diesel prices, which is expected to encourage people to switch to cheaper, environmentally friendly alternatives, specifically non-motorised transport modes.
The remaining transport modes e.g. transit and motorcycles will continue to contribute significant magnitude of trips to the overall trip making. However, their relative share of the total modal split is not expected to increase. Transit utilisation in Windhoek, can be expected to operate at its current levels (under-utilised), unless significant changes in transport policy are made that will enable it to serve its current clientele in a better way and hence expand its customer base.

From Figure 28, it can be seen that in 2005, the total number of person-trips made by car, lift, bus and taxi was estimated at 113,088; 55,399; 13,711 and 138,218 person-trips respectively. By 2014, the former figures can be expected to increase by an aggregated 28.2% to 144,985; 71,024; 17,578 and 177,204 person-trips for all the transport modes concerned. Non-motorised transport modes, such as cycling and walking, were estimated 3992 and 130,136 person-trips respectively, in 2005. After nine years, the former figure is expected to increase to 5,118 and 166,842 person-trips respectively.
6.3.1. MODAL SPLIT, BY ZONE

In the determination of the modal split associated with the generated movement trips, for Windhoek, an additional analysis was carried out, which looked at the relative modal splits in each respective zone. Of the analysed zones, zones seven and ten, exhibited the highest pedestrian modal splits. The next highest modal splits were observed in zones one, two and three respectively.

In the above-mentioned zones, the modal split for private automobiles are expected to range from 35% (in zone four), to 65% in zone five and six, to 65% in zone six. From Figure 28, it can be seen that the trips made by taxis, will continue to constitute a significant share of the total modal split. The highest modal share being found in zone nine, where the taxi makes up more than 82.5% of the total modal split. Trips made via motorcycles and bicycles will continue to constitute a small percentage of the total modal split in comparison to the other transport modes.

For the expected case (in 2008), the analysis revealed that in zones one, two and three, walking can be expected to constitute 32.5% for zone three and more than 50.0% for zones one and two respectively.

Zone ten, had the highest recorded pedestrian modal split. Increased its modal share from...
71.3% to 72.5% for the lower bound case analysis. Similarly, zone seven experienced significant changes in its pedestrian modal split.

For the expected case, in 2008, the modal split was highly in favour of the walking. The associated modal split was estimated at 67% for the expected case analysis. The former figure increased to well over 77% for the lower bound analysis.

The remaining zones also experienced changes, but on a smaller scale. The majority of the recorded changes experienced by each respective mode were in favour of the non-motorised transport modes. Trips being made by motorcar continue to constitute a significant share of the overall modal split. However, its effects are only pronounced in zones five, six, eleven and twelve.

The next significant changes in modal split were in trips made by taxis. For the expected case, the respective modal splits ranged from 25% to 40% for zones one to five, six, eight and twelve respectively. For the lower bound case analysis, the aggregated modal split ranged from as little as 10% in zone one to 61% in zone four.

The upper bound case analysis, yielded results different from those observed for the lower bound analysis. In the scenario, the modal share was still in favour of pedestrians for zones one, two and three respectively. The modal split share of trips made by taxis and lifts have all been substantially reduced (see Figure 29 and 30).
For the upper bound scenario, the aggregated trips being made motorised via private automobiles also decreased considerably. For the expected case analysis, the modal share of trips made by car for zones three, four, five, six, eight, 12 and fourteen were 12.5%, 35%, 66% and 64%, respectively. For the upper bound scenario, the figures decreased to 12.5%, 32.5%, 65%, 61.3%, 56%, 29% and 31% respectively (see Figure 31 and 32).

By 2014, the modal shares for car, taxi, lift, bus, walking and motorcycles can be expected to remain unchanged as was previously observed in the expected case analysis for 2008. The only difference to be expected will be in the magnitudes of generated trips that will be utilising the states transportation modes. For the expected case, in 2014, the majority of trips will be made on foot, particularly for zones one, two, three, seven and ten where the most of Windhoek’s low-income households reside. For the same zones, trips made by bus, taxi and car will continue to constitute a significant share of the total modal split, but not as
pronounced. The lower and upper bound scenario analyses (see Figures 32 and 33) yielded results similar to those obtained in 2008 (lower and upper bound analyses). The respective shares of the identified transport modes too are expected to remain unchanged.

For trips made via car, bus, taxi and on foot and for the with the only differences arising as a result of changes in person-trips generated as a result of population growth and rural to city migration. Analysing the modal split share of trips made via bicycles, the analysis indicated that small changes in modal split is expected in comparison to the other transport modes.

Figure 31: Modal split, by zone for Windhoek in 2014 (Upper Bound Case)

In 2014, for the expected case analysis, these transport modes will be expected to constitute no more than the aggregated 1% for zones five, six and fourteen. For the upper and lower bound scenarios respectively, the modal share is expected to remain virtually unchanged.

The former trend can be attributed to the low modal populations that bicycles and motorcycles make up, thus making any changes in their numbers very small in comparison to the other more established transportation modes.
6.4. OBSTACLES ENCOUNTERED

The section of the report deals with some of the difficulties that encountered, during the trip generation and modal split steps. Of the many hurdles encountered, the most pronounced of these are as follows:

a) Data shortages,

b) Difficulty in predicting scenarios cases,

c) Propagation of error through the model (as analysis period is increased).

These hurdles made the modelling very difficult and sometimes impossible. Sometimes the obstacles that presented themselves required the re-thinking of the overall modelling methodology.

The first problem associated with attempting to derive a sketch-planning tool for Windhoek, was the enormous shortage of data. The only information that was available was Namibia's 2001 National Census data and an ad-hoc report submitted by Africon Consulting Engineers to the city of Windhoek in 2005. This shortage of data meant that the potential number of variables that could be used to compile a trip generation model was greatly reduced. The accuracy of the model will not be affected as long as the model is calibrated as accurately as possible such that the model’s base year corresponds to the collected data.

The second problem to be discussed under this section is the difficulty in predicting the scenario analysis. Since it is virtually impossible to determine the events of the future, this meant that analyses performed would have a certain magnitude of uncertainty associated with it. Therefore, the difficulty in estimating the anticipated changes in travel patterns cannot be over-emphasized. The former statement thus implies that even though the expected case is based on the existing data, deviation of the observed data from the projected ones, can occur relatively quickly, thus causing the model results to be highly inaccurate. In addition to the difficult in estimating the scenario effects, another major problem preceding the former is the translation of the described scenario trends into quantifiable data, whilst having no data to validate it. As a result conservative population
growth rates, transport mode switching factors needs to be used to begin to estimate the effects of socio-economic trends on expressed mobility patterns.

The last hurdle encountered during the modelling phase, was the escalation of the error as the modelling process progresses. The former phenomenon is very pronounced especially in cases where long analysis periods are used e.g. 20 years. This problem can be overcome by reducing the analysis periods to five years. If the analysis needs to be over a period longer than the one specified, then a phased approach could be used where the results of the previous phases are used as base year inputs for the following analysis period.
7. CONCLUSIONS AND RECOMMENDATIONS

The first part of this section of the report summarises and highlights important findings obtained from the performed analyses. Attention will be drawn to the surprising results that stemmed from the performed analyses. The conclusions on some of the findings will enable some light to be shed on the transport equity issues associated with the findings, which could maybe enable policy makers and local authorities to address the transport equity issues.

TRIP GENERATION DISCUSSION

From the performed trip generation analysis it became evident the on average person trips in Windhoek can be expected to increase at the most by 28.2% between 2005 and 2014. With the upper and lower bound cases forming the upper and lower limit of the above-mentioned estimate, slight deviations, were noted.

When the generated trips were analysed by trip purpose, it was found that in both scenario cases (upper and lower bound), similar increases in person trip magnitudes for average, school and serving passenger trips can be expected. Work related trips are the only ones that exhibited slightly lower increases in person trips over the analysis period concerned. The slight increases in person trips within some of the zones can be attributed to the high unemployment levels whose trends suggest that the problem is only likely to get worse particularly due to high population influx levels due rural to urban migration.

Windhoek is characterised by the high prominence of low income households can. Almost 805 of the city’s households can be categorised as being from low earning backgrounds. However, due to the high trip generating frequencies of the middle and high-income households, the highest person-trip generation per capita, are expected to occur within these two income categories respectively. Despite the fact that Windhoek’s majority of the population comprises of medium to low-income households, their respective household trip generating rates are considerably lower in comparison to their higher income counterparts. This is why there are such significant differences in trip making between the income groups.
The aggregated increase in person trips between 2005 and 2014, for low, middle and high-income households respectively is expected to be in the region of 18.8% over the nine-year analysis period. The highest numbers of person trips were generated by the middle-income group. In 2005, the total number of work trips generated by the middle-income group whose work trips are expected to increase from 40,255 (in 2005) to 51,609 (in 2014) work trips. Lower income households yielded significantly lower work-person-trips in comparison to their higher income counterparts due to the high unemployment levels found among low-income households.

School related are also expected to increase significantly, because of increasing natural population of the city, which in turn implies that more parents (accompanying) and children will be travelling to schools. The upper and lower bound cases, for the same trip purpose, yielded similar results. The observed trends of the figure produced, have suggested that slight variations in trip making by category can be expected between the different scenarios, as long as the stipulated scenarios are realised.

MODAL SPLIT DISCUSSION
From the modal split analyses, it can be concluded that Windhoek’s modal split will continue to be motor dominated, because both the taxi and the private motorcar are expected to continue serving the middle and high-income households respectively, which in have the highest trips generating rates.

Walking, which is the more predominant mode of transport, especially among the lower earning households, is expected to continue to be the overall second most popular mode of transport in Windhoek. Other modes, such as bicycles and motorcycles will continue to constitute a minority of the total modal split. Transit service in Windhoek, currently caters for the transport needs of the urban poor .the middle and high-income households are reluctant to use it. Therefore, no significant increase person trips are expected unless the existing system is upgraded to such levels to attract the more affluent households.
When the modal split was analysed by zone, the following points were concluded. Zones, seven and ten exhibited the highest followed modal splits in favour of walking. The next highest modal splits were observed to occur in zones one, 2 and 3 respectively. For the expected case (in 2008), it was concluded that the pedestrian modal split for zones 1, 2, and 3, walking can be expected to make up 32.5% for zone three and more than 50.0% for zones one and two respectively. Despite the significant share of the split being in favour of pedestrians, the majority share is still in motorised transport modes (automobiles and taxis). This is the reason why zones four, five, six and eight have high-motorised vehicle modal splits.

For the above-mentioned zones, the aggregated modal split for private automobiles is 55%. The highest modal split for taxis is found in zone 9. In this zone, taxis make up more than 82.5% of the total modal split. For the expected case, trips made via transit, motorcycles and bicycles contribute a small portion in comparison to the taxis and private automobiles. For the lower bound analysis, the relative proportions of the modal splits have changed considerably. On aggregate the differences between the expected and the upper and lower bound cases respectively ranges between 2% to 5% depending on the transport mode under discussion.

CONCLUDING REMARKS

From the concluding statements, it is evident that the trips distribution and the assignment steps of modelling were not performed, as these two stages were not part of the objectives of the developed model. Given that, data availability hurdle that was encountered throughout the modelling exercise, the omission of the two steps, lowered the data availability burden hence enabling the successful development of the sketch-planning tool.

From the performed analyses, it was established the middle and high-income households have the highest person trips generation rates it is of no surprise to find that in motorcar-oriented town, the provided transport infrastructure favours the user with the highest trip making frequencies. However, since the urban poor make up more than 80% of the
town’s population, maybe it is time to implement equity driven transport provision strategies to uplift the lower income households. In uplifting them, then the household accessibility to the City Centre will potentially increase. The empowerment could be executed through the provision of affordable transport means. The upgrading of the existing public transport system coupled by the re-structuring of the taxi industry is one way improving transport service levels for the poor and hence partially achieves the desired transport equity.

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