Application of the 4-Step Model in Forecasting Private Vehicular Traffic in an African Metropolis with Low Data

The Case of Lagos Metropolis, Nigeria

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Urban transportation is rooted in the concept of visions for the future, and the future transportation environment is a matter of priorities and choices – H. Dimitriou

Abstract

Traffic demand analysis is a vital aspect in the planning process of a transportation system. While most developed countries usually employ disaggregate modelling systems that relies on large amount of data, developing countries that are characterised by lack of robust data still have to rely on the aggregate trip-based approach for strategic level assessment of the transportation system. This study utilised the 4-step process to model private vehicle traffic in the city of Lagos, Nigeria, using GIS-based traffic modelling software, PTV Visum, with only available data being population forecast, Origin-Destination trip matrix and traffic count.

The study defined 20 traffic analysis zones comprising the 20 local administrative areas in the city. The road network comprising arterial and distributor roads totalling 1688km in length were developed using network creation tools in Visum software. Data utilised were gathered from the Lagos transport planning authority and Lagos bureau of statistics. The 4-step process (Trip generation, Distribution, Modal Choice and Assignment) were carried out without the modal choice step.

Trip generation modelling employed log-linear regression method by developing a log-linear relationship between the total car trip production and attraction of each zone and the population of the zone. The developed model was applied in estimating future year (2025) production and attraction using population forecast data for that year. The Trip distribution and parameter estimation employed the gravity model inbuilt in Visum, using the negative exponential deterrence function as the distribution function and free-flow travel time between zones as the impedance. In Traffic Assignment step, the Visum-distributed trips were assigned to the network using the equilibrium assignment model. The volume-delay function used was the BPR function, with parameters set at default values of the basic BPR curve. Assignment was followed by calibration of the demand matrix to traffic count. Two matrix calibration techniques, the T-flow fuzzy and the Lohse Calibration approaches were utilised and compared.

The study showed that for the 62% growth forecast in population between year 2006 and 2025, total produced and attracted car trips will grow by 134% and 194% respectively, while the modelled network mean saturation based on vehicle kilometre travelled will grow from about 68% to 130%. The study also revealed the T-Flow fuzzy to be a better calibration technique based on the good statistical fit achieved between assigned volume and observed traffic count.

Keywords: Traffic Demand, Lagos Metropolis, T-flow fuzzy, Trip Production, Visum

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Acronyms and Definitions

BPR	Bureau for Public Roads
BRT	Bus Rapid Transit
ECA	Economic Commission for Africa
FDOT	Florida State Department of Transportation
FFS	Free Flow Speed
GDP	Gross Domestic Product
HCM	Highway Capacity Manual
LAMATA	Lagos Metropolitan Area Transport Authority
LBS	Lagos Bureau of Statistics
LGA	Local Government Area
LOS	Level of Service
NCHRP	National Cooperative Highway Research Program
NPC	National Population Commission
O-D	Origin- Destination
RMSE	Root Mean Squared Error
TAZ	Traffic Analysis Zones
TDM	Transportation Demand Management
TRB	Transportation Research Board
VCI	Volume Capacity Index
VDF	Volume Delay Function
UITP	Union Internationale des Transports Publics
UN	United Nations
WB	World Bank

Chapter 1

Introduction

1.1 Preamble

Traffic Demand Modelling has been regarded by researchers as a process that aids decision making and planning of transportation infrastructure systems. A detailed travel demand model is required to enable forecast of future travel and to assess alternative planning strategies. It is not confined to just one model, but a series of inter-linked and inter-related models of varying levels of complexity, dealing with different facets of travel demand.

In the developing urban region of the city of Lagos, Nigeria, characterized by its huge population, growing level of economic activity have resulted in an increase in demand for transportation within this metropolis. As pointed out by Obio & Adegbulugbe (1997), the use of private transportation in Lagos is growing uncontrollably to the point where the existing infrastructures can no longer function effectively. Parallel to this, there is an increase in motorisation which is becoming a cause of concern to transport authorities as most parts of the city perpetually experience high levels of traffic congestion. Managing the traffic is now a huge task that consumes quite a large amount of material and human resources. With the increase in travel demand and traffic management problems, in a context of lack of systematic statistical information, simple demand forecasting models could serve as a tool to aid decision making in re-working the current infrastructure or planning the future transportation system.

1.2 Motivation of the Research

Lagos State is one of the 36 states of the Federal republic of Nigeria. With an estimated population of about 17million inhabitants (2006 census)[1], it is the largest city in Africa and the economic hub of Nigeria and the entire West African Sub region. Within the past few decades, this city has witnessed tremendous growth in population. According to the United Nation's World Urbanization Prospects report of 2011, Lagos will be the city with the highest average annual rate of population growth between years 2011-2025 which is projected at about 4% annual growth rate[2]. It is expected to hit well over 25million inhabitants by the year 2025 (Lagos Bureau of Statistics, 2011).The rapid increase in population has resulted in an increase in demand for transportation in the city. At present, the transport demand greatly outweighs the infrastructures and services supply. The lack of parallel transport infrastructures to accommodate the demand has resulted to increased traffic congestion and high level of environmental pollution in the city. Obio and Adegbulugbe (1997) have attributed the

[1] Lagos State Bureau of Statistics – Digest of Statistics 2011. Though there is current controversy on the actual population of Lagos, as census figures reported by the State government varies from the National Census data of the Federal government.
[2] UN world urbanisation report 2011

current traffic congestion in this city to the increasing dependence on private transport and also, to the fact that the current unregulated public transportation system in the city lacks reliability, safety and comfort.

From the statistics on annual vehicle registration in the state, as shown in Table 1 below, an increasing trend could be observed in the number of private transport registered.

TYPE OF OWNERSHIP	NEWLY REGISTERED VEHICLES BY TYPE OF OWNERSHIP AND YEAR OF REGISTRATION LAGOS STATE 1998-2009											
	1,998	**1,999**	**2,000**	**2,001**	**2,002**	**2,003**	**2,004**	**2,005**	**2,006**	**2,007**	**2,008**	**2,009**
Private	10,073	11,260	25,944	107,555	121,646	91,669	53,322	67,246	109,436	138,592	181,632	153,781
Commercial	1,057	1,544	2,270	13,078	15,651	9,700	5,879	5,766	17,446	19,484	28,425	32,490
Government	87	86	204	320	373	148	216	268	571	1,061	651	1,170
Mission School	53	76	105	370	419	365	258	235	332	1,097	843	890
Corporation	1,609	1,890	3,518	11,773	12,531	9,951	7,701	7,563	13,480	27,208	28,371	22,467
TOTAL	12,879	14,856	32,041	133,096	150,620	111,833	67,376	81,078	141,265	187,442	239,922	210,798
% of Private Vehicles	78	76	81	81	81	82	79	83	77	74	76	73

Table 1 Annual vehicle registration (*Lagos State Bureau of Statistics – Digest of Statistics Report 2011)*

From the data above, it could be seen that private vehicles over time has consistently accounted for over 70% of the entire vehicular fleet in Lagos.

1.3 Research Objectives

- ✓ To build a simple aggregated demand model that could be used for strategic level assessment of the road network in Lagos metropolis in terms of private vehicle traffic using limited data.
- ✓ To ascertain the traffic volume and performance level of the modelled road network for the base year (2006) and also estimate performance level of same network at a future year 2025.
- ✓ To establish model improvement needs and associated data requirements for future model calibration and validation.
- ✓ To propose alternative planning strategies that could improve network performance.
- ✓ To establish model deficiencies and improvement needs.

1.4 Data Collection & Methodology

Demographic data were extracted from the Lagos Survey reports published by the Lagos Bureau of Statistics (LBS). Traffic count data and other vehicle statistics were sourced from the Lagos Metropolitan Area Transport Authority (LAMATA).

The 20 administrative regions (also known as Local Government Areas, LGAs) that make up the entire Lagos state were directly used as traffic analysis zones (TAZs) to take advantage of demographic data from the 2006 population census. These are currently the smallest census unit data available for this study. Shape files for these zones were extracted from open-source GIS spatial database available on the internet. The road network comprising the arterial, distributor and few collector roads was built using a combination of Visum and Google Map Imagery.

The Four-step travel demand model approach was carried out using a combination of excel spread sheet and the Visum built-in tool for four-step modelling. However the mode choice step was omitted in the modelling process since the focus is on private transport modelling for which base data was available. The model utilised the Origin-Destination trip data for private transport for year 2009.

Trip generation modelling employed log-linear regression method by developing a log-linear relationship between the total car trip production and attraction of each zone and the population of the zone. The resulting model was applied in estimating future year (2025) production and attraction using population forecast data for that year. The year 2025 was selected due to the many developmental visions being currently set for that year by most planning agencies.

The next step implemented in the modelling process was trip distribution. The Trip distribution step and its parameters estimation employed the gravity model inbuilt in Visum, using the negative exponential deterrence function as the distribution function and free-flow travel time between zones as the impedance. Data inputs to the Visum platform at this stage was the total Origin and Destination trips from each of the traffic analysis zones and the skim matrix of impedance (free-flow travel time) generated from the network. The output of the trip distribution step was the trip Origin-Destination trip matrix and the distribution parameter estimate computed by the software. Distribution was carried out for the base and future year.

The next stage in the modelling process after distribution was the traffic assignment. In the assignment step, the Visum-distributed O-D trip matrix was assigned to the network using the equilibrium assignment model. Assignment was done in conjunction with model calibration. Two matrix calibration techniques, the T-flow fuzzy and the Lohse Calibration approaches were employed to calibrate the demand matrix to traffic count and evaluation was made on both calibration methods.

Matrix calibration was followed by final assignment of the calibrated O-D trip matrix for the base year and the distributed matrix for the future year. Network Performance indicators such as total travel time, Vehicle km travelled, Vehicle hour travelled and mean saturation were computed from the network. Comparisons were finally drawn between the base year and future year network state.

1.5 Thesis Outline

The figure below gives an overall layout of this thesis.

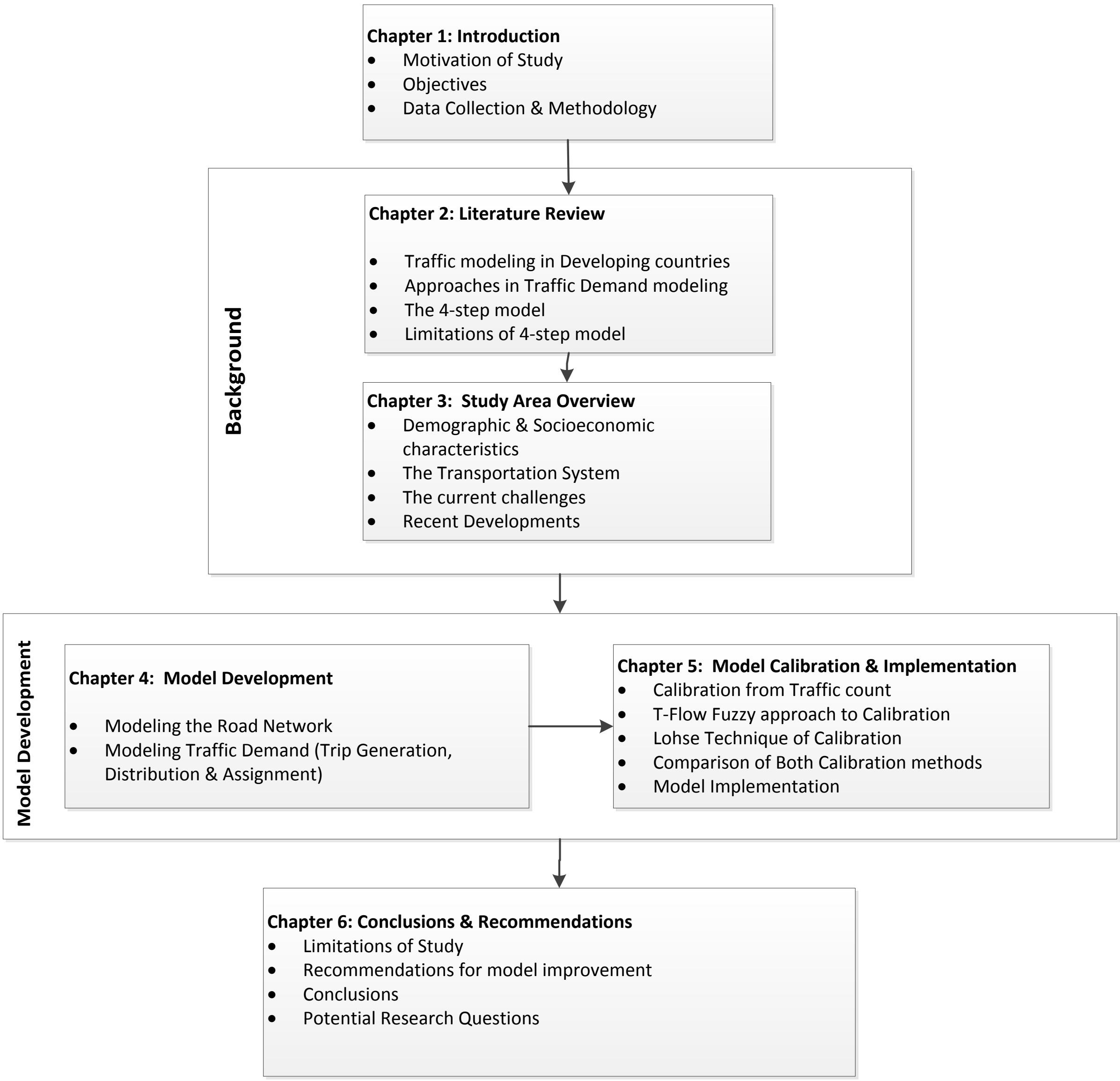


Figure 1 Thesis Outline

Chapter 2

Literature Review

2.1 Introduction

This chapter presents a review of the literature on travel demand modelling. Areas covered include the; roles of models in transportation planning, framework for transportation system analysis and approaches to travel demand modelling and forecasting. Other areas discussed include the classical four-step modelling process, its scope of applicability and its drawbacks. The last section presents a discourse of past research on travel demand modelling in developing societies.

2.2 The Role of Models in Transportation Planning

Transportation science investigates the characteristics of a transportation system and its various modal subsystems (Bovy et al, 2006). These characteristics refer to the design, the use, the maintenance and the operations of the system and its elements. A good operation and performance of the transportation system permanently requires decision making. These decisions are being taken either as part of traffic and transportation policy making or as part of the operation and control of the system. In order to reach good decisions, well-founded knowledge is required on the expected impacts of proposed decisions. The required knowledge depends on the type of decision to be taken while the time horizon for which this knowledge is demanded also plays a role.

Over the past few decades, a vast body of scientific knowledge has been built up and summarized into transportation theories and made operational by the use of mathematical models. These theories and its models are continually being extended, tested and validated using empirical observations. Models may be used as analytical instruments in a 'what-if' analysis to show the impacts of changes in the system or its environment, or they may be used as design instruments that calculate the optimal design of the system in order to achieve maximum performance. An example of such impact analysis could be determining the impact of introduction of new link on the overall congestion level in a given network. Bovy et al (2006) described a development process of a model as shown in figure 2.

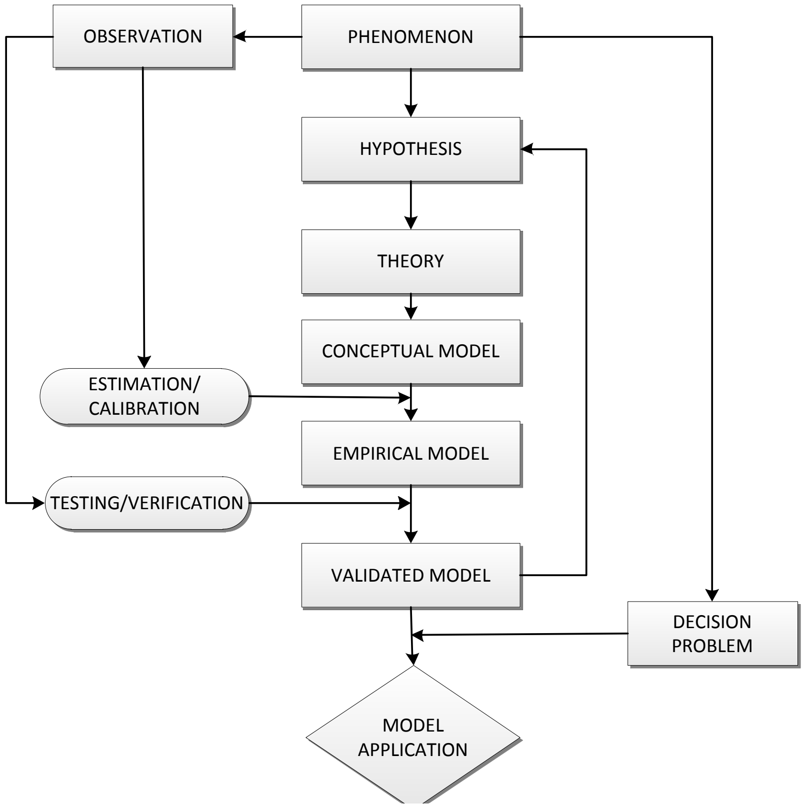


Figure 2 Development process of a model *(Bovy et al, 2006)*

2.3 Transportation Systems Analysis Framework

McNally (2007) provided a comprehensive description of the Manheim/Florian structure shown below, as the basic framework on which transportation demand modelling is built. In this representation, the Transportation system T is defined as all the elements of transportation infrastructures and services. The Activity system A represents everything else comprising the spatial distributions of land use, the demographic and economic activities that occurs in those land uses. These are the exogenous inputs to Performance procedures P and the Demand procedures D. These demand and performance procedures make up the basic four step model, which will be discussed in detail in the subsequent sections of this thesis.

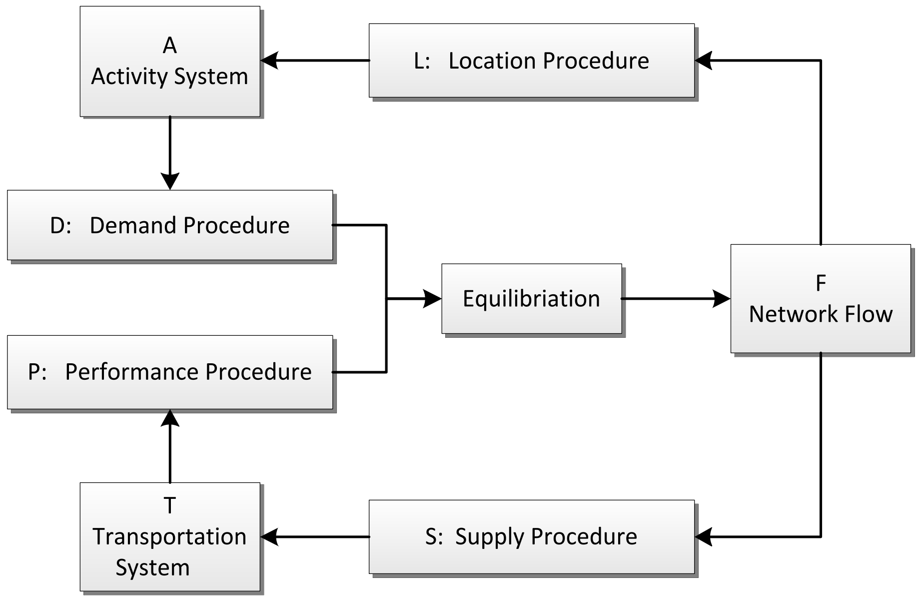


Figure 3 Manheim/Florian Transportation Systems Analysis Framework (McNally, 2007)

In addition to the demand and performance procedures, some form of Location procedures L and Supply procedures S are also executed but independently of the demand and performance procedures which make up the four step process.

As concluded by the author, the importance of this approach to transportation systems analysis is an understanding of the units of analysis for these procedures, defined spatially and temporally. Demand Procedures typically produces person trips, defined as the travel required from one origin location to an access destination for the purpose of performing some activity. These trips reflect units of time and space such as daily person trips per household or peak hour person trips per zone. Performance procedures P reflect mode-specific trips (person or vehicle) defined as a link volume (such as vehicle trips per hour or boarding per hour for particular transit route segment). The equilibration process resolves demand and performance procedures defined at different spatial levels. Demand procedures defined at the zonal level and performance procedures defined at the link level are interconnected by the path level: paths comprise sequences of links that connect the various origin-destination pairs in the area under analysis.

2.4 Typical Approaches to Travel Demand Modelling

This subsection gives an overview of the various approaches that has being developed and currently utilized in travel demand modelling. Most literature on transport modelling has recognised four approaches; Aggregate trip-based approach, Disaggregate trip-based, Tour based and the Activity-based approaches. While this thesis is based on the first approach (Aggregate trip based), a brief discussion of other approaches is presented.

2.4.1 Aggregate Trip Based Approach

The trip based approach to travel demand modelling was the earliest being developed. The demand models were simple mathematical models such as the gravity or an entropy model (Sivakumar, 2007) and they quantified travel as a function of the size of a zone. The number of trips generated from a zone was considered to be proportional to the population of the zone, while the number attracted to a zone was considered to be proportional to the number of sources of attraction in the zone. Moreover, the travel between zones was considered to be inversely proportional to the distance between the zones also known as the impedance.

According to Ortuzar & Willumsen (2011), the design of any transportation planning study always has to follow the level of aggregation selected for the measurement of data. If the model is aiming to represent the behaviour of more than one individual such as a population segment of car owners in a zone, using aggregated data is inevitable. However, if the model is aimed at representing the behaviour of individuals, disaggregated data will need to be obtained and used separately for each traveller.

Aggregate models have been severely criticized for their inflexibility and inaccuracy. Unfortunately, other approaches such as the disaggregate approaches discussed in the next section have adopted sophisticated treatments of the choices and constraints faced by individual travellers and have failed to take the process through to the production of forecasts, sometimes because they require data which cannot reasonably be forecasted. (Ortuzar & Willumsen, 2011).

2.4.2 Disaggregate Trip-based Approach

According to Sivakumar (2007), advances in modelling techniques have resulted in a shift from the aggregate models to the development of disaggregate trip-based models. These approaches use disaggregate level data on the trips made by individuals between the zones in the study area, and apply modelling methodologies such as constrained optimization and random utility maximisation. The fundamental difference between aggregate and disaggregate models is that the disaggregate models view the individual (or household or firm) as the decision-making unit. In other words, the disaggregate models take into account the effects of individual socio-demographics (or firm characteristics) on travel-related choices.

Despite the move to a disaggregate approach, trip-based models continued to exhibit several critical limitations. The most criticised of these limitations was the fact that trip-based models do not consider the linkages between trips. For instance, a commute trip from home to work in a trip-based model is treated independently of the return commute from work to home, and both trips are classified as home-based work trips. As a result, these early models could potentially assign different modes of travel to the home-work and the work-home trips. Tour-based models were developed to address this limitation.

2.4.3 Tour Based Approach

Most travel demand models currently in operation use a tour-based 4-step modelling approach (Sivakumar, 2007). This approach aggregates all individual travel into tours based at home which retain the information about the relations between trips. For instance, a home-based work tour involves travel from home to work and back to home. Operational tour-based models typically consider the following home-based tour purposes – work, education, shopping, personal business, employers' business and other. Within the 4-step modelling framework, the frequency of these tours and trips is first predicted (known as the tour generation step). This is typically followed by mode-destination choice models or mode-destination-time period choice models in more advanced model systems (combined tour distribution and mode choice step). And finally, the network assignment procedure allocates the tours to the transport network (Ortuzar & Willumsen, 2011).

2.4.4 Activity Based Approach

A study by Ben-Akiva et al (1996) on the status of travel demand concepts indicated a change in perspective on the modelling approach, from purely a transportation system oriented approach to the activity-behaviour approach. The basic theme is that the demand for travel is derived from a demand for activities. Their activity-based framework was based on three points:

- Conceptual development must be based on demand for travel explicitly for activities
- The modelling unit must be an individual considering his household involvement and other constraints, and
- An activity-based modelling system must be used to integrate the daily activity and travel choice in a single framework.

The above references point out a direction for travel demand modelling where involvement in activities is the prime concern. Considering accessibility as the proximity of activities via the transportation network, a concept could be developed in which accessibility of activities essentially leads to the involvement in activities.

Bowman & Ben-Akiva, (1999) also pointed out that the demand for activity and travel is viewed as a choice among all possible combinations of activity and travel in the course of a weekday. The activity based approach uses a day time frame because of the day's primary importance in regulating activity and travel behaviour; people organize their activities in day sized packages, allowing substantial interactions among within-day scheduling decisions as they cope with time and space constraints while attempting to achieve their activity objectives.

2.5 The Four Step Model

The approach to Aggregate travel demand modelling is conventionally known as the Sequential Four-step process consisting of Trip generation, Trip distribution, Modal split and Trip assignment. These are the four major model components of the travel demand forecasting process. The output at each stage of the model serves as in input to the successive step.

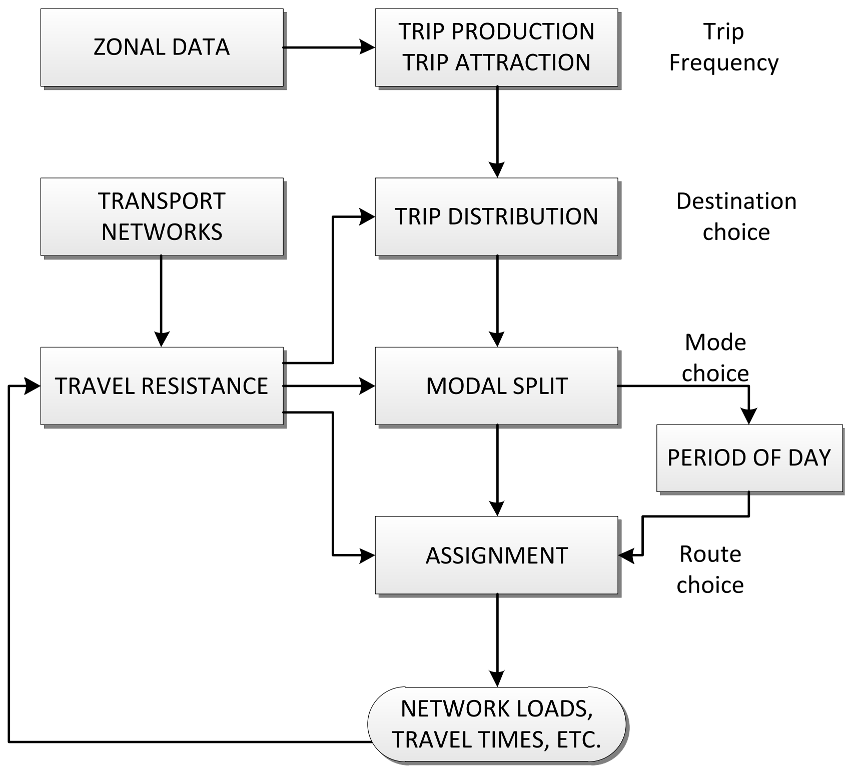


Figure 4 The Four-Step Modelling Framework

2.5.1 Trip Generation

Trip generation is the first step in the travel forecasting process and it is the process of determining the number of person or vehicle trips that will begin or end in each traffic analysis zone within a study area. Trip generation is functionally related to the land use which is described in terms of the character, intensity and location of activities (Martin & McGuckin, 1998).

Since the trips are determined without regard to destination, they are referred to as trip ends. Each trip has two ends, and these are described in terms of trip purpose, or whether the trips are either produced by a traffic zone or attracted to a traffic zone. For example, a home-to-work trip would be considered to have a trip end produced in the home zone and attracted to the work zone.

Trip generation modelling has two functions:

1. To develop a relationship between trip end production or attraction and land use and
2. To use the relationship to estimate the number of trips generated at some future date under a new set of land use conditions.

The reliability of forecasting results influences the subsequent steps such as trip distribution, mode split, and traffic assignment. Therefore, improved trip generation models are needed to improve forecasting precision.

Ortuzar & Willumsen (2011) stated three approaches generally considered for trip generation modelling. They are; the linear regression, the cross-classification and the discrete choice method. All three approaches can be applied to estimate the trip generation using different units of analysis (zones, households or person). Only the zonal-based linear regression model is discussed as it lies within the scope of this thesis.

2.5.1.1 Zonal-based multiple linear regression model

The zonal-based multiple regression is the most common methodology used in the aggregate approach for modelling trip generation. It is used to develop a linear relationship between the number of trips produced or attracted to a zone and the average socio-economic characteristics of the households in each zone.

These models can be used to explain the variation in trip making behaviour between each of the zones; hence they can only be successful if the inter-zonal variations adequately reflect the real reasons behind trip variability. In formulating this model, there is a choice of using aggregate or total variables, such as trips per zone or cars per zone, or rates such as trips per household per zone and cars per household per zone. Zonal based regression is conditioned by the nature and size of the zones. (Ortuzar & Willumsen, 2011).

A hypothetical regression form for a zonal trip generation model is;

$$Ti = \beta_1 + \beta_2 x_{2i} + \beta_3 x_{3i} + \cdots . + \beta_k x_{ki} + \mathcal{E}i \qquad \text{Equation 1}$$

Where;

y_i= Zonal Trips

β_k= coefficient to be estimated

x_{ki}= variable k for zone i. *(usually socio-economic and demographic characteristics)*

$\mathcal{E}i$= error term

One drawback that has been identified with zonal-based linear regression is the problem of spatial aggregation. That is, the error reflected in the model is directly dependent on the size of the zone. (Ortuzar & Willumsen, 2011).

2.5.1.2 Log-Linear Regression Modelling

A linear regression model, obtained from a logarithmic transformation of the response variable, is useful in studying the effect of covariates on the response variable (Desmond et al, 2012). As stated by Newman, (1993), power and exponential relationships are common in most quantitative discipline, hence the wide application of log-linear regression procedures. While the Ordinary Least Square regression approach assumes a linear relationship between the dependent and independent variables, in reality, the relationship might quite be different. Such data that does not follow a linear relationship could be log-transformed before applying the least square linear regression approach. The transformation could either be carried out on both the X and Y variables or on the Y variables only. (Newman, 1993).

2.5.1.3 Factors Influencing Trip Generation

The estimation of long-term travel demand requires specific modelling, which identifies the structural factors of travel. Researchers have identified several of these factors as the key determinants of the level of travel. Some of these factors include; price, income, quantity and the spatial factors.

Price Effect

McFadden (1974) revealed that price affects demand for travel. In the case of the private car, when the user cost of the car falls. It also increases when income and the cost and waiting time for public transport increase. Likewise, demand for public transport travel rises when the user cost of the car increases and falls when the cost and waiting time for public transport increase.

Bresson et al. (2004) have also shown, in the case of public transport, that the elasticity of demand with respect to fuel prices is positive. However, this elasticity is lower than the fare variation elasticity of demand. This has led these scholars to judge that a fare reduction may play a substantial role in increasing public transport use.

Income Effect

Travel demand has also been found to be affected by level of income. Mogdridge, M (1989) used the distribution of incomes and expenditures to estimate the number of cars in a thirty years horizon. Dargay and Hanly (2002) also showed that there is a negative relationship between the number of bus trips and income level. This quite follows the reasoning that private transport usage will increase as the level of income increases. According to Ortuzar & Willumsen (2011), economic growth leads to higher car ownership rates.

The income variable has also been seen to reveal differences between countries. Dargay and Gately (1999) have shown, in connection with total vehicle stock and the economic development of different countries that, the rise in car ownership rates, linked to rising per capita income, is greater the faster the country’s economy is growing (as, for example, in South Korea and Taiwan). Button et al. (1993), paying particular attention to the lowest-income countries, showed that car ownership rates become increasingly sensitive to income as these rates and income increase. However, while the stock of vehicles is dependent on per capita income levels, the level of market saturation varies according to the country with reference, in particular, to the user cost of the vehicle (Medlock and Soligo, 2002).

The Spatial Effect

Travel demand has also been found to be affected by spatial factors. Kain and Faun (1977) have considered urban development as measured by the population density in each zone and the socioeconomic characteristics of each household and the location of their jobs and residences as determinants of their modal choice. Button et al (1993) posited that there is a positive relationship between car ownership rates and the level of urbanization. But according to him, this relationship applies only up to a point. Beyond this point, the infrastructure becomes so saturated that the higher the urban density the car use levels, car ownership rates, the number of trips and energy consumption are reduced. Paulley et al, (2006) showed that demand for bus transport depends on the residential zone. Individuals who live in rural zones with low population densities tend to be more dependent on car relying less on public transport, than those living in urban zones. The fare variation elasticity of bus travel in the English counties was calculated as –0.51 in the short term compared with –0.21 in metropolitan zones.

2.5.2 Trip Distribution

Trip distribution analysis is the process of by which trips originating in one zone are distributed to the other zones in the study area. As stated by Ortuzar & Willumsen (2011), though production and attractions resulting from the first step of the modelling process provide an idea of the level of trip making in a study area, it is not often enough for decision making and modelling. An idea and analysis of the pattern of trip making, which is, where do the trips come from and where do they go, provides a key aspect in the overall modelling process.

Origins	Destinations				$\sum_j T_{ij}$
	1	2	...	n	
1					P1
2		?			P2
...					...
m					Pm
$\sum_i T_{ij}$	A1	A2	...	An	

Figure 5 Trip Distribution

The trip patterns are often represented in several ways. Ortuzar & Willumsen (2011) presented 3 ways for this representation; first, as a trip-matrix or Origin-Destination matrix, which stores the trips made from an origin to a destination during a particular time period. The trips could further be disaggregated by person type, purpose or activity. The second way of presentation is on the basis of the factors that generate the trips, that is, on a Production-Attraction (P-A) basis. In this representation, Home is generally treated as the producing end while Work, Shop, leisure, etc is regarded as the attracting end.

Another representation of trip patterns is through intercept surveys made during roadside interviews or public transport questionnaires. According to Ortuzar & Willumsen (2011) however, this will result in an Origin-Destination matrix which are incomplete and biased. The main reason being that, not all origin-destination pairs would have been sampled. The intercept survey through roadside interview on which this thesis is based, has been pointed out by some authors as the most commonly used technique in getting information on trip patterns in the developing societies. As stated by Abrahamsson (2002), since the O-D matrix is often difficult and often costly to obtain by direct measurement and surveys, using traffic counts and other available information could result to reasonable and acceptable estimates.

Various techniques have been proposed and applied by researchers in modelling trip distribution. Ortuzar & Willumsen (2011) classified these methods into three; Growth Factor method, Synthetic or gravity method, and the Entropy-maximising approach. This study utilised the gravity model.

2.5.2.1 The Gravity Model

The gravity model estimates trips in the cells of an O-D matrix without directly using the observed trip patterns. It starts from assumptions about group trip making behaviour and the way this is influenced by external factors such as total trip ends and distance travelled.

The gravity model was originally motivated by the observation that flows decrease as a function of the distance separating the zones, just as the gravitational pull between two objects decreases as a function of the distance between the objects. As implemented for planning models, the Newtonian analogy has been replaced with the hypothesis that the trips between zones i and j are a function of trips originating in zone i and the relative attractiveness and/or accessibility of zone j with respect to all zones. According to Ortuzar & Willumsen (2011), modern derivations of the gravity model show that it can be understood as the most likely spatial arrangement of trips given limited information available on zonal origin totals, zonal destination totals, and various supporting assumptions or constraints about mean trip lengths.

After many experiments and researches, it was concluded that the effect of distance on trip making could be modelled better by decreasing function with the following equation;

$$T_{ij} = \alpha O_i D_j f(c_{ij}) \qquad \text{Equation 2}$$

Where;

O_i and D_j are the number of total trip ends in zone i and j respectively.

α is a balancing factor

$f(c_{ij})$ is the deterrence function or impedance function. This function decreases as travel cost or distance (time) increases. There are three popular versions of the impedance functions that are usually used in travel demand modelling.

$f(c_{ij}) = \exp(-\beta c_{ij})$ (Exponential function) Equation 3

$f(c_{ij}) = c_{ij}{}^{-n}$ (Power function) Equation 4

$f(c_{ij}) = c_{ij}{}^{n}\exp(-\beta c_{ij})$ (Combined function) Equation 5

These functions are used to describe the relative attractiveness of each zone. In the equations, Cij is the generalised cost, time or distance of travel between the origin i and destination j.

Prior to applying the gravity model, one has to calibrate the impedance function. Typically, calibration entails an iterative process that computes coefficients such that the gravity model replicates the trip length frequency distribution and matches base year productions or attractions. (Bovy, 2006).

2.5.2.2 Gravity Model Types

The gravity model could be carried out as singly constrained or doubly constrained model. Singly constrained models are either origin (production) constrained or destination (attraction) constrained while the doubly constrained models implies constraints on both origin and destination.

Origin Constrained Model

Production constrained gravity models require more complex computational techniques to match the estimated and observed trip production rates for each zone. This is usually possible where the estimates of trip production are more complete due to the availability of relevant data, such as from home interview surveys. In cases where more data is available to support trip attraction than trip production, the attraction constrained gravity model should be adopted (Jones, 1977; Oppenheim, 1995).

In the origin constrained trip distribution model, the number of trip departures, P_i is imposed as a set of constraints on the general trip distribution model;

$$\Sigma_j \boldsymbol{T_{ij}} = \boldsymbol{P_i} \quad \text{(Equation 6)}$$

Where P_i is the known number of trips departing from zone *i,* which is determined exogenously (for example, using the trip generation model). Combining this with the general trip distribution model;

$$\boldsymbol{T_{ij}} = \boldsymbol{\alpha O_i D_j F_{ij}} \quad \text{(Equation 7)}$$

It could be written that,

$$\Sigma_j \boldsymbol{T_{ij}} = \Sigma_j(\boldsymbol{\alpha O_i D_j F_{ij}}) = \boldsymbol{\alpha O_i}\Sigma_j(\boldsymbol{D_j F_{ij}}) = \boldsymbol{P_i} \quad \text{(Equation 8)}$$

This yield,

$$\boldsymbol{O_i} = \frac{\boldsymbol{P_i a_i}}{\boldsymbol{\alpha}} \qquad \text{(Equation 9)}$$

Where a_i is defined as

$$\boldsymbol{a_i} = \frac{\mathbf{1}}{\Sigma_j(\boldsymbol{D_j F_{ij}})} \qquad \text{(Equation 10)}$$

Combining the equation above gives the origin constrained distribution model

$$\boldsymbol{T_{ij}} = \boldsymbol{P_i}\frac{\boldsymbol{D_j F_{ij}}}{\Sigma_j(\boldsymbol{D_j F_{ij}})} = \boldsymbol{a_i P_i D_j F_{ij}} \qquad \text{(Equation 11)}$$

Where,

a_i= balancing factor

P_i= number of trips departing from zone i

D_j= attraction potential of zone j

F_{ij}= accessibility of zone j from zone i.

The origin constrained trip distribution model is therefore a proportional model that splits the given trip numbers originating in i over the destinations j in proportion to their relative accessibility and utility opportunity. (Ortuzar & Willumsen, 2011).

Destination Constrained Model

Analogous to the origin constrained trip distribution model is the destination constrained trip distribution model. In this model, the internal trip numbers are constrained to exogenously given arrivals. The number of arriving trips A_j in j is known, which implies;

$$\Sigma_j \boldsymbol{T_{ij}} = \boldsymbol{A_j} \qquad \text{Equation 12}$$

The derivation which is similar to that of the origin constrained model gives,

$$\boldsymbol{T_{ij}} = \boldsymbol{A_j}\frac{\boldsymbol{O_i F_{ij}}}{\Sigma_j(\boldsymbol{O_i F_{ij}})} = \boldsymbol{b_j O_i A_j F_{ij}} \qquad \text{Equation 13}$$

With;

b_j = balancing factor $= \frac{1}{\Sigma_i(O_i F_{ij})}$; O_i = production potential of i; A_j = number of trips arriving at zone j

F_{ij}= accessibility of zone j from zone i

The destination constrained trip distribution model is therefore a proportional model that splits the given trip numbers arriving at j over the origins i in proportion to their relative accessibility and utility proportions (Ortuzar & Willumsen, 2011).

Doubly constrained Model

The doubly constrained model arises if both the number of trip departures and number of trip arrivals are imposed on the general distribution model. This model has the form;

$$\boldsymbol{T_{ij} = a_i b_j P_i A_j F_{ij}} \qquad \text{Equation 14}$$

Where $\boldsymbol{a_i}$ and $\boldsymbol{b_j}$ are balancing factors for the trip constraints, defined as;

$$\boldsymbol{a_i} = \frac{\boldsymbol{1}}{\sum_j(\boldsymbol{D_j F_{ij}})} \qquad \text{Equation 15}$$

$$\boldsymbol{b_j} = \frac{\boldsymbol{1}}{\sum_i(\boldsymbol{O_i F_{ij}})} \qquad \text{Equation 16}$$

P_i= number of trips departing at zone i

A_j= number of trips arriving at zone j

F_{ij}= accessibility of zone j from zone i

2.5.3 Modal Split

Modal split is the third stage in travel demand modelling where the trip O-D matrix obtained from the trip distribution is shared into a number of matrices representing each mode of transport. The mode choice model is probably one of the most important in transport planning. As stated by Ortuzar & Willumsen (2011), these models can reflect a range of performance variables and trip maker characteristics which produce disaggregate results and must be aggregated to the zonal level prior to route choice.

The choice of mode is influenced by several factors. Ortuzar & Willumsen (2011) classified these factors into three broad categories which are; characteristic of the trip maker, characteristics of the journey and the characteristics of the transport facility.

On the trip maker characteristics, features such as car availability, possession of driving license, income, household structure and residential density are considered as important decision variables. For the characteristics of the journey, the trip purpose and time of day are considered important. The transport facility characteristics comprise quantitative and qualitative factors. Quantitative factors include components of travel time, monetary cost, availability and cost of parking and reliability of travel time and service. Qualitative factors include comfort and convenience, safety, protection, demands of the driving task as well as opportunities to undertake other activities during a journey period.

Several approaches to mode choice modelling are discussed in Ortuzar & Willumsen (2011) and Bovy et al (2006). The common approach is to distribute the total travel demand for a given OD-pair over the available modes using the logit model;

$$\beta_{ijv} = \frac{\exp[bV_{ij}{}^{v}]}{\Sigma_w(\exp[bV_{ij}{}^{w}])} \qquad \text{Equation 17}$$

Where β_{ijv} = proportion using mode v on OD-pair ij

b= variance or scale parameter in the logit model

$V_{ij}{}^{v}$= observable part of the utility of travelling between OD-pair $i-j$ with mode v

2.5.4 Traffic Assignment

This step is performed in the last stage of the modelling exercise where origins and destinations of trips by a particular mode are loaded to the transport network. These are the trips computed in the distribution/modal split step.

Traffic assignment has several functions in traffic planning amongst which are;

- *Gaining insights into the characteristics of the network:*
  Through several assignments, insight may be gained in the shortcomings of the existing network, such as missing links and capacity deficiency. Ideas can also be gained for solving existing problems. The same analysis is useful for planned network scenarios in the future.
- *Traffic Forecasts:*
  Regarding the current and future network scenarios, a number of aspects are computed to be able to forecast the future traffic situation. These include, among others, link loads, travel time, speed and congestion levels. These information are useful in the evaluation of alternative plans.
- *Computation of derived impacts:*
  Also, on the basis of traffic assignment, impacts are computed such as noise levels, air pollution, energy consumption, and traffic safety, which are of importance for the evaluation of plans.
- *Supply of Input Data*
  In the other steps of traffic analysis such as distribution and mode choice, resistance characteristics of O-D pairs (travel times, distances, travel costs) are used which are computed in the assignment step as attributes of routes.

There is a number of traffic assignment models developed in the past years. The most common are the All-or-nothing, Equilibrium and Stochastic assignment models

2.5.4.1 All-or-Nothing Assignment

The simplest route choice model is the All-or-Nothing assignment. In this assignment, all the trips from the origin to any destination are assigned to single minimum cost path between them. This method assumes that all trip makers are aware of the shortest route before making the trip and cost of travel stays the same. Traffic is assigned to the links without considering the capacity of the links and the congestion levels.

The method however, has some limitations because it ignores the fact that cost on link is a function of the volume and that when there is congestion, multiple paths may be used (Ortuzar & Willumsen, 2011). Usually, there is a separate assignment for each mode since the network for each of the mode is different.

Mekbib (2007) pointed out that simplified models like all-or-nothing (AON) assignment can be very useful for developing countries, where versatile packages for traffic modelling and spatial data analysis are lacking for long term planning.

2.5.4.2 Equilibrium Assignment

The Equilibrium assignment distributes the demand according to Wardrop's first principle, which states that "Every road user selects his route in such a way, that the impedance on all alternative routes is the same, and that switching to a different route would increase personal travel time (user optimum)." The state of equilibrium is reached by multi-successive iteration based on an incremental assignment as a starting solution. In the inner iteration step, two routes of a relation are brought into a state of equilibrium by shifting vehicles. The outer iteration step checks if new routes with lower impedance can be found as a result of the current network state.

This behavioural hypothesis of equilibrium assignment underlies the unrealistic assumption that every road user is fully informed about the network state. In transport planning this hypothesis is approved of given a fundamental methodical advantage of the equilibrium assignment - with quite general requirements, the existence and uniqueness of the assignment result (expressed in volumes of the network object) is guaranteed. Moreover, measures for the distance of an approximation solution from the equilibrium exist, from which an objective termination criterion can be derived for the procedure, which generally is an iterative problem solution. (PTV AG, 2012)

The equilibrium assignment determines a user optimum which differs from a system optimum. A user optimum means that the same impedance results for all routes of a traffic relation between zones i and j (within the scope of calculation accuracy). This results directly from the condition that changing to another route is not profitable for any road user (Yi-Chang, 2010).

A system optimum however means that the total impedance in the network, which is the product of route impedance and route volume, is minimized for all OD pairs. On average, this procedure leads to shorter journey times per road user, but there are (few) road users which use routes to serve the general public, with an impedance above average.

2.5.4.3 Stochastic Assignment

In urban areas, there are many alternative routes that could be and are used to travel from a single origin zone to a single destination zone. Often trips from various points within an origin zone to various points in the destination zone will use entirely different major roads to make a trip.

Stochastic methods of traffic assignment emphasize the variability in drivers' perceptions of costs and the composite measure they seek to minimize (distance, travel time, generalized costs). Stochastic methods need to consider second-best routes (in terms of engineering or modelled costs); this generates additional problems as the number of alternative second-best routes between each O–D pair may be extremely large (Ortuzar & Willumsen, 2011).

2.5.4.4 Stochastic Equilibrium Assignment

This is an assignment that combines the properties of the stochastic assignment and the deterministic user equilibrium assignment which was proposed by Daganzo & Sheffi (1977). Known as stochastic user equilibrium (SUE), this model is premised on the assumption that travelers have imperfect information about network paths and/or vary in their perceptions of network attributes. (Bovy, et al 2006)

2.5.5 Limitations of the Four step model

The four step modelling process has come under criticisms due to several reasons that have been identified through various researches. Some of the reasons include the problem of aggregation and the problem of performing the sequential process. Spatial, demographic and temporal aggregation has been identified to result in aggregation errors in the model, while the sequential process has been identified not to fully represent the decision making patterns of trip makers.

As stated by McNally & Craig (2007), in the conventional four step model, trip generation being the first step effectively serves to scale the problem. The structural absence of feedback at this stage results to overall travel demand being fixed and essentially independent of the transportation system. The production and attraction ends of each trip are split and aggregated, parameters are estimated via independent models, and the basic unit of travel, the trip, does not again exist as an interconnected entity until the second phase of the standard process, trip distribution, produces aggregate estimates of total interzonal travel. According to the same author, these models explicitly ignore the spatial and temporal inter-connectivity inherent in travel behaviour. The fundamental tenet of travel demand, that travel is a demand derived from the demand for activity participation, is recognised to be explicitly ignored in the four step procedures. Another weakness that has been associated with the four step modelling process is its lack of integration of land use forecasting models, which will result to future activity systems being made independent from the future transportation network.

McNally & Craig (2007) summarised these deficiencies of the four step model as follows;

1. Ignorance of travel as a demand derived from activity participation decisions;
2. A focus on individual trips, ignoring the spatial and temporal interrelationship between all trips and activities comprising an individual's activity pattern.
3. Misrepresentation of overall behaviour as an outcome of a true choice process, rather than as defined by a range of complex constraints which delimit (or even define) choice.
4. Inadequate specification of the interrelationships between travel and activity participation and scheduling, including activity linkages and interpersonal constraints.
5. Misspecification of individual choice sets, resulting from the inability to establish distinct choice alternatives available to the decision maker in a constrained environment; and
6. The construction of models based strictly on the concept of utility maximization, neglecting substantial evidence relative to alternate decision strategies involving household dynamics, information levels, choice complexity, discontinuous specifications, and habit formation.

2.6 Traffic Demand Modelling in Developing Societies

One of the principal objectives of travel demand modelling as stated by Meyer & Miller (1984) is to predict the demand for transportation facilities and services in the future by extrapolating present travel behaviour, growth characteristics and changing socioeconomic conditions. As such, demand modelling is a process that relies on data on land use, existing transportation system and socioeconomic indices. While transport modellers in developed countries are accustomed to working with relatively rich datasets including transport networks and land use data, such databases are rarely available in developing countries (Walker et al, 2008). Due to the inherent lack of robust data in developing countries, several researchers such as Dimitriou, et al (1990) and Adhvaryu B, (2010) have also presented opinions regarding traffic modelling in developing countries and the need to use simplified models that respect the data constraints.

Adhvaryu B, (2010) developed a simplified planning tool (SIMPLAN) for the city of Ahmedabad, India where he showed that simplified models in the contexts of developing countries (developed within the limits of available data) would continue to be useful for both current and strategic planning of the transportation systems.

Wirasinghe & Kumarage (1998) developed and calibrated an aggregate demand model for estimating inter-district passenger travel by public transport in Sri Lanka. In the course of their research, an investigation was made about the common problems in the aggregate approach. They also examined possible remedial measures to improve the accuracy and the usability of the aggregate model. They posited that commonly used variables and functional forms are inappropriate for making accurate estimates in developing countries. Consequently, their model calibration was shown to incorporate variables representing urbanisation levels, under-development, transfers, a mode-abstract cost function and intrinsic features.

Timberlake, (1988) identified some drawbacks in the use of conventional modelling systems in its Western context in developing countries. According to him, the variables affecting travel demand in developed countries and developing countries quite vary in form and pattern. For instance, while growth patterns of land use and population can be assumed to be constant in developed countries, that same assumption might not hold in developing countries which have a great potential for growth.

Bwire (2008) presented a unified approach for selecting travel demand forecasting model for developing countries. He posited that the ability to judge and select a model that is appropriate for a particular application should be considered as one of the most important aspects in contemporary transport planning. According to him, the need for further guidance on a model selection procedure for developing countries arises due to the fact that data provision in these areas are highly susceptible to higher sampling and measurement errors. The framework he proposed was based on a set of selected criteria which were classified into two main levels of assessment; methods of data collection, and models. The assessment of methods of data collection was further divided into two sublevels of assessment. The first level involved data quality assessment while the second level focussed on assessment of efforts for data provision. The data quality assessment level comprises three stages; general assessment, qualitative assessment and quantitative assessment. The general assessment seeks to provide information needed to inform the qualitative and quantitative assessment of data quality. It provides general information about methods of data collection and also comprises criteria which are not good measures of data quality but which seek to provide information that is directly related to the general usefulness of the data. Qualitative assessment examines factors that influence the quality of methods of data collection while at the quantitative assessment level; data quality is assessed in terms of quantitative measures.

On the assessment of models, a distinction is made at the outset between a model and the modelling software/planning software package. This distinction is used only where the term modelling or planning software or model system is used, otherwise the term model is meant to carry both meanings. The assessment of models is itself, divided into five levels of assessment;

- Model data needs assessment – which focuses on assessing data input requirement of models.
- Model functional assessment – ascertains major functions of the models
- Model reliability assessment – aims at examining the validity of model's underlying theory and basis for the structure and development
- Modelling efforts assessment – determines the efforts needed to implement, operate and maintain the model.
- Modelling software assessment – ascertains if the modelling software possesses the features and properties that provide ease with which the analyst can apply it to achieve intended functions.

Assessment level	Criteria
Data Quality Assessment	Survey purpose and objectives
- General Assessment	Data types
	Survey duration
	Consistency of definitions and classifications Data adjustment methods
	Reasons for the selection of a particular method for data collection
	Problems and strategy to overcome them
- Qualitative Assessment	Level of aggregation of data
	Target population
	Sampling unit
	Quality of sampling frame
	Sampling method
	Sample selection procedure
	Choice or design of measurement instrument Quality control procedure.
- Quantitative Assessment	Sample size
	Coverage error
	Sampling error
	Observational errors
	Statistical comparison of survey results with secondary data
	Cross validation of survey results
	Unit non-response.
- Assessment of Efforts for Data Provision	Characteristics of the study's area of interest
	Experience and knowledge from past surveys Quality of potential methods for data collection versus desirable data quality
	Resource requirements versus resource available

Table 2 Bwire's Criteria for assessment of method of data collection (Bwire,2008)

Chapter 3

Study Area Overview

3.1 Lagos – Demographic and Socioeconomic Characteristics

Lagos is one of the 36 states of the Federal Republic of Nigeria with a population of about 17 million inhabitants (Lagos state government census 2006) which is projected to grow to over 25 million by the year 2025 at an estimated average annual growth rate of about 4%. When compared with 8-9 million in London, 8 million in New York and 11 million in Paris, Lagos is undoubtedly one of the world's mega cities, with its population exceeding the entire population of many countries. Though it is the smallest state in Nigeria by landmass with a total surface area of about 357,700 Hectares, it is by far the most populated. It accommodates over 10% of the entire population of the country. The city is located close to the Atlantic and surrounded by water bodies (lagoons) with about 22% of its total surface area being water (Lagos Bureau of Statistics, 2011).

Figure 6 Metropolitan Lagos

It is a historically important city in West Africa with an economic history extending from pre-colonial days. From a small fishing settlement in the 17th century, Lagos grew into an important port city during the slave trade of the 18th and 19th century (Lagos Bureau of Statistics 2011). Lagos is now Nigeria's most prosperous city and much of the nation's wealth and economic activity are concentrated here. It is also one of the seven New Economic Partnerships for Africa Development (NEPAD) cities. The commercial, financial and business centre of Lagos and of Nigeria remains the business district of

Lagos Island, where most of the country's largest banks and financial institutions are located. Some key data on Lagos state is presented in the table below;

Land size	**3577 sq. km**
Population	17.6 million (Lagos state census)
Population growth rate	6 % per annum
Projected Population by 2025	25 million (UN Projections)
Motor vehicle per sq km in Metropolis	212
% Contribution to National GDP	25 % (US $ 43.25 Billion)
Percentage of Nigeria's skilled Labour force	45 %
% of International Air Traffic to Nigeria	70 %
% of Seaport Activities in Nigeria	90 %

Table 3 Lagos Demographic data (*Source; Lagos State Public Private Partnership office*[3])

A global comparison of Lagos with other major African cities using some key economic indicators is as shown below;

INDICATORS	ABIDJAN	ACCRA	ADDIS ABABA	DAKAR	DAR ES SALAAM	DOUALA	JOHANN ESBURG	LAGOS	NAIROBI	WINDHOEK
GDP/capita (euro)	1,800	1,562	700	1,700	1,100	2,300	10,600	2,200	1,600	5,200
Population (million inhab.)	4.2	3.8	2.9	2.4	3.2	2.5	3.8	17.6	4.7	0.23
Area (km2)	1,183	1,994	530	549	1,800	923	1,645	3,569	4,200	645
Urbanised Area (km^2)	120	1,994	530	214	572	210	1,645	2,831	3,900	645
Human density ($inhab/km^2$)	3,593	2,682	5,608	4,519	1,831	2,708	1,962	4,918	1,127	356
Human density urbanised area ($inhab/km^2$)	35,441	1,922	5,608	11,583	5,762	11,904	2,310	6,200	1,214	356
Total no. of cars	201,134	270,026	116,297	159,982	240,483	150,665	917,042	405,430	519,185	26,209
Car density per km^2 of Urbanised area	170.0	135.4	219.4	291.2	133.6	163.2	557.5	113.6	123.6	40.6
Car/1,000 hab	47.3	70.5	39.1	64.4	73.0	60.3	241.3	23.1	109.6	114.0

Table 4 Comparison among major African cities (source: UITP, 2010)

[3] *http://www.lagosstateppp.gov.ng/about_lagos_state_ppp/about_lagos_overview.asp*

The modal share of private car in these cities plotted against their respective GDP per capita is shown in Figure 7 below. From the figure, private car modal share for the city of Lagos is given as about 17% with a GDP per capita of about 2,200 euros/inhabitant.

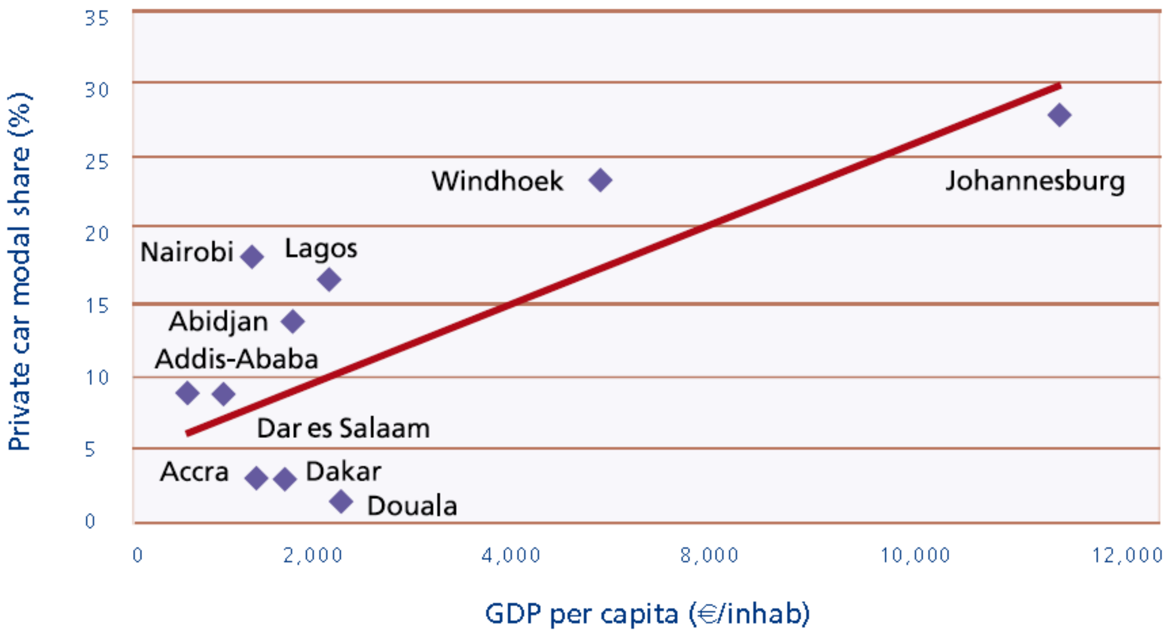


Figure 7 Private car modal share among select African cities *(Source: Trans-Africa Consortium, 2010)*

3.2 Transportation System of Lagos

The transportation system of Lagos state is mainly road based. Though there is a limited use of waterways and rail transit. The road network basically provides accessibility to the different parts of the state. For this reason, all descriptions of about the transportation system of Lagos in this study will be that of the road transport system only.

Lagos has one of the largest and most extensive road networks in West Africa. The strategic road network in Lagos - the major primary, distributor and collector roads - covers no more than 650 kilometres. The road network density of Lagos is put at 0.4 kilometres per 1000 inhabitants. This value has been considered low even by the standards of other African cities. The network's efficiency is similarly low, with a limited number of primary corridors carrying the bulk of the traffic. Currently some 200,000 vehicles are registered annually in Lagos. Nationally there are 11 vehicles to every kilometre of road, whereas in Lagos state, there are 222 vehicles to every kilometre (LAMATA, 2008).

The table 5 below gives a comparison of the total road network length in Lagos with other major African cities.

INDICATORS	ABIDJAN	ACCRA	ADDIS ABABA	DAKAR	DAR ES SALAAM	DOUALA	JOHANN ESBURG	LAGOS	NAIROBI	WINDHOEK
Length of road network (km)	2,042	2,355	640	804	1,140	1,800	10,000	5,180	2,385	2,042
Length of paved road (km)	1,205	1,437	400	520	445	450	8,500	4,818	1,153	1,205
Percentage paved	59%	61%	63%	65%	39%	25%	85%	93%	48%	59%

Table 5 Road network comparison with major African cities (source: UITP, 2010)

Basorun & Rotowa (2012) referring to Mabogunje (2008), gave the estimate of transport demand in Metropolitan Lagos in the 1990s to be between 7-10million passenger trips daily, with over 95 percent being undertaken by car, bus and taxi, with some 80-85 percent made by some forms of privately provisioned public transport. In a study of the public transport operations in the Lagos Island, one of the 20 local government areas making up the entire Lagos state, the author presented a breakdown of the share of various modes used for public transportation. These modes are Molue (46-seater bus), Danfo (16-seater minibus), Okada (motorcycle), Private-Driven Bus Rapid Transit (BRT), Lagos state government BRT (or LAGBUS) and the train. The modal share is shown in the figure below.

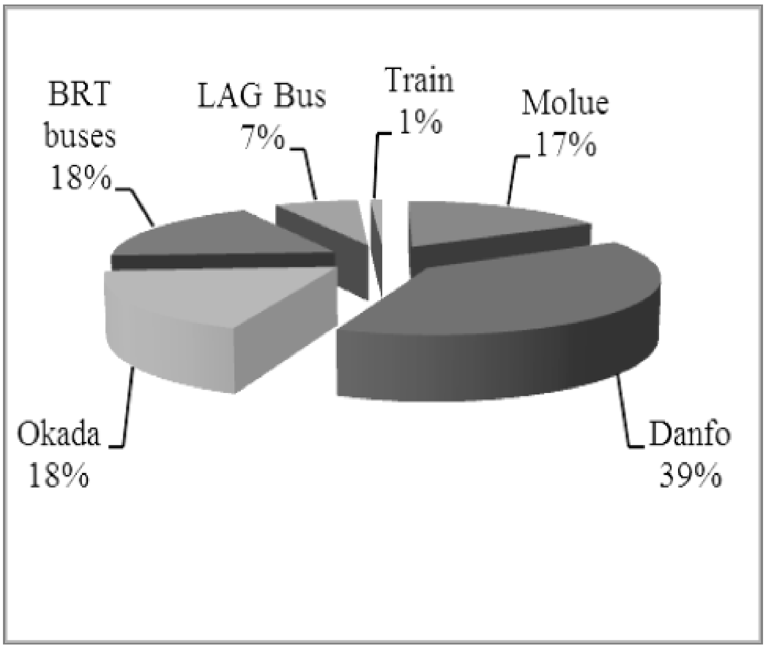


Figure 8 Share of various modes of public transportation in Lagos Island (Basorun & Rotowa, 2012).

3.3 Lagos and the Trans African Highway Network

Lagos is a major connecting point in the Trans-Africa highway network with three major corridors cutting across the state. The Trans-African Highway network comprises transcontinental road projects in Africa being developed by the United Nations Economic Commission for Africa (UNECA), the African Development Bank (ADB), and the African Union in conjunction with regional international communities. These agencies developing the highway network are influenced by the idea that road infrastructure stimulates trade and so alleviates poverty, as well as benefitting health and education since they allow medical and educational services to be distributed to previously inaccessible areas. The total length of the nine highways in the network is 56,683 km (UNECA, 2003)[4].

The three corridors terminating at Lagos are the; Lagos-Algiers Corridor, Lagos-Mombasa Corridor and the Lagos-Dakar Corridor. A brief description of these corridors is presented in the subsections below. The Trans-African Highway Network and the three corridors that converge at Lagos are shown below;

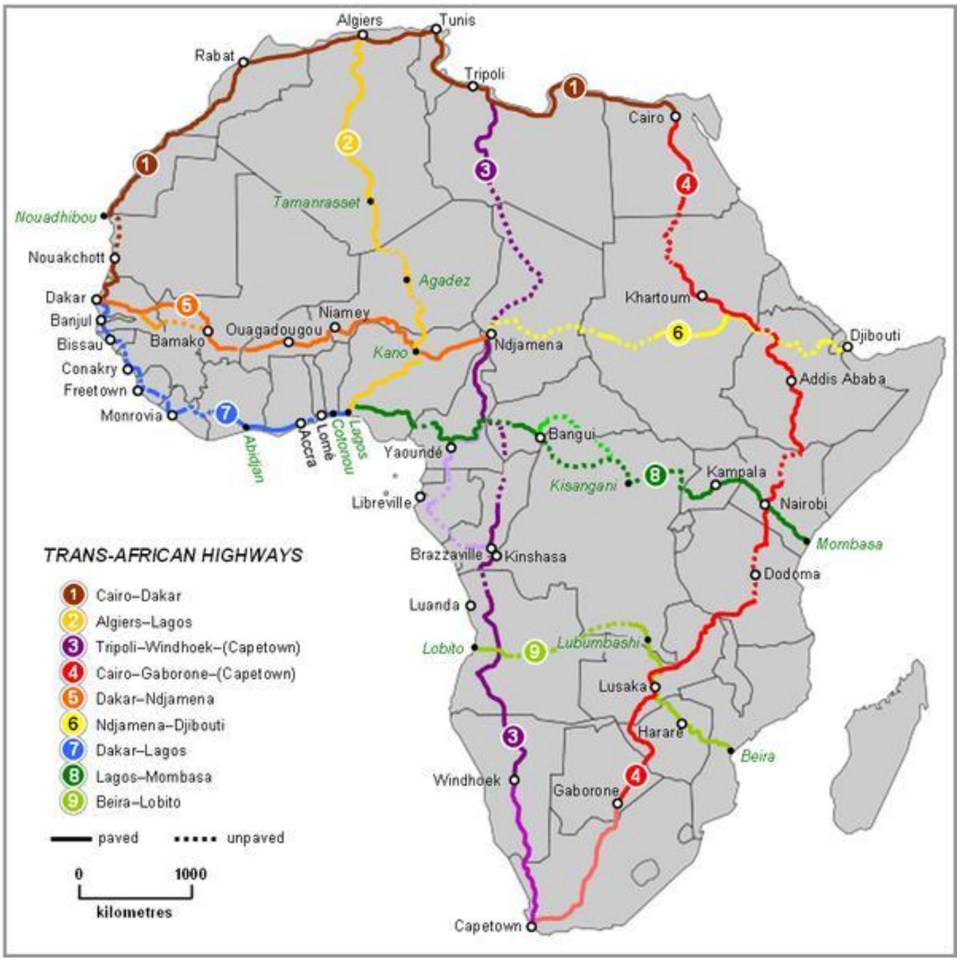


Figure 9 Trans-African Highway Network (with 3 corridors terminating at Lagos) –*UNECA 2003*

[4] United Nation Economic Commission for Africa- Review of the Implementation status of the Trans African Highways, Main Report 2003.

3.3.1 Lagos – Algiers Corridor

This corridor with the Trans Saharan Highway constitutes the oldest of the Trans African Highways. It was officially initiated through a resolution by Economic Commission for Africa in 1962 which foresaw that the possibilities of improved transports through the Sahara should be studied. The idea behind it was to open up vast areas of the Sahara and to promote the integration of Africa on a continental scale. Since then impressive results have been achieved in constructing a highway from the Mediterranean to the Gulf of Guinea. The main alignment, from Algiers through Niger to Lagos in Nigeria, a distance of more than 4500 km, is paved on about 85% of the length and with more pavement works presently underway. (UN ECA 2003).

The Trans Saharan Highway as an idea to enable road traffic from Algiers to Lagos has made tremendous progress in the last 30 years, especially after taking into consideration the limited resources of the concerned countries. Road connection is now possible, although the middle sections present problems and are appropriate for only specialized vehicles (UN ECA, 2003).

3.3.2 Lagos – Dakar Corridor

The Dakar-Lagos Trans African Highway also called the Trans Coastal West African Highway, traverses all the eleven coastal countries between Senegal and Nigeria. The definition of its northern extension varies; sometimes it is defined as starting in Nouakchott, but more often in Dakar. Consequently, the connecting Trans African Highway, coming from Cairo have been defined as going all the way to Dakar. Dakar is also the connecting point to the Trans Sahelian Highway and in Lagos it connects to two other Trans African Highways, the Trans Saharan and the Lagos-Mombasa. The main importance of the Highway is that it provides the most direct, and in some cases the only, road connection between the capitals of the countries along its alignment. It also provides the starting points for the roads leading from the ports to the landlocked countries in the hinterland. It has a total length of 4010 km of which about 3260 km are paved, in various conditions with respect to maintenance (UN ECA, 2003).

3.3.3 Lagos – Mombasa Corridor

The Lagos-Mombasa Trans African Highway provides a road connection between the ports of Nigeria and Cameroon in West Africa and the East African port of Mombasa. The flow of traffic along this highway and the condition of different sections of the road reflects the limited trade between West and East Africa. The Highway consists for all intents and purposes of two separately functioning sections. One connecting the landlocked countries around the Great Lakes with the East African Coast, the other providing access from the Atlantic Coast to north-western DR Congo and the Central African Republic. The highway has a total length of about 6260 km of which about 54 % is paved, in various conditions, with the remainder as either gravel or earth.

The summary of the various corridors terminating at Lagos is shown in table below.

Corridor	Total Length (km)	Paved Length (km)	Unpaved length (km)
Lagos-Algiers	4504	3924	580
Lagos-Dakar	4010	3263	747
Lagos Mombasa	6259	3402	2857

Table 6 Length of various corridors terminating at Lagos.

3.4 Transport Planning & Management in Lagos

The overall transport sector in Lagos is supervised both at the federal (National) level by the Federal Ministry of Transport and at state level by the Lagos State Ministry of Transportation. The State is responsible for the road infrastructures network, road traffic and public transport provision within the Lagos State boundaries through a large number of departments and agencies both at State level and local municipal level.

In order to address the various transport challenges in the State, the Lagos State government established, with the support of the World Bank in 2003, the Lagos Metropolitan Area Transport Authority (LAMATA). LAMATA has the overall role of coordinating the transport policies, programmes and actions of all transport related agencies and of implementing and managing public transport services in the Lagos metropolitan area. As such, it also acts as advisory body to the Governor of Lagos State on public transportation policy issues. In 2007, LAMATA was successful in passing the necessary regulation through the Lagos State House of Representative to improve transportation in Metropolitan Lagos such as the franchise regulation. It empowered LAMATA with the tendering of exclusive operating rights for specific transport services on defined routes or within geographical areas. In this framework, a pilot Bus Rapid Transport scheme called “BRT lite” was designed and was successfully implemented in March 2008. It is known for being the first BRT scheme implemented in Sub-Saharan Africa (LAMATA, 2008).

3.5 Transportation Challenges in Lagos

The density of the Lagos population, the inadequate level of road space, the land use characteristics and the poor mass transit system, combined with inadequate or poorly executed development plans, have given rise to numerous transportation problems in the Lagos metropolis. These include high level of traffic congestion and road accidents, worsening state of disrepair of roads, deteriorating physical attractiveness and comfort of road-based public transport, noise pollution and high level of traffic-related emissions.

The inadequacy of the road network (low lane length in relation to population, limited number of multilane arterial roads, and generally poor maintenance condition), and the relatively high level of car ownership for a developing country (encouraged by subsidized petrol prices and unrestricted import of second-hand vehicles) exacerbated the traffic congestion witnessed in most parts of the state. As a result the typical journey for commuters to Lagos Island from the main residential areas to the north and west of the city could take in excess of two hours, especially when vehicle breakdowns, accidents, and flooding acted to block the roads (World Bank, 2002).

Traffic congestion is however exacerbated by another phenomenon – *danfos, molues & Okadas*. There is an increasing need for road-based public transport to serve the ever-growing population and this gap has been filled by the informal private sector. The number of mini-buses has increased tremendously in the last few years to the extent that there are now around 75,000 mini-buses registered in Lagos according to LAMATA. Unfortunately these vehicles now constitute another cause of congestion on Lagos roads.

The figure below shows a popular look of public transport in most parts of the city of Lagos.

Figure 10 Image of unregulated public bus transportation in Lagos *(Source: LAMATA ,2008)*

3.6 Recent Developments in Transportation

In an effort to improve the public transportation system in Lagos, the government in 2008 embarked on development of a Light Rail Transit (LRT) system while a Bus Rapid Transit (BRT) system was implemented to compliment the public transportation in most parts of the metropolis. While the light rail is still under development through a public-private partnership, the BRT system has since been operational and currently serves about currently serves an average of 200,000 passengers daily (LAMATA, 2008).

The BRT scheme (known as BRT-Lite) is the first of its type in Africa. It relies on the use of dedicated interference-free segregated lanes to guarantee fast and reliable bus travel in a situation where there is traffic congestion. As reported in LAMATA (2008), the BRT had carried 9.7 million passengers after the first 100 days of its operation and a total of 29million after 6months of operation.

Chapter 4

Model Development

4.1 Building the network model

The network model for this study is comprised of the zones and the urban road transport network. The vector shape file of the study area, Lagos state was extracted from open source GIS database. These shape files was exported to the Visum software platform where proper geo-referencing was carried out. The road network was built using the network creation tools on Visum software.

4.1.1 Zoning of Study Area

Study areas are divided into traffic analysis zones (TAZ). All travel (car trips in this case) to or from each TAZ are assumed to start or finish at a single point, the centroid. These trips are connected to the network using hypothetical links or centroid connectors. In some cases, there are multiple hypothetical links (centroid connectors) between the centroid and different points on the transport network. The zones were formed from the administrative units for which population data were available. The twenty (20) local government areas making up Lagos state were taken as the traffic analysis zones for this study.

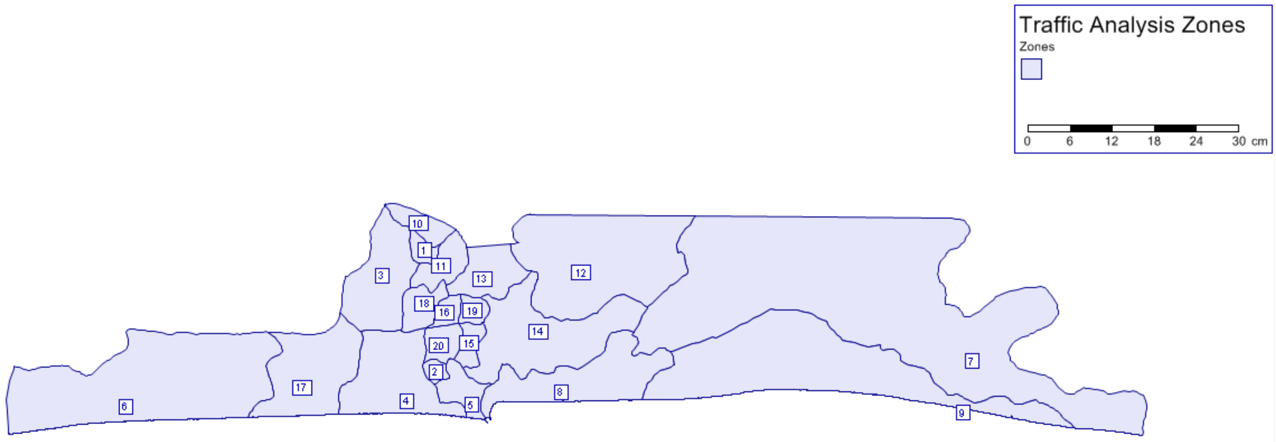


Figure 11 Traffic Analysis Zones

Trips which start and end in the same zone are known as intrazonal and they were included in the model of the network. Only internal zones covering the whole of the study area are considered in this study and all travel between these zones is modeled. External zones were omitted from this study since there were no available data of external trips.

The traffic analysis zones with population as shown in the table below;

Zone No.	Local Government Areas (TAZ)	Population	Area (Sq. Km)	Population Per Sq. Km.
1	Agege	1,033,064	17	60,768.47
2	Ajeromi/ifelodun	1,435,295	13.9	103,258.63
3	Alimosho	2,047,026	137.8	14,855.05
4	Amuwo/odofin	524,971	179.1	2,931.16
5	Apapa	522,384	38.5	13,568.42
6	Badagry	380,420	443	858.74
7	Epe	323,634	965	335.37
8	Eti-osa	983,515	299.1	3,288.25
9	Ibeju-lekki	99,540	653	152.43
10	Ifako/ijaiye	744,323	43	17,309.84
11	Ikeja	648,720	49.92	12,995.19
12	Ikorodu	689,045	345	1,997.23
13	Kosofe	934,614	84.4	11,073.63
14	Lagos/island	859,849	9.26	92,856.26
15	Lagos/mainland	629,469	19.62	32,083.03
16	Mushin	1,321,517	14.05	94,058.15
17	Ojo	941,523	182	5,173.20
18	Oshodi/isolo	1,134,548	41.98	27,025.92
19	Shomolu	1,025,123	14.6	70,213.90
20	Surulere	1,274,362	27.05	47,111.35
	Total	17,552,942	3,577.28	4,906.78

Table 7 Traffic Analysis Zones with Population

4.1.2 Building the road Network

The road network for the study area was developed using Visum network development tools. Combining Visum with the imagery from openstreetmaps (OSM) and Google Earth, the network was developed comprising the arterial, distributor and collector links.

4.1.2.1 Level of Service (LOS) and Capacity Definition

The level of service and capacities were defined for all link types using the Highway capacity manual (HCM 2000). A principal objective of capacity analysis is to estimate the maximum number of vehicles that the links can accommodate with reasonable safety during a specified time period. Vehicle capacity is therefore the maximum number of vehicles that can pass a given point during a specified period under prevailing roadway, traffic, and control conditions. This assumes that there is no influence from downstream traffic operation, such as the backing up of traffic into the analysis point.

The framework for level of service definition according to the manual is as shown below.

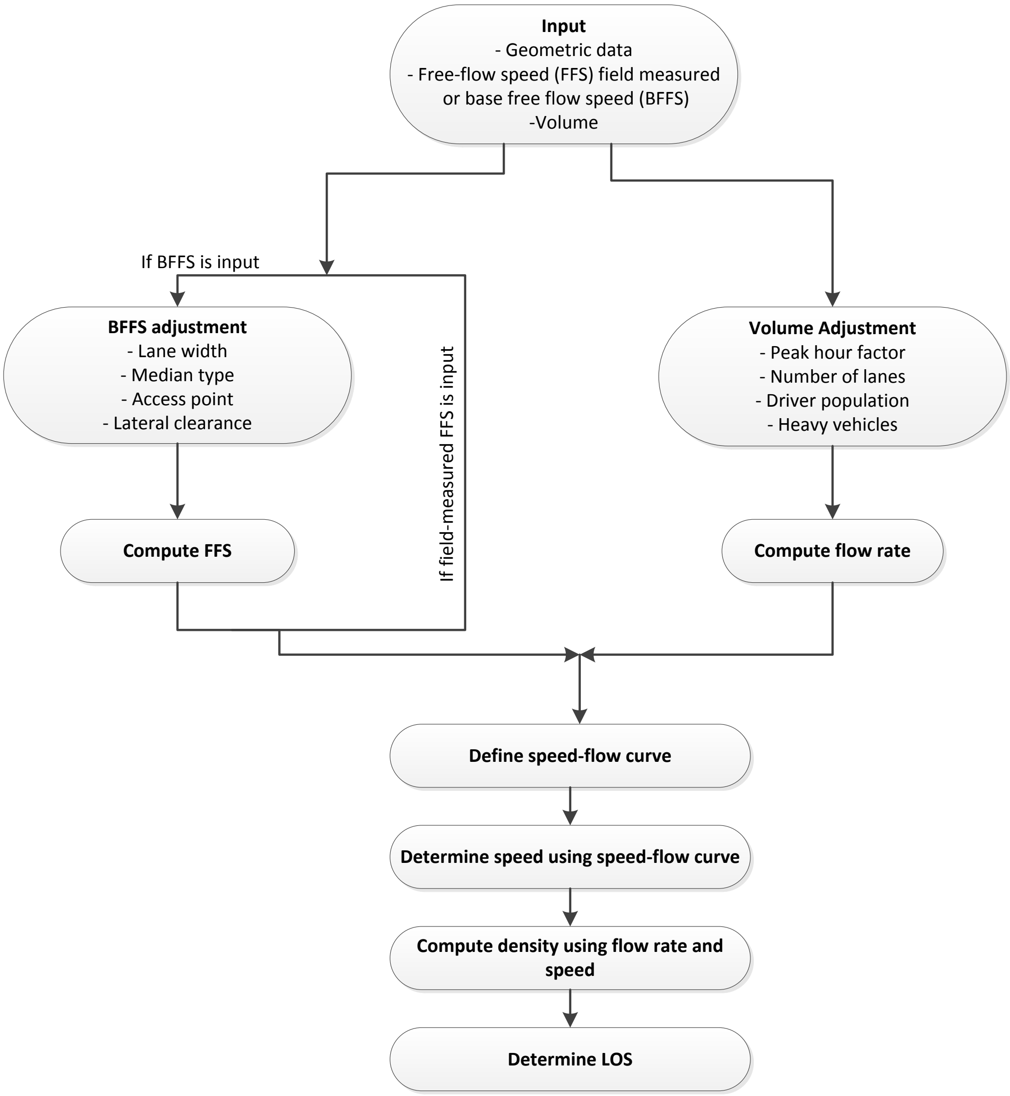


Figure 12 Methodology for Level of Service (LOS) definition *(Highway Capacity Manual 2000)*

The LOS criteria for definition of speed and capacity for multilane highway is shown in the Appendix. The criteria, LOS and capacities of the links in the network under study were defined as shown below.

Link Type	No of Lanes per direction	Free-flow speed (Km/H)	Maximum flow (PC/hr/L)	Capacity (Veh/hr)
Express road	4	110	975	7800
Major Road	3	100	990	6000
Minor road	2	80	900	3600
Collector (2lane street)	1	60	810	1800

Table 8 Main Links and Capacities for the Lagos Network

4.2 Building the Demand Model

The Four-step Travel Demand Model was developed using a combination of excel spread sheet and the Visum built-in tool for four-step modelling. The workflow for the four-Step modelling on Visum is shown in the figure below. The trip generation step was modelled separately using excel spread sheet while the model choice analysis was omitted in the modelling process since the focus is on private transport. The trip distribution and assignment steps were modelled on Visum. The decision to represent only private transport in the model is due to the non-availability of trip data on public transportation. Hence a key assumption made in the modelling exercise is that overall network is being assessed based on private vehicle traffic only.

The model utilises the available Origin-Destination survey data for private transport for year 2006. Hence the base year was taken as 2006 and a future design year of 2025 was selected. The design year was selected to accommodate the available population forecast data.

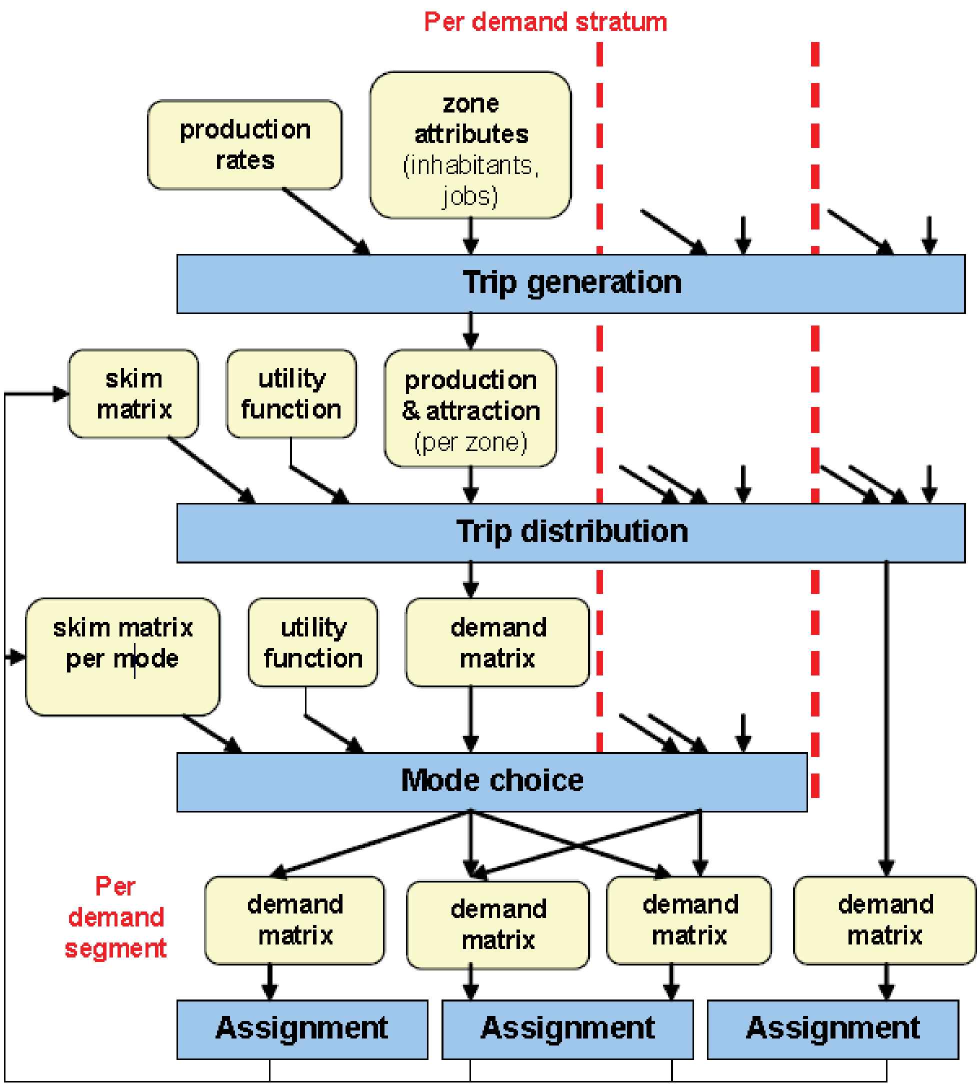


Figure 13 Work flow for integrated 4-Step demand model in Visum *(Source: PTV AG, 2012)*

4.2.1 Trip Generation

Trip generation modelling was carried out with log-linear regression using the base O-D matrix for the survey year 2006 The aim of this step was to establish a linear relationship between the total productions/attractions from each of the traffic analysis zone and the population of the zones. A multiple linear regression model was used. Due to the data constraints faced in this study, only population and employment were considered as the predictive variables. While other factors such as car ownership and average household income could have been considered as part of the predictive variables, such data were not available for this study.

4.2.1.1 Trip Production Model

The two variables considered as predictive (population and employment) were checked for correlation due to possible problems of collinearity. Multicollinearity refers to a situation in which two or more explanatory variables in a multiple regression model are highly linearly related. The resulting effect of a high degree of correlation between variables is that the estimate of one variable's impact on the dependent variable (trips in this case) while controlling for the others, tends to be less precise than if predictors were uncorrelated with one another.

Having observed a high correlation between the predictive variables, population and employment, only the population was selected in modelling trip production. A scatter plot of the produced/attracted trips against population showed a non-linear relationship hence a log transformation of the variables was carried out as tabulated below.

y1 = Total Originating trips						
y2 = Total Destination trips						
x1 = Population						
Zone No.	y1	y2	x1	ln y1	ln y2	ln x1
1	2006	1492	1033064	7.603898	7.307873	13.848040
2	1411	404	1435295	7.252054	6.001415	14.176881
3	7844	5828	2047026	8.967504	8.670429	14.531899
4	5216	6918	524971	8.559486	8.841882	13.171098
5	741	724	522384	6.608001	6.584791	13.166158
6	1440	1985	380420	7.272398	7.593374	12.849031
7	75	146	323634	4.317488	4.983607	12.687369
8	9538	10265	983515	9.163039	9.236495	13.798888
9	33	2	99540	3.496508	0.693147	11.508315
10	1903	1574	744323	7.551187	7.361375	13.520230
11	7434	8199	648720	8.913819	9.011767	13.382756
12	2071	2006	689045	7.635787	7.603898	13.443062
13	5648	4542	934614	8.639057	8.421123	13.747889
14	2792	3872	859849	7.934513	8.261526	13.664512
15	3604	4219	629469	8.189800	8.347353	13.352632
16	3835	4402	1321517	8.251925	8.389814	14.094291
17	2732	2749	941523	7.912789	7.918992	13.755254
18	5001	4521	1134548	8.517393	8.416488	13.941745
19	1280	796	1025123	7.154615	6.679599	13.840323
20	3322	3225	1274362	8.108322	8.078688	14.057956

Table 9 Log transformed values of variables

Regression Model output

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.771367033							
R Square	0.595007099							
Adjusted R Square	0.572507493							
Standard Error	0.938541787							
Observations	20							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	23.29455768	23.29455768	26.44522349	6.82732E-05			
Residual	18	15.85549233	0.880860685					
Total	19	39.15005002						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-15.25564094	4.44990162	-3.428309711	0.002997479	-24.60453733	-5.906744548	-24.60453733	-5.906744548
ln x1	1.68982489	0.328600396	5.142491954	6.82732E-05	0.999461077	2.380188703	0.999461077	2.380188703

Table 10 Regression output for Trip production

The regression plot is as shown in the figure below,

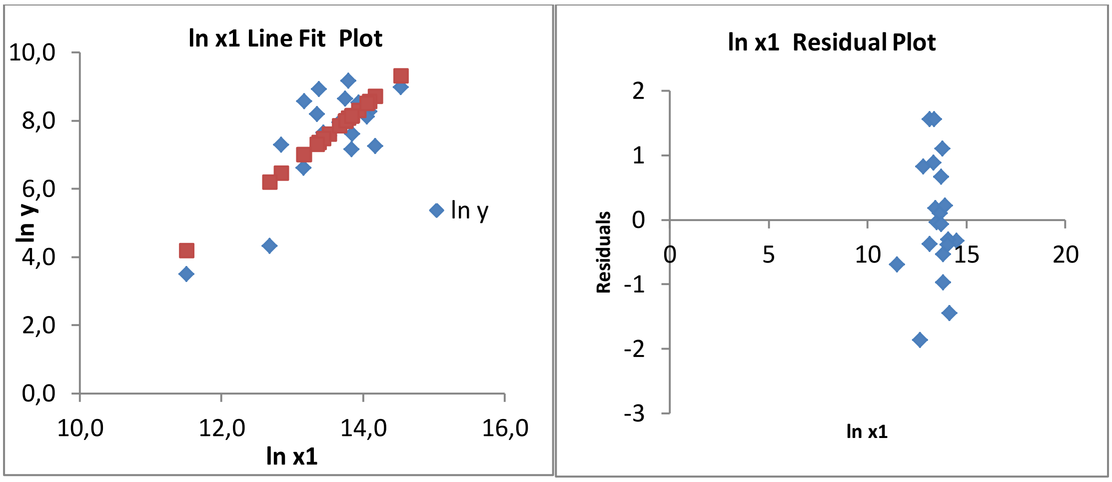


Figure 14 Line Fit and Residual plot (Trip Production)

From the regression summary output, the regression equation can be written as,

$$In\ y = 1.69\ Inx - 15.25 \qquad \text{Equation 18}$$

Retransformation of the equation gives, the trip production model as,

$$\boldsymbol{Zonal\ Originating\ Car\ Trips\ (y) = exp^{(1.69\, *\, In\ (zonal\ population\ x) - 15.25)}}$$

The above function however has some constraints. Since trips and population cannot be negative, the function only holds for all population (x) value greater than 8,297. Therefore, a key assumption in application of the trip production model is that population must be sufficiently large enough.

4.2.1.2 Trip Attraction Model

The Attraction model follows the same pattern as the production, with the total destination trips to each zone being the dependent variables and population taken as the predictive variable.

Regression output is as shown below;

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.725169191							
R Square	0.525870356							
Adjusted R Square	0.49952982							
Standard Error	1.349416014							
Observations	20							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	36.3534644	36.3534644	19.96429988	0.000297172			
Residual	18	32.77662443	1.82092358					
Total	19	69.13008883						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-21.13508195	6.397976727	-3.30340088	0.00395153	-34.57673227	-7.69343163	-34.57673227	-7.69343163
In x1	2.110995807	0.472454868	4.468142777	0.000297172	1.118404961	3.103586652	1.118404961	3.103586652

Table 11 Regression output for Trip Attraction

The line fit and residual plot of the regression are shown in the figures below.

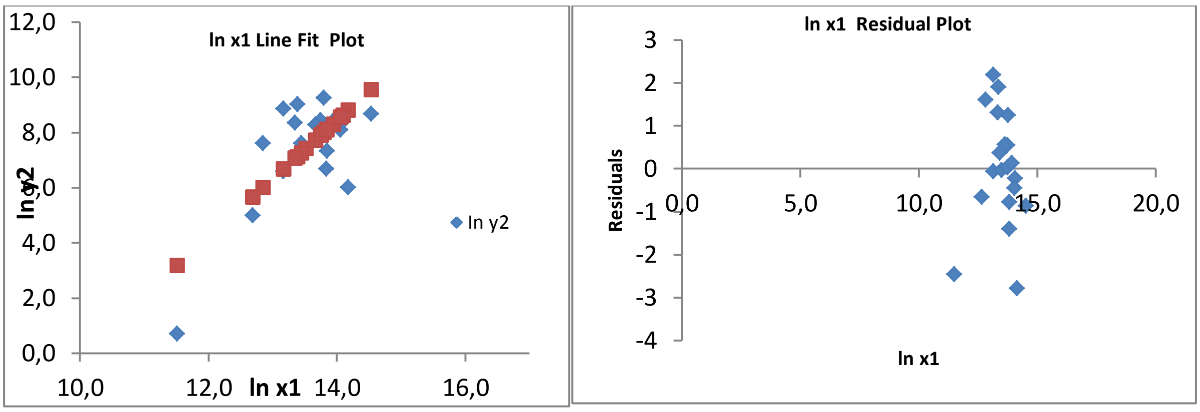


Figure 15 Line Fit and Residual Plot (Trip Attraction)

From the regression summary output of Table 14, the regression equation can be written as;

$$In\ y_2 = 2.11\ Inx - 21.13 \qquad \text{Equation 19}$$

Retransformation of the equation gives the attraction model as;

$$\boldsymbol{Zonal\ Destination\ Car\ Trips\ (y) = exp^{(2.11 * In\ (zonal\ population\ x) - 21.13)}}$$

Again, due to the non-negativity of trips, this function has a constraint. It is only applicable for population value (x) greater than 22,341. Since the zonal population of the study area ranges from hundreds of thousands to millions, both trip production and attraction models would be quite applicable.

4.2.1.3 Comments on Trip Production & Attraction Model

The results of the linear regression analysis shown in the preceding section can be interpreted based on the Coefficient of Determination R^2, F-Significance, and Coefficient of explanatory variables, Standard error as well as the t-statistics and corresponding p-values.

On Coefficient of Determination R^2

The Coefficient of Determination R^2 is a measure of the proportion of variability in a data set that is accounted for by a statistical model. The closer the value is to 1, the higher the proportion of variability explained by the model.

The R^2 value for the production regression model was found to be approximately 0.60, which means, about 60% of the variability in the zonal originating car trips is explained by the model while the other portion is attributed to the error term. For attraction model, the value is about 0.53 (53%). In both cases (Production and Attraction) therefore, with population taken as the only predictive variable in the model, more than half of the variability observed in trips can be explained.

On F- Distribution

The F value and its Significance give the probability that the regression equation does NOT explain the variation in y, i.e. that any fit is purely by chance. This is based on the F probability distribution. If the Significance F is not less than 0.05 (5%) we do not have a meaningful correlation. More formally it is a test of whether all the coefficients are jointly equal to zero. If they are, effectively the model is not really explaining anything. Hence we will ideally want a high F-value, and a low corresponding P-value.

The F value observed in the production regression model was 26.44 (which is largely different from zero), while the F significance is observed to be far less than 0.05 (with a value of 6.8E-05). Hence the probability of our model fit occurring by chance is significantly small. For the trip attraction model, the F-value and significance were respectively 19.9 and 2.9E-04, another indication that the model fit does not occur by chance.

On Variable Coefficients

In regression model it is critical to ensure that the coefficients of the independent variables are significantly different from zero otherwise the model will lack good predictive power. The coefficients observed in the production and attraction models (1.69 & 2.11) are quite different from zero while the error term associated with the variables is also relatively small compared to these coefficients. This also shows the explanatory capacity of the model independent variable. The intercept term however are seen to be negative. This, however, do not affect the predictive capacity of the model as the variable coefficient is what really matters.

On t-statistic and p-values

The t-stat can be a measure of the relative strength of prediction of the model and it takes into account the coefficients error and the generalizability of the findings beyond the sample. The greater the t-stat, the greater the relative influence of the independent variable on the dependent variable. A t-stat of greater than 1.96 with significance less than 0.05 indicates that the independent variable is a significant predictor of the dependent variable within and beyond the sample.

In both the production and attraction regression, the t-stat value of 5.14 and 4.47 respectively, with a corresponding p-value of 6.8E-05 and 2.9E-04, indicates a relatively good strength of the model predictive capacity.

4.2.2 Trip Distribution

The main purpose of this step is to develop a procedure that creates the trip linkages between traffic zones. In other words, trip distribution approximates the travel pattern, by distributing the production and attraction ends of the trips into different traffic zones based on some deterrence function.

The gravity model was used in the process and the distribution procedure was carried out using the Visum software. As discussed in the section 2.7.2 , the gravity model is given by;

$$T_{ij} = \alpha O_i D_j f(c_{ij}) \qquad \text{Equation 20}$$

Where; T_{ij} is the number of trips from zone i to j.

O_i and D_j are the number of total trip ends in zone i and j respectively.

α is a balancing factor (which takes a value of 1 if trip production and attraction ends are equal); $f(c_{ij})$ is the deterrence function or impedance function.

Deterrence function used is the negative exponential function given by;

$$f(c_{ij}) = \exp(-\beta c_{ij}) \qquad \text{Equation 21}$$

4.2.2.1 Key consideration in Trip Distribution Step

Two main considerations are being made in the trip distribution modelling of this study;

- The inclusion of intrazonal trips and impedance and
- The consideration of travel impedance as a function of only the free flow travel time in the unloaded network. Since the study is concentrated on just one mode of transport, this consideration would be reasonable.

Consideration of Intrazonal Trips & Impedance

While some researchers such as Gahreib, (1996) have supported exclusion of intra-zonal trips in the overall modelling process on the basis of their relative difficulties in estimation, others have posited that such exclusion of intra-zonal trips or impedance will result to biased estimation. One of such works on whether intrazonal trips are ignorable in model estimation or not, was carried out by Bhatta & Larsen (2011). According to the authors, while intrazonal trips are not always included in model estimation because they do not appear on the network in a centroid-to-centroid basis, their omission results to model bias which consequently result to biased parameter estimation.

Since the decision to include or omit intrazonal trips has been based on the level of service attribute of the intrazonal network, several methods have been proposed and applied for computing and inputting level of service attributes in the network. The length of intrazonal trip has been taken to depend on the size of a zone, with average length of trips estimated as a function of zone area.

The U.S. Bureau of Public Roads (BPR) suggests that intrazonal driving time be estimated as a half the average driving times from the centroid of a particular zone to the adjoining zones' centroids (U.S. Department of Commerce, 1965). The BPR function in the Visum software was used in estimating intrazonal travel times in this study.

Consideration of Impedance as a function of Travel Time

Travel impedance has been considered as a function of the generalised cost of travel. However, the lack of comprehensive data on cost of travel and data on value of time of trip maker in the study area has resulted in the consideration of impedance as only a function of the network travel time.

4.2.2.2 Visum Procedure Sequence for Trip Distribution

Trip distribution on Visum software follows the process described below. In estimating the gravity model parameter, the inbuilt parameter estimation tool in Visum (KALIBRI parameter estimation) was utilised. The procedures for trip distribution and parameter estimation are set sequentially as shown below;

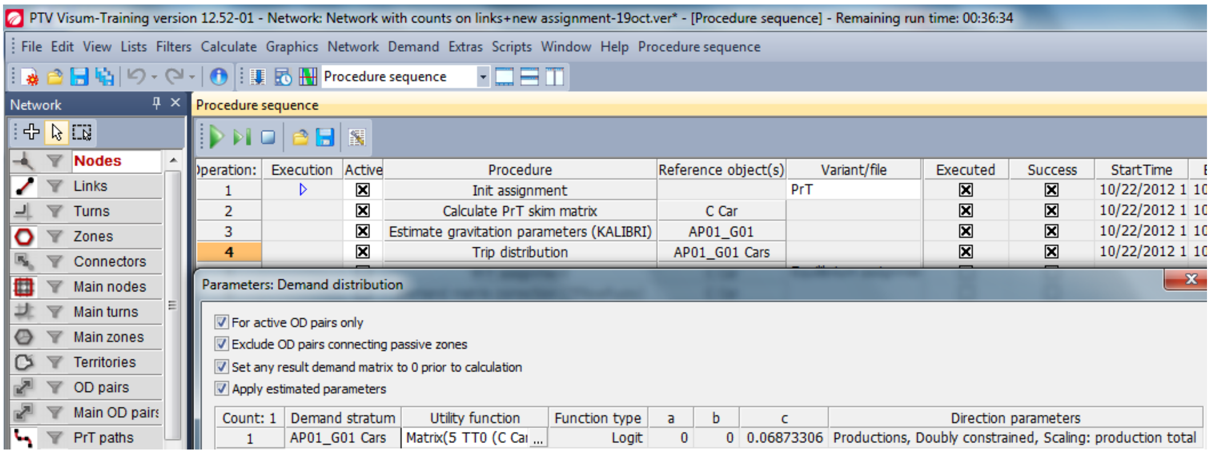


Figure 16 Visum Procedure sequence for Trip Distribution & Parameter Estimation

4.2.2.3 Distribution Output

The end result of the trip distribution step computed in visum is the OD matrix and the estimated parameter of the exponential deterrence function used in the distribution. Distribution parameter computed for the deterrence function using the KALIBIRI tool in visum is;

$$\beta = 0.068733$$

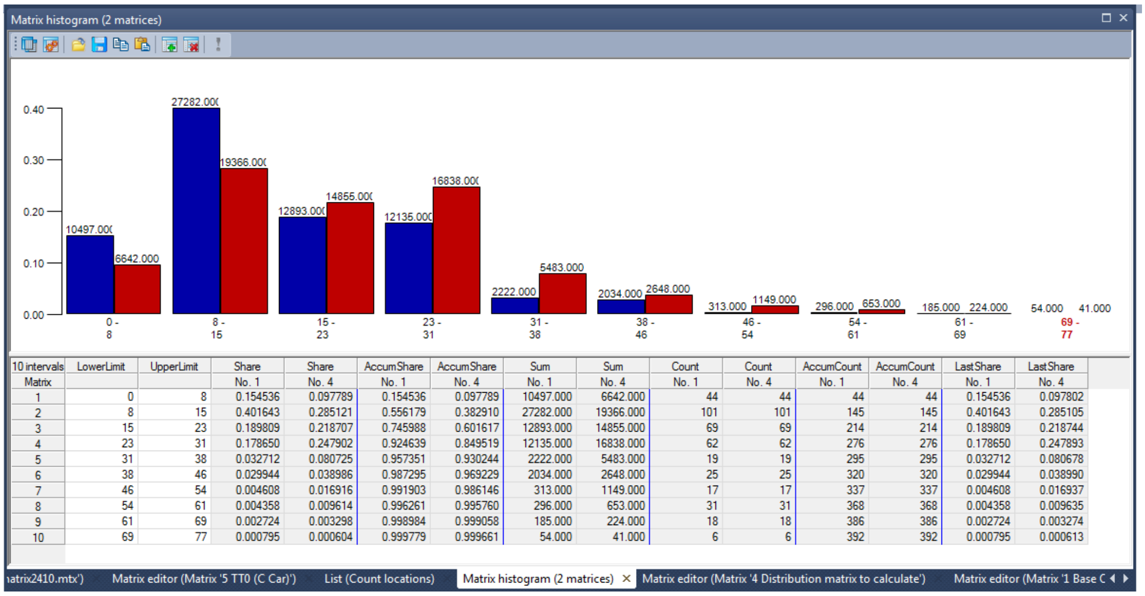
The above parameter apart from being a distribution parameter reflects an interaction between the trip maker and willingness to make the trip. A value closer to zero indicates that trips would be made irrespective of cost. While values that are further from zero indicates decreasing willingness to travel should there be a change in travel cost. This also gives a measure of how the trip maker values its time.

Comparing the estimated value of the parameter above with those estimated in some literature such as Martin & McGuckin (1998), which were between 0.09 and 0.1, it could be concluded that the above parameter is within reasonable estimate.

The distributed trips are shown in the appendix.

4.2.2.4 Trip Frequency Distribution of Observed Matrix and Visum-Distributed Matrix

The O-D matrix computed with the Visum software was compared with the observed O-D trip matrix according to the network travel time skim distribution of each O-D pair. The histogram below shows the comparison between the two matrices. The height of each bar represents the proportion of trips belonging to specific travel time interval indicated on the horizontal axis. The blue bar shows the trips of the survey O-D matrix while the red bar shows the trips from the Visum-computed O-D matrix.



10 intervals	LowerLimit	UpperLimit	Share	Share	AccumShare	AccumShare	Sum	Sum	Count	Count	AccumCount	AccumCount	LastShare	LastShare
Matrix			No. 1	No. 4	No. 1	No. 4	No. 1	No. 4	No. 1	No. 4	No. 1	No. 4	No. 1	No. 4
1	0	8	0.154536	0.097789	0.154536	0.097789	10497.000	6642.000	44	44	44	44	0.154536	0.097802
2	8	15	0.401643	0.285121	0.556179	0.382910	27282.000	19366.000	101	101	145	145	0.401643	0.285105
3	15	23	0.189809	0.218707	0.745988	0.601617	12893.000	14855.000	69	69	214	214	0.189809	0.218744
4	23	31	0.178650	0.247902	0.924639	0.849519	12135.000	16838.000	62	62	276	276	0.178650	0.247893
5	31	38	0.032712	0.080725	0.957351	0.930244	2222.000	5483.000	19	19	295	295	0.032712	0.080678
6	38	46	0.029944	0.038986	0.987295	0.969229	2034.000	2648.000	25	25	320	320	0.029944	0.038990
7	46	54	0.004608	0.016916	0.991903	0.986146	313.000	1149.000	17	17	337	337	0.004608	0.016937
8	54	61	0.004358	0.009614	0.996261	0.995760	296.000	653.000	31	31	368	368	0.004358	0.009635
9	61	69	0.002724	0.003298	0.998984	0.999058	185.000	224.000	18	18	386	386	0.002724	0.003274
10	69	77	0.000795	0.000604	0.999779	0.999661	54.000	41.000	6	6	392	392	0.000795	0.000613

Figure 17 Comparison of Visum-distributed trip matrix with Observed trip matrix

Interpreting the first blue bar shows that, 10,497 trips representing about 15% of the total trips in the observed OD matrix, falls within the free flow travel time interval of 0-8 minutes, while for the Visum computed OD matrix, about 6,642 trips (10%) falls within that same time interval.

A line plot of the same histogram is shown in figure 17

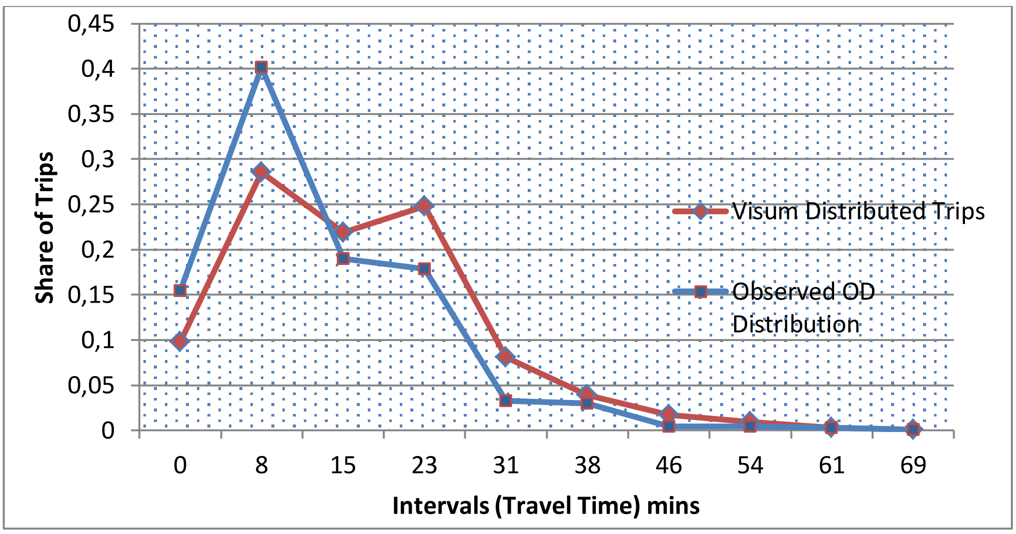


Figure 18 Line Plot comparison of observed O-D and Visum-Computed O-D

This line plot shows that both the initial OD-matrix provided by the Lagos Transport Authority and the Visum computed OD-matrix quite follows similar patterns when the trips in all OD pairs are classified according to free-flow travel time skim. The plot reveals higher proportion of trips falling between 0-

15minutes for the observed OD-distribution than for the Visum computed distribution, while the reverse is the case for trips exceeding 15minutes.

4.2.2.5 Desire Lines of Major OD Flows

The Desire lines display the values of the OD pairs between zones. Such values could either be direct distance, travel times or number of trips between the OD pairs. The desire lines represented below show the distributed trips among the OD pairs with the top 30 values. The value on the lines represents the sum of both originating and destinating trips between the OD pairs. The highest values are represented by the thickest lines. From the figure, it could be concluded that OD pairs between zones 3 & 8, and 11 & 8, carries the highest flows in the network.

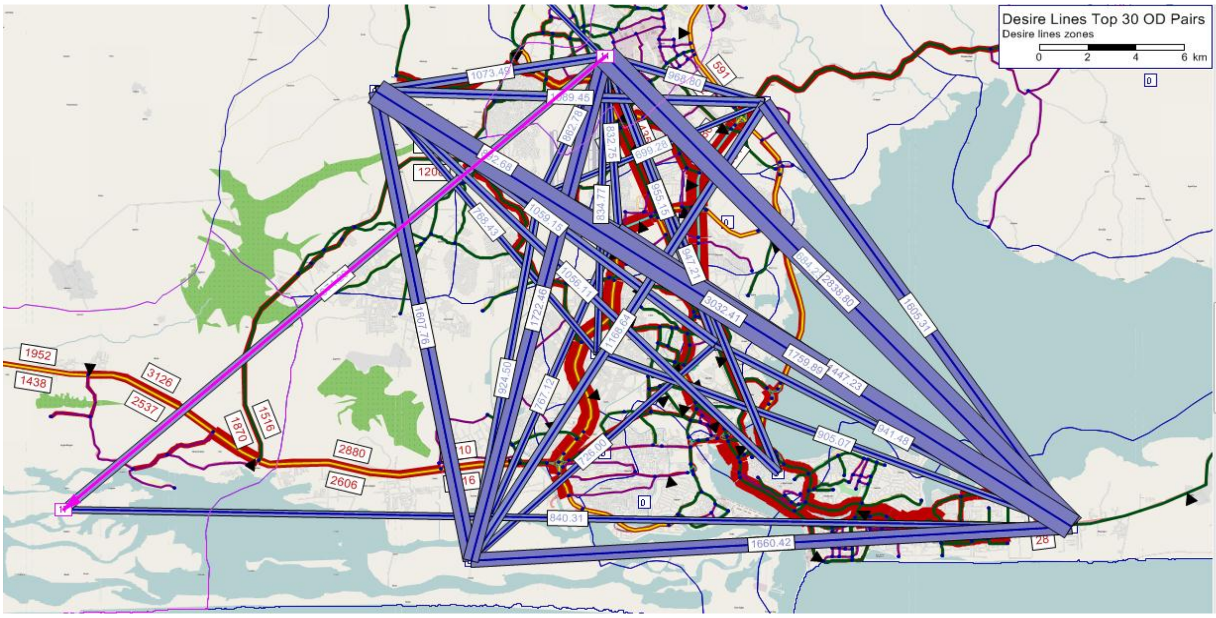


Figure 19 Desire lines of Top 30 OD pairs.

4.2.3 Traffic Assignment

The traffic assignment is the last step carried out in the four step modelling process where the derived OD trip matrix is assigned to the network. As discussed in the literature review section (Chapter 2), various procedures can be employed in traffic assignment. In this study, the equilibrium assignment procedure on Visum was employed. The data input in the assignment step is the O-D matrix computed in the trip distribution step discussed in the previous section, while the output is vehicle volumes assigned to each link in the network. Prior to assigning traffic to the network, it was necessary to define the network impedance/Volume Delay function for each network elements such as links, turns or nodes.

4.2.3.1 Route Impedance

In Visum the assignment procedures are based on a short-route algorithm that determines low impedance routes (Visum 12.0 user manual). The impedance of a Private Transport (Car) route is volume-dependent and consists of the following impedances;

- Impedances of used links.
- Impedances of used turns, which are also called 'node impedance.
- Impedances of the used connectors.
- Impedances of the used main turns.

In other words, for a detailed network definition, all direct and indirect numerical attributes of the network objects such as links, turns, connectors and main turns, are utilised for the definition of the impedance of a route. For the scope of this thesis however, only the impedance of links are being considered and this impedance is taken as the travel time on the links.

4.2.3.2 Link Performance (Volume Delay) Function

The travel time of a network object is calculated with capacity restraint functions or Volume Delay function (VDf). Based on the assumption that the travel time (impedance) of network objects increases with increasing traffic volume, all assignment procedures are in turn based on the assumption that travel times of network objects are a monotone incremental function of traffic volume. Hence, a Volume Delay function gives a mathematical description of the relationship between travel time and link flow.

For every transport system permitted on a link, a transport system-specific travel time (t_0) for free flow is defined which is calculated from the following attributes: link length, permitted speed (V_0) of the link used and the maximum speed of the transport system (V_{max}).

A Volume-Delay function continuously adapts this basic travel time depending on the current traffic volume. Several variants of this function have been developed over the years. However the commonly used version is the Bureau of Public Roads (BPR) function given by,

$$t_a(q_a) = t_a^0 \left[1 + \alpha \left(\frac{q_a}{C_a}\right)^{\beta}\right] \qquad \text{Equation 22}$$

Where;

t_a = (congested) travel time on link *a*

q_a= flow on link *a*

t_a^0= free-flow travel time on link a (with q_a= 0)

C_a= capacity of link a

α, β are parameters (taken as 0.15 and 4.0 respectively)

In Visum assignment, the BPR function was used as the volume delay function with the parameters set as 0.15 and 4.0. These values are the coefficients of the basic structure of the BPR curve, as used in Martin & McGuckin (1998). Since data on flow-speed characteristics for the study area were not available, it was reasonable to assume these basic coefficients.

A first trip assignment was carried out using the calculated O-D matrix in the trip distribution stage. However, this matrix had to be calibrated before final assessment was performed. The matrix calibration process is presented in the next chapter.

Chapter 5

Model Calibration and Implementation

5.1 Introduction

This chapter discusses the calibration of the Visum distributed OD trip matrix using traffic count data. Two calibration techniques, the T-flow fuzzy process and the Calibration by Lohse method are discussed and outputs of both procedures are compared. Other part of the chapter presents the implementation of the trip generation and distribution model in forecasting future year trips on the network. The concluding part presents the assignment output of the calibrated base year and future year OD matrices and a comparison between network behaviour for both years.

5.2 Matrix Calibration from Traffic Counts

After the estimation of the O-D matrix and performing the trip assignment as described in the last chapter, a calibration process was necessary to correct the demand matrix according to the observed count data. The calibration entails the adjustment of the O-D matrix so that the traffic volumes on links, resulting from the assignment, closely match with the observed traffic counts.

Two calibration procedures in Visum are Demand matrix calibration tool (Lohse method) and the T-Flow fuzzy approach. Both methods provide a calibration function that uses traffic count data to calculate projection factors, based on assignment results, for origin and destination sums of a demand matrix. Using a balancing procedure the matrix is then projected to the sum values. These two procedures are discussed in subsequent sections in this chapter.

5.2.1 Preparing Count Data - Deriving Peak Hour Count from Average Daily Traffic

The recalibration process starts with inputting the traffic counts from the count data available from the Lagos Metropolitan Area Transport Authority (LAMATA). However, since these counts were Average Daily Traffic, only a certain proportion that reflects peak hour counts was needed as inputs in the network under analysis. This was necessary since the trips in the model estimation (trip generation, distribution and assignment) was carried out in a per peak hour traffic basis.

In deriving peak hour counts from the Average Daily Traffic, the methodology prescribed in the Traffic Forecasting Handbook of the Florida State Department of Transportation (FDOT, 2012) was employed. According to the manual, obtaining the design hourly traffic from the average daily traffic (ADT) involves the application of a K-factor to the ADT. The K- factor converts the 24-hour ADT to an estimate of two-way traffic in the analysis hour which is required for design purposes.

The standard K-factors are as shown in the Appendix A.

5.2.2 Adding Counts Data to Network on Visum

A total of 35 count locations were inputted on the network and marked using the count location creating tool in Visum. The factored count figures (from ADT count data) were provided as 'Add Value 1' attribute on the links. In addition to the count values, an allowance was also inputted for those counts as an 'Add Value 2' attribute. The allowance was arbitrarily set at 10% of the count figures.

The positions of the count locations were determined from Google Maps in accordance with the available information from the Lagos Transport Authority. The base information only contains the description of the roads and the locations where counts were taken. Hence digitizing these count locations on the network in Visum was based on the hind knowledge of the study area. A key limitation of this approach however, is, getting the exact point in the network where those counts were taken.

5.3 Calibration Methods on Visum

As pointed out in the beginning of this chapter, the matrix calibration was performed using the two in-built techniques in Visum, which are; the T-flow fuzzy correction and the Demand matrix calibration (Lohse) tool. The two techniques were utilised and compared for performance.

5.3.1 T-Flow Fuzzy Technique

The T-Flow Fuzzy process on Visum, also discussed by Jin & Aziz (2009), is a matrix correction procedure used to adjust a demand matrix after the traffic assignment has been executed, so that its assignment output actually matches the real supply observed (actual counts on link sections). This procedure can be useful in several situations;

- A demand matrix based on empirical survey data is outdated and needs to be updated without having to conduct a new (origin-destination) survey.
- A matrix generated from the transport network model is to be calibrated, therefore counted volume data are to be used.
- A matrix generated from incomplete or not reliable data is to be improved by more comprehensive/reliable volume data counted simultaneously.
- A survey contains the journey distance distribution, but the model does not reflect the data with the level of accuracy required.

The calibration involved in this study aligns with the second point noted above. In this case the trip distributed from the network model in Visum is being calibrated to the traffic count data.

Before the calibration procedure is carried out, it was necessary to ensure the following;

- The count values are provided as "AddValue" data on links.
- The network contains a Demand Segment (in this case, Private Transport) assignment result.

- The existing Demand Matrix is an optimally generated matrix which may have resulted from previous counts or calculations and whose inner structure must correctly represent the impedance situation in the network (PTV AG, 2012).

The workflow for the matrix calibration and balancing is as follows,

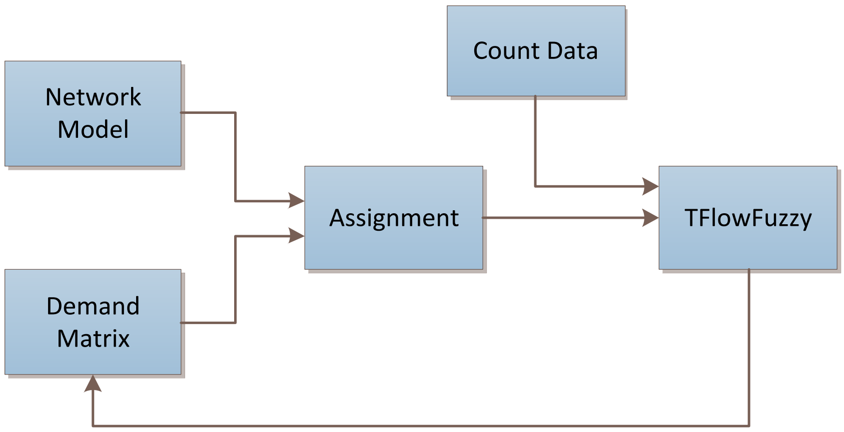
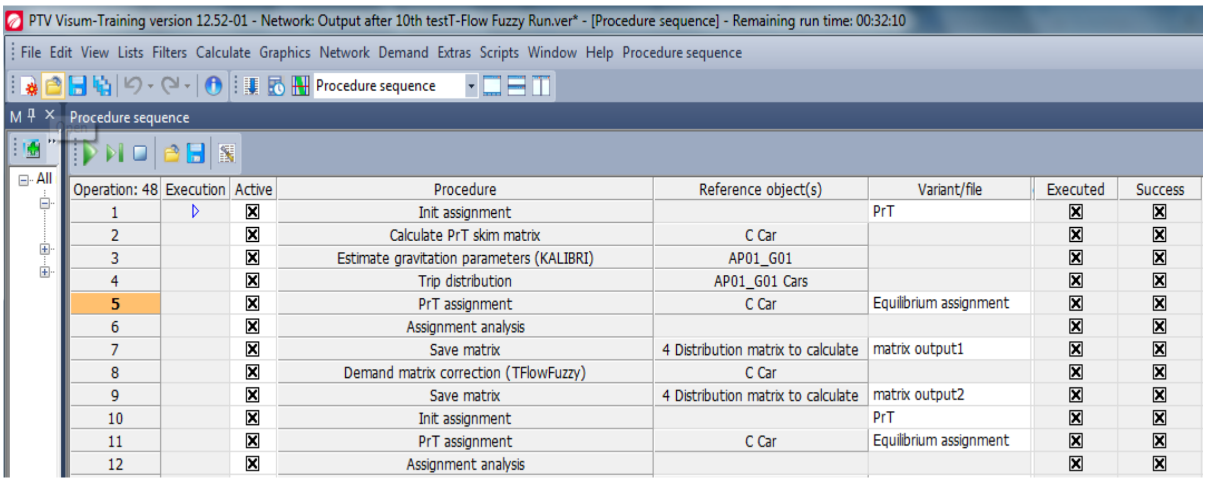


Figure 20 T-Flow Fuzzy work flow (PTV AG, 2012)

For the calibration, the specified count values are compared with the volumes which result from a pre-calculated assignment of the previous demand matrix. Differences between count values and volumes are balanced by adjustment of the demand matrix for the assigned demand segment, which is private transport in this case study. The volumes from the selected network object are then taken from the assignment result of this demand result, and the count values also only refer to this demand segment (PTV AG, 2012).

5.3.1.1 Procedure Sequence

The procedure sequence set in Visum for the T-flow fuzzy is shown below;



Operation: 48	Execution	Active	Procedure	Reference object(s)	Variant/file	Executed	Success
1	▷	☒	Init assignment		PrT	☒	☒
2		☒	Calculate PrT skim matrix	C Car		☒	☒
3		☒	Estimate gravitation parameters (KALIBRI)	AP01_G01		☒	☒
4		☒	Trip distribution	AP01_G01 Cars		☒	☒
5		☒	PrT assignment	C Car	Equilibrium assignment	☒	☒
6		☒	Assignment analysis			☒	☒
7		☒	Save matrix	4 Distribution matrix to calculate	matrix output1	☒	☒
8		☒	Demand matrix correction (TFlowFuzzy)	C Car		☒	☒
9		☒	Save matrix	4 Distribution matrix to calculate	matrix output2	☒	☒
10		☒	Init assignment		PrT	☒	☒
11		☒	PrT assignment	C Car	Equilibrium assignment	☒	☒
12		☒	Assignment analysis			☒	☒

Figure 21 Visum Procedure sequence for T-Flow Fuzzy

For the network under analysis, count values were added on 35 links and only those links were activated for the T-flow fuzzy process. Other parameters for the T-flow fuzzy such as the correction factor and the maximum number were set to default values on Visum. It was also set that only network objects with assigned volume and count value greater than zero are only used in the T-flow fuzzy process.

After setting the procedures and parameters, T-Flow fuzzy process was run on the network. The T-Flow on Visum does not run as a stand-alone process but rather, it runs in conjunction with Assignment, recalculating the input O-D matrix in the process.

The recalculated O-D matrix (which was automatically saved to the Demand Segment, Private Transport) was then reassigned to the network which resulted to an expected change in assigned volumes when compared to the assignment output before T-flow. About 5 runs of the T-flow process were carried. Each successive assignment was based on recalculated matrix of the preceding T-Flow fuzzy process.

At the end of each assignment, an assignment analysis was run on the network. The assignment analysis is a statistical analysis that uses indicators such as Coefficient of determination, R^2 and Root-Mean-Squared Error, RMSE to measure how the assigned volumes compares with the observed counts earlier inputted on the links. In setting the assignment analysis, it was specified that only links with count values above zero are analysed. A tolerance or bandwidth for observed count was also set in the analysis process. The tolerance is basically an allowed envelope within which traffic counts might deviate. On Visum, this tolerance is specified based on the NCHRP 255 hourly standard, in which the percentage tolerance varies according to hourly volume count. It starts at 100% tolerance for vehicle counts of about 100, to 14% tolerance for counts of about 10,000. The network assignment analysis outputs before and after T-flow fuzzy are shown in the next sub-section.

5.3.1.2 Analysis Output for T-Flow fuzzy

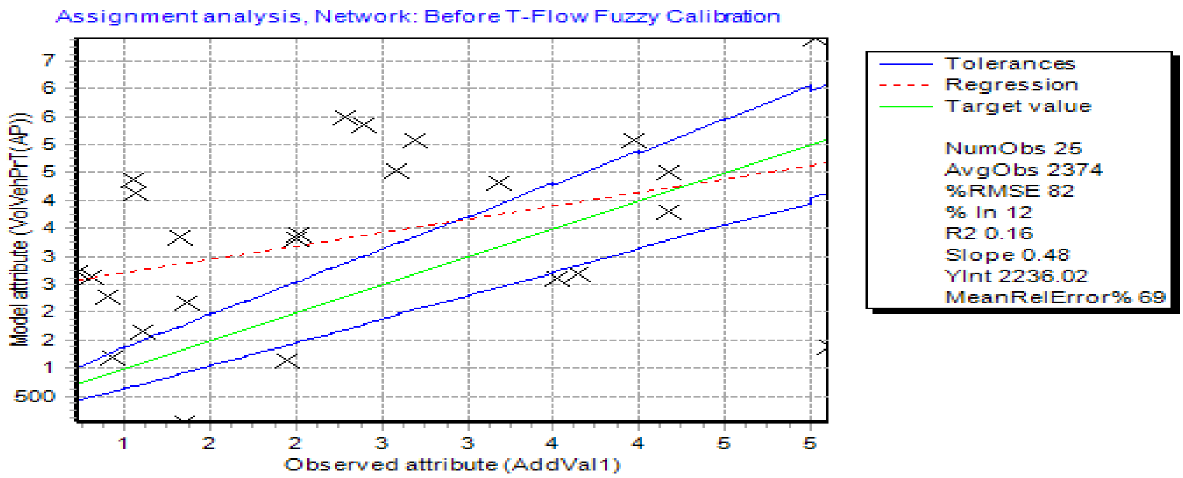


Figure 22 Outputs before T-Flow Fuzzy Run

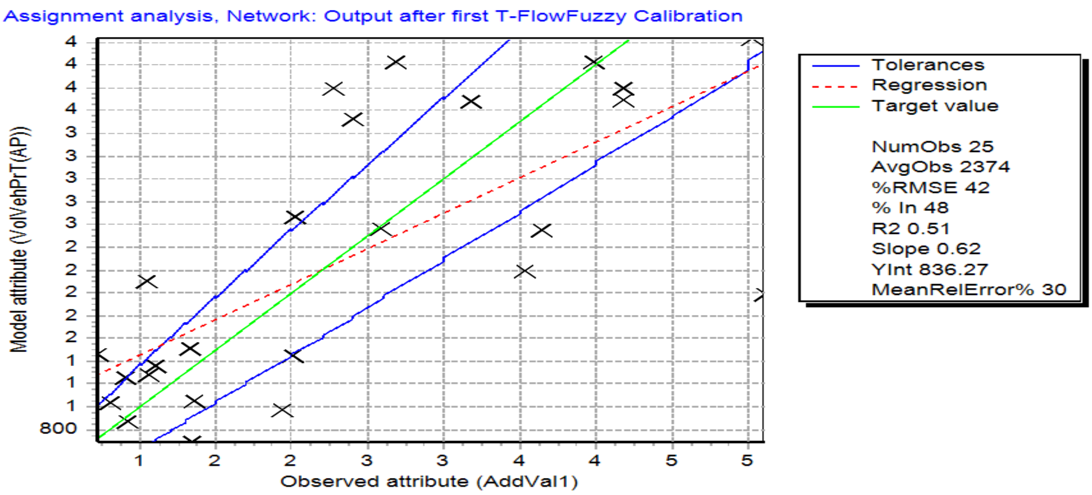


Figure 23 Output after 1st Run of T-Flow fuzzy.

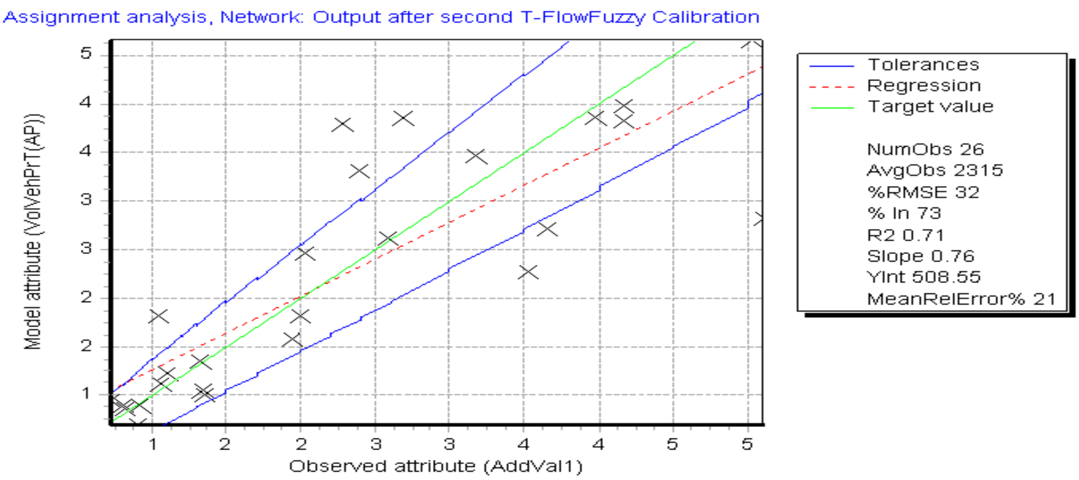


Figure 24 Output after 2nd Run of T-Flow fuzzy

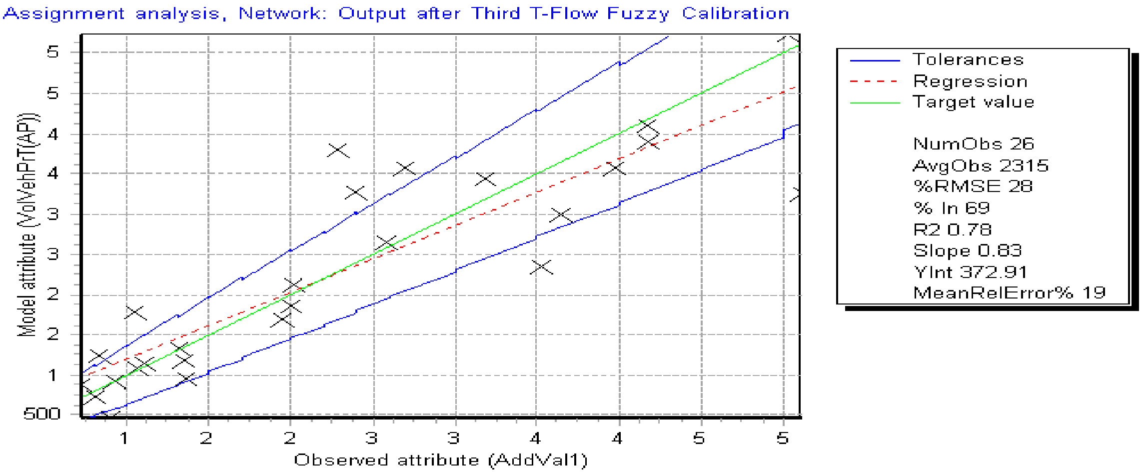


Figure 25 Output after 3rd Run of T-Flow fuzzy

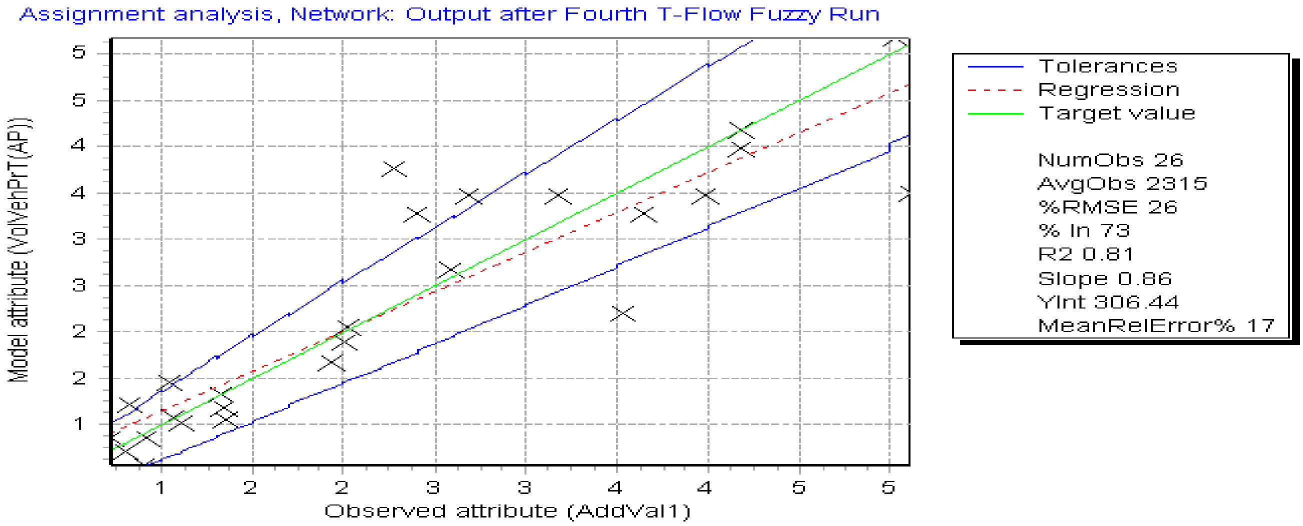


Figure 26 Output after 4th Run of T-Flow fuzzy

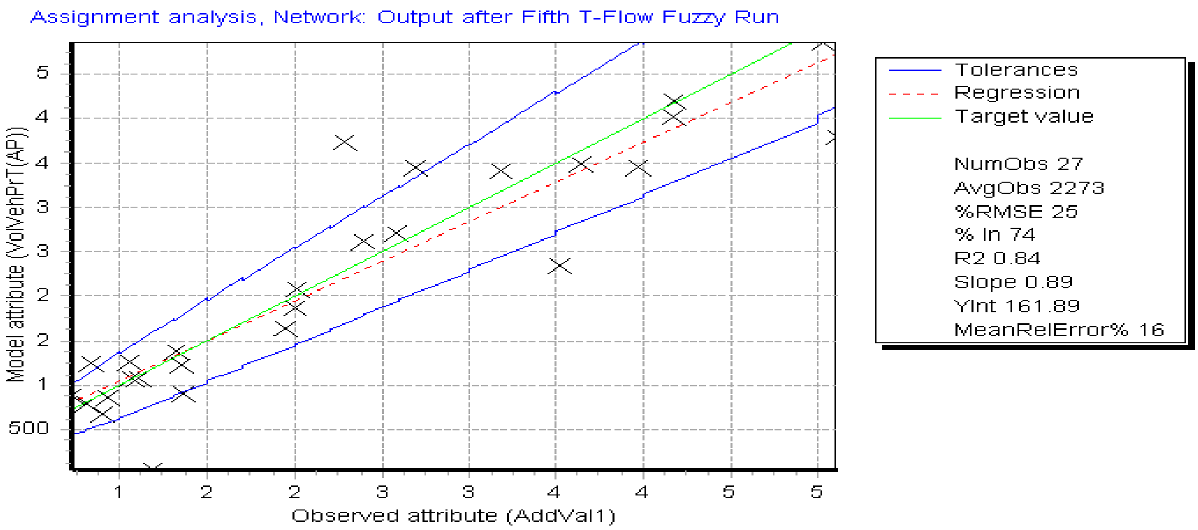


Figure 27 Output after 5th and final Run of T-Flow fuzzy

5.3.2 Demand Matrix Calibration by Lohse Technique

The second approach also tested for calibration was the Demand Matrix calibration tool otherwise known as the Lohse technique. The calibration procedure provides a calibration function that uses count data to calculate projection factors based on assignment result for origin and destination sums of the demand matrix. Using a balancing procedure, the matrix is projected to the sum values. The calculation basically involves two processes;

The first stage involves the determination of adjustment factor for each count value provided on the link across all relevant flow bundles. This results in modifications potentials for all relevant origin and destination traffic. Since the adjustment factors belonging to a zone might have been calculated using different count value adjustment factors, these factors are averaged and balanced. Adjustment factors are thus generated for those origins and destinations which were found by flow bundles. Rows and columns which were not found by flow bundles are assigned a mean adjustment factor determined by the adjustment factors for traffic flow elements (PTV AG 2012).

The last step involves the projection of the matrix using the projection factors generated as described above.

5.3.2.1 Setting the Procedure Sequence on Visum

The procedures for Demand matrix calibration by the Lohse method were set on Visum as shown below;

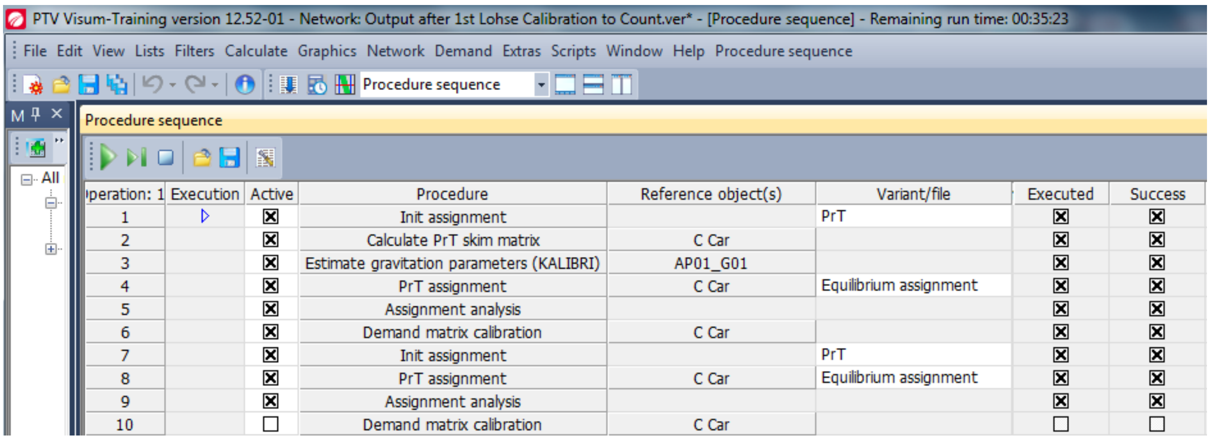


Figure 28 Procedure sequence for Lohse Calibration

The parameters for the calibration were set at maximum of 20 iterations with a threshold of precision set at 3. The count data which was earlier added to the network as an 'Add Value 1' attribute, was used in the Lohse calibration. As performed in the T-flow fuzzy approach, the calibration process was run 5 times and assignment were carried out and analysed at the end of each run. The aim was to assess the performance of this method against the T-Flow fuzzy technique. Results of this approach are presented in the next subsection.

5.3.2.2 Analysis Output of Lohse Calibration

The following graphs are the output of analysis carried out after assignment, to compare assigned volume with observed counts.

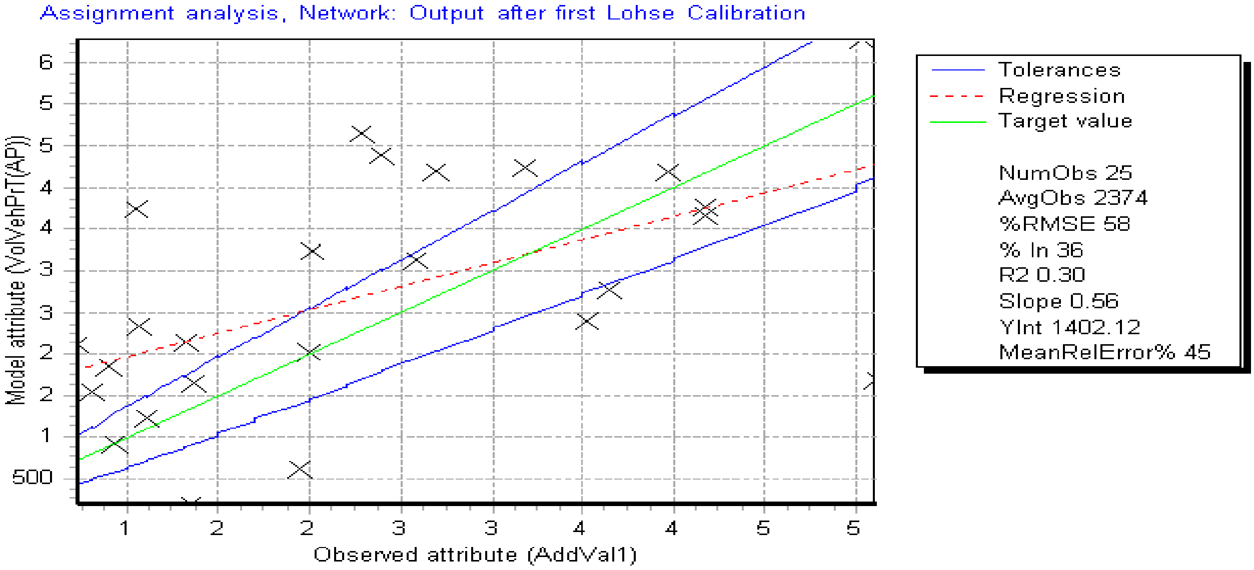


Figure 29 Output after 1st run of Calibration

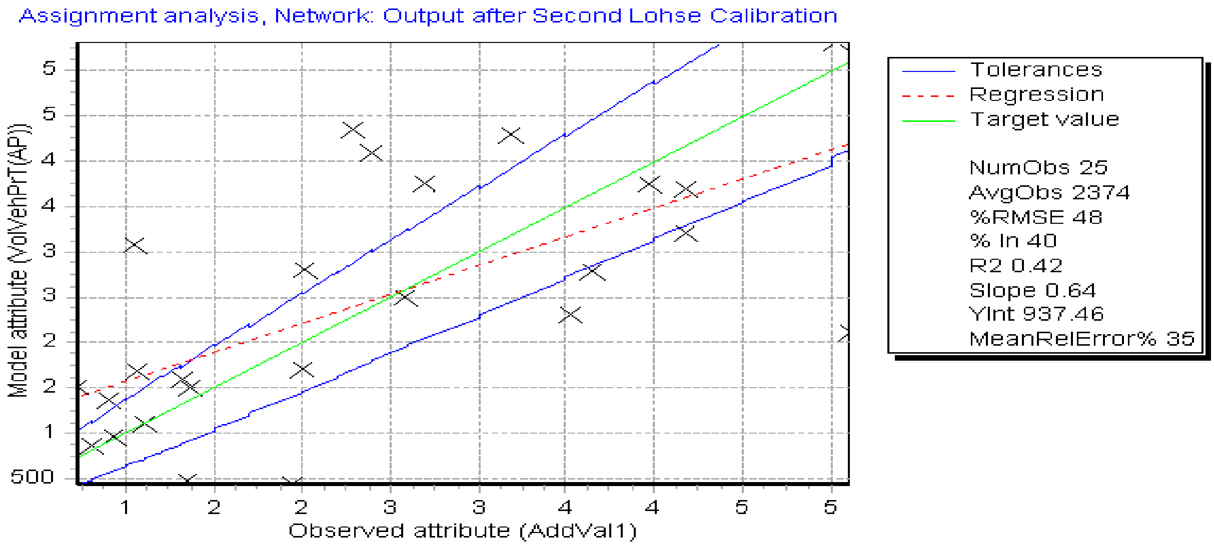


Figure 30 Output after 2nd Run of Calibration

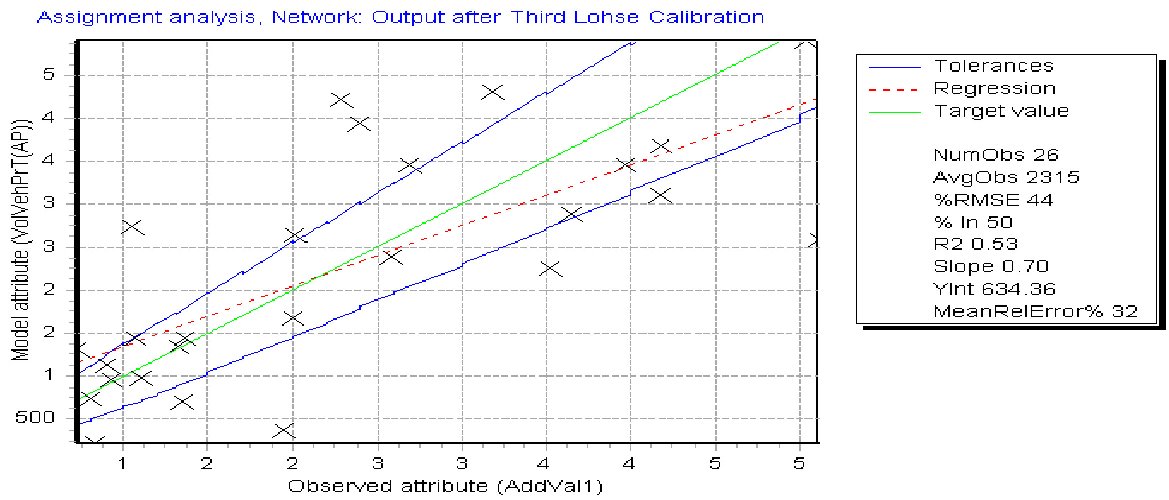


Figure 31 Output after 3rd Run of Calibration

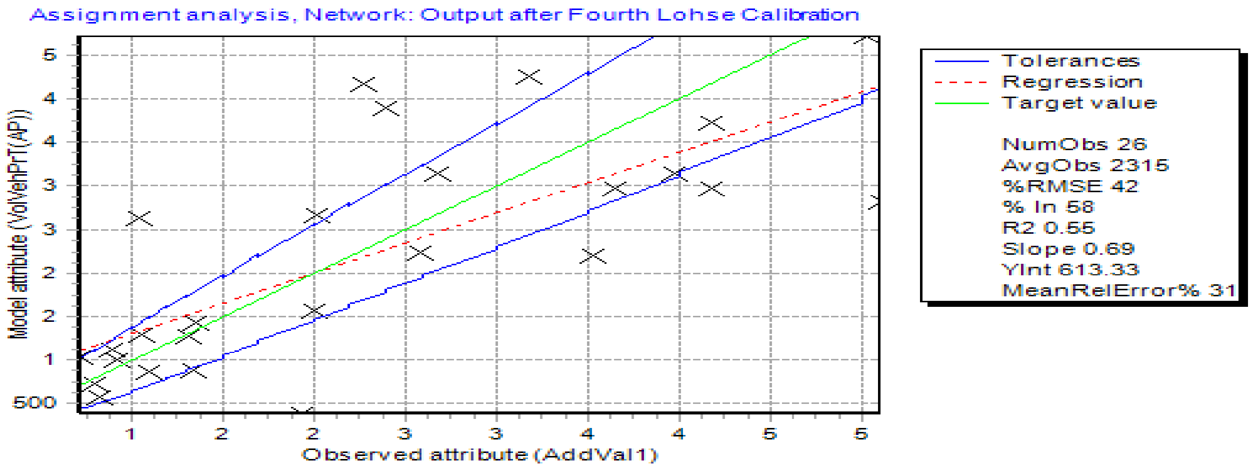


Figure 32 Output after 4th Run of Calibration

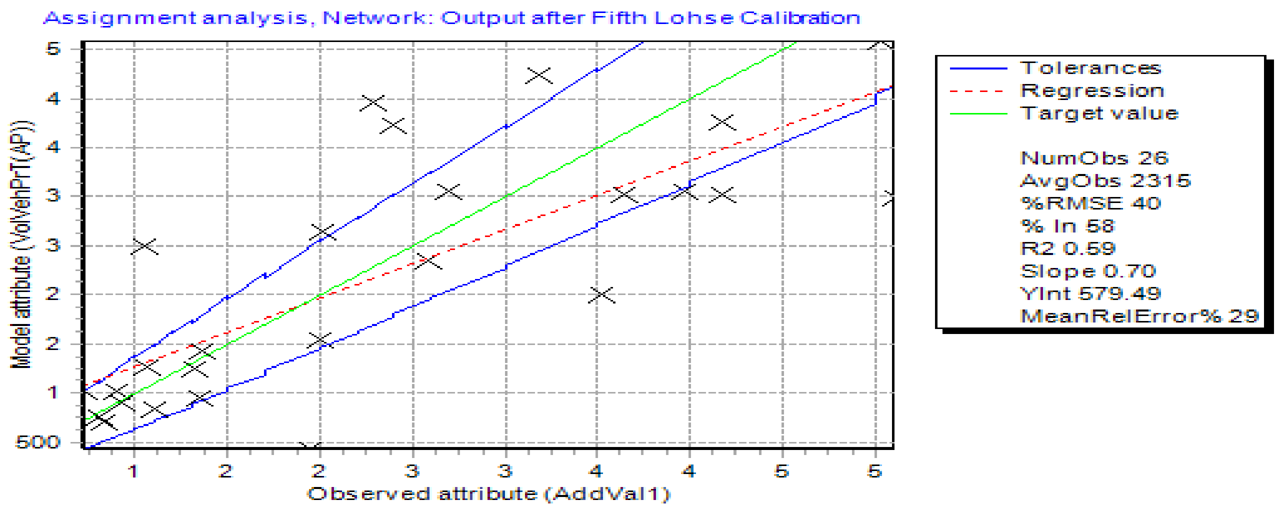


Figure 33 Output after 5th Run of Lohse Calibration

5.3.3 Summary of Output - Comparison of both Calibration Methods

The table below gives a summary of outputs from both calibration methods. These outputs gives a relation of how well the model assigned volumes matches with the observed counts. From these figures, it could be seen that the T-Flow fuzzy process actually performs better, with a higher R^2 and lower %RMSE when compared with the Lohse method for each calibration run. The performance could also be analysed based on the total number of trips that was redistributed at the end of the calibration run. For the T-flow fuzzy, the total trip recalculated at the fifth run was closer to the total trip in the initial O-D matrix when compared to the Lohse method.

		Before Calibration	**1st Run**	**2nd Run**	**3rd Run**	**4th Run**	**5th Run**
No. of Observations	Lohse Method	25	25	25	26	26	26
	T-Flow Fuzzy	25	25	26	26	26	27
R^2	Lohse Method	0.18	0.30	0.42	0.53	0.55	0.59
	T-Flow Fuzzy	0.18	0.51	0.71	0.78	0.81	0.84
% RMSE	Lohse Method	80	58	48	44	42	40
	T-Flow fuzzy	80	42	32	28	26	25
% MeanRelError	Lohse Method	68	45	35	32	31	29
	T-Flow fuzzy	68	30	21	19	17	16
Total Trips Redistributed	Lohse Method	67,926	52,511	46,714	45,211	45,135	46,013
	T-Flow Fuzzy	67,926	52,035	54,423	57,323	60,007	62,881

Table 12 Summary Comparison of both calibration methods

5.4 Model Implementation

5.4.1 Estimating Future Trips from Production & Attraction model

With the production and attraction models derived in section 4.2.1 (and shown below), the zonal car trips is estimated for the future year 2025 using the population forecasts (Appendix F) available for that year. The output is as shown in the table below;

Trip Origins	Trip Destinations
$T_0 = exp\text{^}\ (1.69 In\ x - 15.25)$	$T_D = exp\ \text{^}\ (2.11 In\ x - 21.13)$

	Zones	Population forecast, Year 2025 (millions)	Trip Origins (T_o)	Trip Destinations (T_D)
1	Agege	1.84	9178	10962
2	Ajeromi-Ifelodun	2.55	16000	21939
3	Alimosho	3.64	29153	46403
4	Amuwo Odofin	0.93	2924	2628
5	Apapa	0.93	2899	2600
6	Badagry	0.68	1696	1332
7	Epe	0.57	1291	947
8	Eti-osa	1.75	8447	9882
9	Ibeju lekki	0.18	176	79
10	Ifako-ijaiye	1.32	5274	5489
11	Ikeja	1.15	4181	4107
12	Ikorodu	1.22	4629	4664
13	Kosofe	1.66	7749	8874
14	Lagos Island	1.53	6731	7442
15	Lagos Mainland	1.12	3973	3854
16	Mushin	2.35	13915	18431
17	Ojo	1.67	7846	9013
18	Oshodi-Isolo	2.01	10753	13358
19	Somolu	1.82	9059	10785
20	Surulere	2.26	13087	17071
	Total Forecast	**31.19**	**158961**	**199860**

Table 13 Estimate of Future Trips

5.4.2 Comparison of Base and Forecasted Trips

The table below give a summary comparison of the base year and the future year forecasted trips;

	Base year (2006)	Future Year (2025)	% change
Population (millions)	17.5	31.2	62
Originating Trips (Car Trips/hr)	67,926	158,961	134
Destination Trips (Car Trips/hr)	67,869	199,860	194

Table 14 Comparison of base and forecast year trips

5.4.3 Estimation of Base and Future year OD Matrix

The 5th run of the T-flow fuzzy (described in section 5.3.1) yielded a recalculated base year OD trip matrix which was used for final assignment and base year network evaluation.

In estimating the future year OD matrix, the zonal trip origin and destination estimated in section 5.4.1, was fed into the Visum software and using the same distribution parameter $\boldsymbol{\beta}$ gotten from the base year, along with the same travel time skim matrix, distribution was executed. A key assumption in using the same distribution parameter is that the network structure does not change for the base and forecast year and trip makers continue to perceive travel impedance in same way.

The two matrices for base and future years are as shown below, while a more vivid presentation can be found in appendix E.

Zones			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Name		Agege	Ajeromi-I	Alimosho	Amuwo O	Apapa	Badagry	Epe	Eti-osa	Ibeju lekk	Ifako-ijaiy	Ikeja	Ikorodu	Kosofe	Lagos Isla	Lagos Mai	Mushin	Ojo	Oshodi-Is	Somolu	Surulere
		Sum	1676	399	3990	6460	775	837	348	2024	1229	2483	4348	4168	9205	6213	5487	3124	1532	3446	1815	3323
1	Agege	4713	20	17	93	269	23	33	50	7	5	18	133	975	1936	38	562	121	45	114	141	114
2	Ajeromi-Ifelodun	1258	21	5	214	86	8	13	4	31	26	48	167	43	97	65	67	130	18	146	16	55
3	Alimosho	7121	94	60	320	962	119	82	58	62	82	102	644	378	452	68	1347	509	119	359	899	406
4	Amuwo Odofin	4870	34	18	585	222	36	33	22	115	109	97	120	360	1034	278	285	471	46	533	205	266
5	Apapa	597	5	2	112	40	3	7	2	22	14	8	14	30	65	36	36	68	9	76	11	38
6	Badagry	381	9	1	23	15	3	2	1	12	9	10	59	17	67	20	23	38	9	26	16	21
7	Epe	46	5	0	0	0	0	0	0	0	0	7	8	0	3	22	0	0	0	0	0	0
8	Eti-osa	6700	448	26	1034	557	71	106	28	324	310	1009	518	208	448	152	25	139	249	549	65	437
9	Ibeju lekki	25	2	0	4	3	0	0	0	1	0	3	3	1	2	1	0	1	1	2	0	2
10	Ifako-ijaiye	6785	16	20	91	259	33	32	101	103	81	12	126	1121	2847	1301	232	124	44	110	34	96
11	Ikeja	8045	89	108	431	1104	178	144	14	86	65	95	579	189	416	1155	1623	428	198	406	124	613
12	Ikorodu	1174	161	1	4	7	1	1	0	4	3	201	220	12	78	456	5	6	2	7	1	5
13	Kosofe	4620	564	2	21	43	4	3	7	764	52	535	586	94	271	1591	14	15	20	17	2	14
14	Lagos Island	854	21	9	40	181	20	31	0	126	29	9	31	6	16	93	9	15	50	40	2	127
15	Lagos Mainland	2438	58	18	240	147	26	13	7	3	5	137	476	99	218	12	196	236	83	275	37	154
16	Mushin	3113	9	18	38	652	23	148	14	4	8	10	48	193	425	267	442	225	113	204	71	201
17	Ojo	740	17	2	43	29	5	12	5	10	16	19	112	36	141	31	43	71	26	50	31	40
18	Oshodi-Isolo	5011	68	68	297	1258	170	78	22	69	182	104	312	266	374	81	320	260	228	225	106	522
19	Somolu	1923	17	8	71	360	12	60	2	156	138	39	145	30	66	351	69	70	158	81	12	78
20	Surulere	2468	19	16	329	266	39	40	8	125	95	20	49	112	248	194	188	199	117	225	41	135

Table 15 Calibrated Base year (2006) matrix

Zones			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Name		Agege	Ajeromi-If	Alimosho	Amuwo O	Apapa	Badagry	Epe	Eti-osa	Ibeju lekk	Ifako-ijaiy	Ikeja	Ikorodu	Kosofe	Lagos Islan	Lagos Mai	Mushin	Ojo	Oshodi-Is	Somolu	Surulere
		Sum	8719	17449	36907	2090	2068	1059	753	7860	63	4366	3267	3710	7058	5919	3065	14659	7169	10624	8578	13578
1	Agege	9178	225	1573	1193	179	168	84	44	618	5	91	102	217	403	469	219	863	568	591	517	1051
2	Ajeromi-Ifelodun	16000	1261	792	5213	98	78	61	88	484	4	642	440	431	802	368	233	1463	408	1252	931	950
3	Alimosho	29153	911	4665	3390	532	612	162	163	2248	18	475	444	801	1491	1706	796	3141	1089	1499	1882	3129
4	Amuwo Odofin	2924	228	141	941	11	18	7	17	107	1	116	79	83	155	81	51	264	47	226	177	172
5	Apapa	2899	230	98	951	15	10	11	17	93	1	117	80	83	155	71	45	267	74	228	179	173
6	Badagry	1696	131	105	329	8	14	0	13	79	1	68	59	62	115	60	38	196	8	152	131	127
7	Epe	1291	72	154	342	22	16	13	0	60	0	31	23	2	27	41	21	105	90	93	50	128
8	Eti-osa	8447	620	540	2956	82	51	51	37	45	0	316	212	184	342	83	100	829	344	710	397	547
9	Ibeju lekki	176	13	11	62	2	1	1	1	1	0	7	4	4	7	2	2	17	7	15	8	11
10	Ifako-ijaiye	5274	104	917	711	104	98	50	22	360	3	35	59	110	205	270	127	503	338	346	301	612
11	Ikeja	4181	123	662	700	75	71	47	17	260	2	62	56	84	157	192	89	363	313	250	217	442
12	Ikorodu	4629	256	551	1224	78	59	48	1	216	2	111	83	14	97	146	73	375	324	334	181	456
13	Kosofe	7749	421	906	2013	128	97	79	18	356	3	183	136	86	222	238	121	616	532	549	297	750
14	Lagos Island	6731	485	443	2311	68	42	42	28	93	1	245	161	140	260	96	73	642	282	571	302	448
15	Lagos Mainland	3973	265	312	1261	48	33	29	16	122	1	134	88	76	142	93	57	350	198	312	165	271
16	Mushin	13915	763	1608	3636	183	201	113	57	738	6	389	266	279	519	542	250	1170	765	761	592	1078
17	Ojo	7846	604	483	1516	37	66	6	58	365	3	314	271	285	530	277	176	904	63	698	604	587
18	Oshodi-Isolo	10753	577	1420	1918	162	189	95	57	694	6	301	206	278	518	527	250	847	642	523	591	952
19	Somolu	9059	510	1034	2433	140	110	87	31	405	3	260	176	153	284	269	138	676	584	602	342	823
20	Surulere	13087	921	1035	3808	118	133	73	69	515	4	469	321	337	627	391	206	1069	492	915	715	868

Table 16 Forecasted O-D matrix

5.4.4 Network Evaluation for Base and Future year

The estimated base and future year OD matrices were assigned to the network separately using equilibrium assignment algorithm and same volume delay functions and impedance parameters. Performance indicators such as total travel time, total vehicles, vehicle kilometers travelled, vehicle hours travelled and the saturation levels were generated. The assignment outputs of both years are as shown in the figures below;

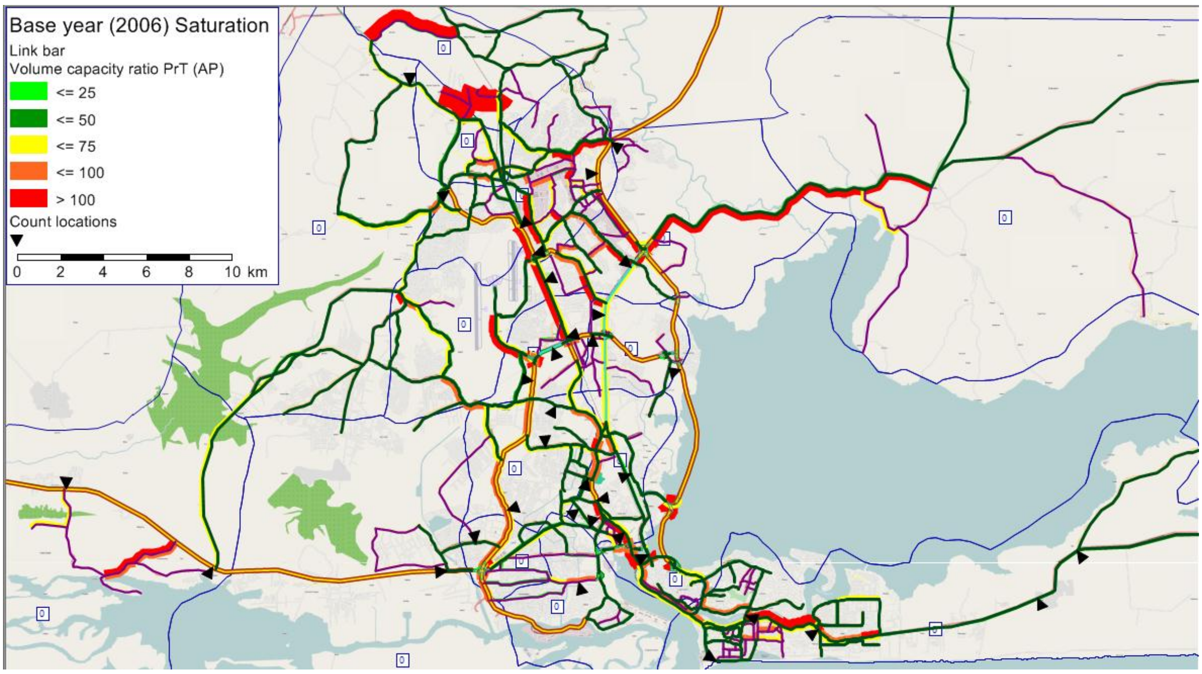


Figure 34 Base year Network

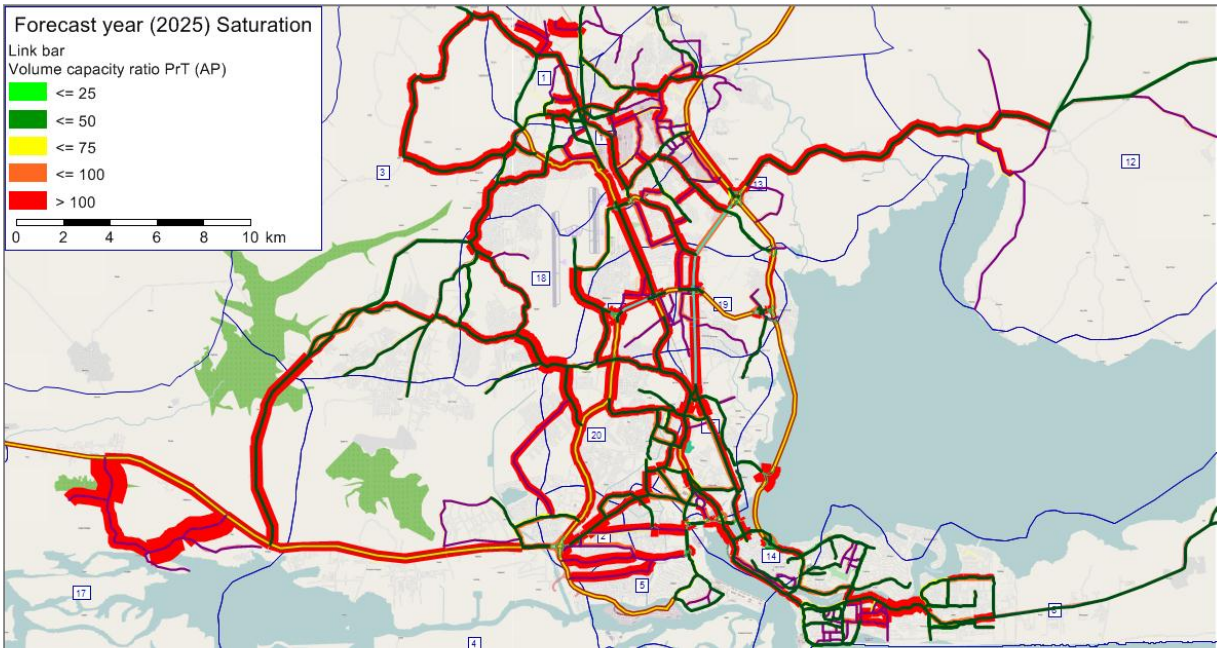


Figure 35 Forecast Network

From the two assignment figures above, it could be observed that traffic was not assigned to some of the links. One reason that could be attributed to this is the aggregated nature of the study. A 20-zone structure for such a large population could have resulted to traffic being confined to a limited number of paths.

The Mean saturation of the network (an overall performance indicator) is computed from all links using the two formulas;

$$SatMean_l = \frac{\Sigma \frac{(Vol\,Veh)}{Capacity} * Link\ length}{\Sigma\, Link\ Length}$$

$$SatMean_{Vkm} = \frac{\Sigma \frac{(Vol\,Veh^2)}{Capacity} * Link\ length}{\Sigma\, Vol\,Veh * Link\ Length}$$

Where,

$SatMean_l$ = Network Mean Saturation flow level based on length of links.

$SatMean_{Vkm}$ = Network Mean Saturation flow level based on Vehicle Km travelled on links.

Table 17 below shows the result of the network at the base and future year,

Indicators	Base Year (2006)	Future year (2025)	% change
Volume Vehicle per day	1,195,998	2,912,185	143
AverageTravel time, (mins)	1.68	8.14	384
Average Speed (Km/h)	67.4	42.8	37
Total Vehicle Km Travelled (km)	1,272,316	3,442,087	170
Total Vehicle Hour Travelled (hrs)	37,614.29	508,699.39	1252
Total Network length (km)	1,688	1,688	-
Total length of links with assigned traffic (km)	880.37	1073.68	22
Network Mean Saturation based on link length (SatMean) (%)	21	61	190
Network Mean Saturation based on Vehicle km (SatVehkm) %	68	130	91

Table 17 Network Performance Indications

From the above results, a wide difference could be observed between network mean saturation computed based on link length and that computed based on vehicle kilometre. The later gives a better picture of the saturation due to the fact that traffic were not assigned to a good number of links, which definitely would be a deviation from the reality as it would be hard to see links with zero traffic. As a result of this, computing the mean saturation based on link length (inclusive of empty links) will have a reduction effect on the real saturation picture of the network. This reduction effect is however eliminated when mean saturation is computed based on vehicle kilometre.

The results also reflected a not totally saturated network at the base year, with mean saturation just about 70%. While this result might be reasonable due to the fact that only private transport was considered in the model, it should be noted that consideration of other modes such as freight and public transport on the same network would definitely have increased the congested levels.

The volume of vehicles reported in the above table has also been validated by statistical report of the number of vehicles on the road in Lagos daily. The Trans-Africa Consortium (2010) reported that Lagos has over a million vehicles on the road daily. With the about 1.2million private vehicles estimated from this study and the over 100,000 unregulated minibuses operating as public transport (LAMATA 2008), that figure is verified.

A further analysis of the proportion of link length with saturation above 100%, 80% and 50% were also carried out on the network, with results as shown below.

Saturation criteria	> 100%		> 80% and < 100%		>50% and < 80%	
Year	2006	2025	2006	2025	2006	2025
Length of links (Km) within sat criteria	70.63	506.81	42.19	115.9	189.3	117.2
Total length of links with assigned traffic (Km).	880.37	1073.68	880.37	1073.68	880.37	1073.68
Percentage	8%	47%	5 %	10%	22 %	11 %

Table 18 Proportion of Saturated links

From the above table 18, it could be seen that for the base year 2006, only about 70km, representing 8% of the total length of assigned links, had saturation of 100% and above. For the forecast year 2025 however, about 47% of the links had saturation levels above 100%. Similarly, about 5% of the links had saturation between 80 and 100% for the base year. For the forecast year, 10% of the links had such saturation.

The plot of the percentage of links against each saturation criteria is shown in Figure 35 below. For the forecast year, a sharp rise in percentage of links is observed between saturation range 80-100% and above 100%.

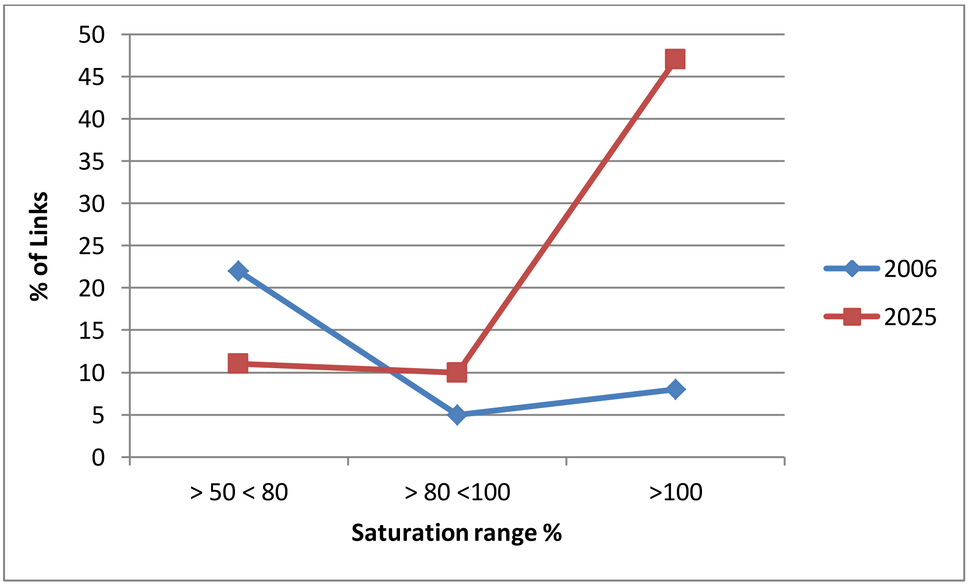


Figure 36 Proportion of Saturated links within Select saturation range

5.4.5 Assessing Future Planning Options

The network analysis in this study, though might lack exactness due to error associated with aggregation coupled with effects of several assumptions at various stages of the model building process, it however presents a broad insight and level of magnitude comparison between performance of the network at the base and forecast year. This would provide guidance for assessing planning options of the transport system.

From the results presented in Tables 17 and 18, the over saturation of the network at the forecast year would require several measures to be considered in addressing congestion. These measures could either be through supply or demand side of the infrastructure. The supply measures would involve capacity increment of existing links or building of new links. While this may have been the conventional approach adopted over the past years, such measures are likely not to be the best solution in the future based on the extremely high congestion forecasted. Also, the high population density of Metropolitan Lagos with its associated road space constraints may not support further road network expansion in the future. As such, demand management and land-use planning measures discussed in ECMT (2007), are recommended to provide more sustainable solution to the congestion.

Key among these measures would be the provision of reliable public transportation system. From Table 17, it can be seen that if the saturation level of the network at the base year 2006 is to be maintained at the future year 2025, about 1.8million car trips will have to be moved to public transport daily. This is a high figure that can only be achieved with only a highly efficient and high-capacity public transit system. The Lagos authority has taken some steps in this direction by the implementation of a BRT system which has been in operation in some parts of the metropolis since 2008, and also, with the light rail transit currently under development.

As reported in LAMATA (2009), the BRT is serving about 200,000 passengers daily. If the occupancy rate of private car in Lagos is to be assumed as 1 person per car[5], then the daily capacity of the BRT will need to be increased by a factor of at least 9 by the year 2025 (amounting to 1.8 million daily passengers) in other to keep the network at the same performance level as the base year 2006. While such expansion may not be realisable with the BRT system, the Light rail transit could be made to provide such required capacity.

[5] From personal observation and knowledge of study area, average occupancy should be between 1.5 – 2.0.

Chapter 6

Conclusions and Recommendations

6.1 Limitations of Study

Several factors have restricted the scope of this study and the overall modelling process. These include the lack of robust data of the study area, software capacity restriction and study time constraints.

Data Constraints

Though this study was motivated with the idea to see how limited data could be utilised to build a simple travel forecasting model, the non-availability of robust socioeconomic data at a disaggregated level of household however, created lot of restrictions in the model. For instance, trip generation stage could have been modelled better if other variables such as household income, car ownership, etc, were considered in the model. However, such data were not readily available, hence the usage of only population as the predictive variable.

Also, the smallest level of detail of the population in the study area was at the local government area level and as such the zoning could only be created to accommodate this population level. Using population data at a more disaggregated level could have led to utilisation of higher zoning arrangement assuming there was no software restriction. This also could have yielded better model estimation and network analysis.

In the trip assignment, the parameters for volume-delay function utilised were mere assumptions adopted from literature on similar studies, as there were no available data on speed-flow characteristics for the various links defined in the study area.

Software Capacity Restriction

This study was designed to accommodate the modelling capacity of the available software. The Visum software that was available and utilised in this study was the student version 12.0 which has a lot of restrictions to its usage as compared to the full version. This software only permits analysis of a maximum of 35 zones, 500links and 1500 nodes. Due to this reason, the network elements for the study area were built only to accommodate these limits. Without such restrictions in the software, a better and more robust network would have been developed and utilised for the study, which possibly could have resulted to better model estimation and overall network analysis. Using a 20 zone structure for a study area of over 17million people would have definitely resulted in lots of aggregation errors as highlighted in the earlier chapters of this work.

6.2 Recommendations for Model Improvement

While this study was based on an aggregated approach to travel demand modelling, a literature review has revealed various setbacks associated with this approach. Of key importance in these drawbacks is the error due to aggregation. To reduce the effect of these aggregation errors, a more disaggregated modelling approach that uses data at the household level is recommended. This would however require a detailed survey of household characteristics of the various administrative zones in the study area would provide more data such as the income level, car ownership, age distribution, etc. This would enable more variables to be considered and included in future trip generation modelling.

This study utilised a zoning system of 20 zones for a population of over 17 million inhabitants because demographic data was only available at the local government level. The availability of Census data at a more disaggregated level would aid model improvement in the future.

The Volume-Delay Function parameters utilised in this study were borrowed values from other studies. Also, the same parameter values were assumed for link types. The inherent drawback in this is that the actual flow behaviour of the network will not have been modelled to a good degree of accuracy. To improve this aspect of the model, a Speed-Flow survey of the traffic in the various link types of the study area is recommended. This would yield data required for estimation of link-specific parameters in defining future distribution function.

The lack of comprehensive spatial GIS database of the transportation network also created an important deficiency in this study. As such, the transport network was developed from scratch using hind knowledge of the study area along with so many assumptions. While the study tried as much as possible to replicate the road network with considerable level of accuracy, there is no doubt that some of the road network attributes such as number of lanes, permissible speed and capacity defined for some links could have been different from the actual. For better future modelling, a comprehensive spatial dataset of the road network and all attributes is required. However, in the case of non-availability of such data, as exemplified in this study, a simple modelling approach that respects the data constraints should be employed.

6.3 Conclusions

The trip generation modelling in this study showed that private car trips will continue to grow into the future as the population grows. While only population was considered as the decision variable, there is no doubt that consideration of other factors other than population as trip-making decision variable, could have yielded a more reliable model. Also, since the trip production and attraction were modelled from a prior OD trip matrix, the reliability of the model output is highly dependent on the level of accuracy of the zonal origin and destination trip values in the base matrix provided by the Lagos Transport Authority. Ascertaining the level of accuracy of the base matrix was beyond the scope of this study.

Furthermore, the trip generation was based on population forecasts that projected a 3% constant annual growth rate for a 20 year period. A lot of uncertainties surround this forecast. There is the possibility that the actual population growth pattern in the coming years might deviate from the forecasted trend, which will, as a result, affect the overall model. One key reason why the population growth might not obey the forecasted trend is the fact that the growth being witnessed in Lagos could be attributed to the economic underdevelopment and consequent limited employment opportunities in neighbouring States to Lagos. As such, there has always been a drift of people from these States towards Lagos in search of better opportunities and living standards. While this trend has continued over the past years, it may likely not proceed into the future as some of the less developed states are beginning to witness economic growth and infrastructural development. If such economic growth continues into the future, the number of people moving to Lagos could be drastically reduced.

Also, the high population density in Lagos could be attributed to the fact that Lagos has been the only fully operational port city in the country over the years, which has resulted to the majority of the manufacturing industries and large businesses being located there. But with the planned move of the Federal government of Nigeria to decentralise the Lagos port by opening up new ports and resuscitating non-functioning ones in other parts of the country, there might be a change in pattern of industry location. This again will affect the forecasted population growth trend.

However, despite the uncertainties surrounding population growth forecast as highlighted above, this study, still within the scope of such forecasts, presented an insight into how the future network will behave. It is shown that a continued growth in population and the consequent increase in private transport will result in an extremely congested network. At year 2025, the majority of the network links will be fully saturated. As such, heavy investment will be required on network improvement if the infrastructure will be expected to continue functioning adequately. However, if the amount of investment on network infrastructure is to be minimised, other demand management measures must be considered to reduce the dependence on private transport and motorization rate. One of the key measures as already discussed in section 5.4.5, would be improvement on the public transportation system. Others could include proper land-use planning, promoting non-motorised travel such as walking or cycling and also adopting road pricing measures to control vehicle ownership and motorisation rate. While the some of these measures have been recognised and practiced in some developed countries, a study of its feasibility in a developing country city like Lagos would be required.

This study has also justified the decision of the Lagos state authority to embark on development of Light rail transit system in addition to the already operational BRT system as a means of combating increase in motorisation and consequent congestion problems within the Lagos Metropolis. On the overall, it has demonstrated that a simplified aggregate 4-Step travel demand model can indeed be a valuable tool for strategic road network planning and policy evaluation. In the context of developing countries cities like Lagos, which are characterised by lack of comprehensive household, socioeconomic and transportation network data, these kinds of models have great potential in transportation planning and strategic level decision-making.

6.4 Potential Research Questions

Based on the outcome of this study, further research centred on network improvement and private transport demand management is recommended. Potential research questions include;

- Considering all the network modes and activities relating to the existing poor transportation network, how can this transportation network be restructured or redesigned for better performance?
- With the existing poor public transit system, how can public transit be planned, managed, and regulated so they could serve both private transport users and the non-motorized majority of the population?
- What is the feasibility of managing private transport demand in a developing country city like Lagos, using road pricing mechanisms?

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Appendix

A: FDOT Standard K Factors

The Standard K- factors are multiplied by the 24-hour Average Daily Traffic (ADT) count to get an estimate of two-way traffic in an analysis hour which is required. The Factor value varies according to the road type.

FDOT Standard K Factors

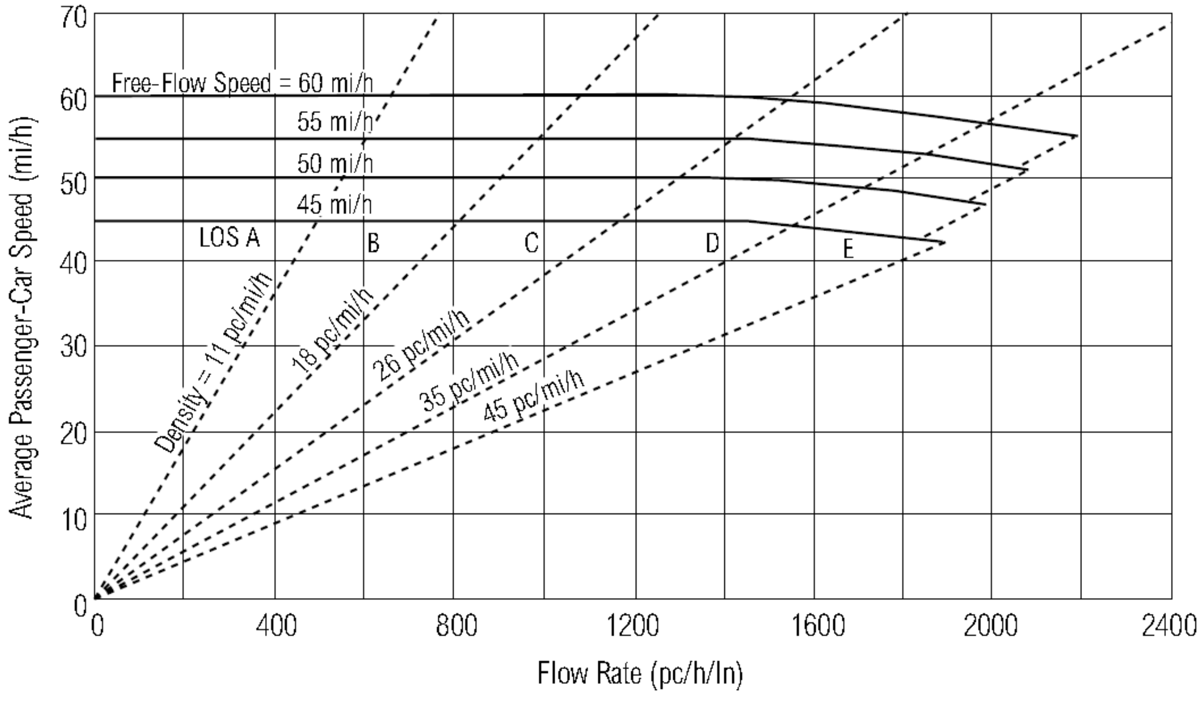
Area *(Population) [Examples]*	**Facility Type**	**Standard K Factors*** (%AADT)	**Representative Time Period**
Large Urbanized Areas with Core Freeways *(1,000,000+) [Jacksonville, Miami]*	Freeways	8.0 - 9.0 ***	Typical weekday peak period or hour
	Arterials & Highways	9.0**	Typical weekday peak hour
Other Urbanized Areas *(50,000+) [Tallahassee, Ft. Myers]*	Freeways	9.0 **	Typical weekday peak hour
	Arterials & Highways	9.0 **	Typical weekday peak hour
Transitioning to Urbanized Areas *(Uncertain) [Fringe Development Areas]*	Freeways	9.0	Typical weekday peak hour
	Arterials & Highways	9.0	Typical weekday peak hour
Urban *(5,000-50,000) [Lake City, Key West]*	Freeways	10.5	100th highest hour of the year
	Arterials & Highways	9.0 **	Typical weekday peak hour
Rural *(<5,000) [Chipley, Everglades]*	Freeways	10.5	100th highest hour of the year
	Arterials	9.5 **	100th highest hour of the year
	Highways	9.5	100th highest hour of the year

*	Some smoothing of values at area boundaries/edges would be desirable.
**	Value is 7.5% in approved Multimodal Transportation Districts where automobile movements are deemphasized. Essentially, this lower value represents an extensive multi-hour peak period rather than a peak hour.
***	Value is 8.0% for FDOT-designated urbanized core freeways and may be either be 8.5% or 9.0% for non-core freeways. Values less than 9% essentially represent a multi-hour peak period rather than a peak hour.

B: Level of Service Definition for Multilane Highway (HCM2000)

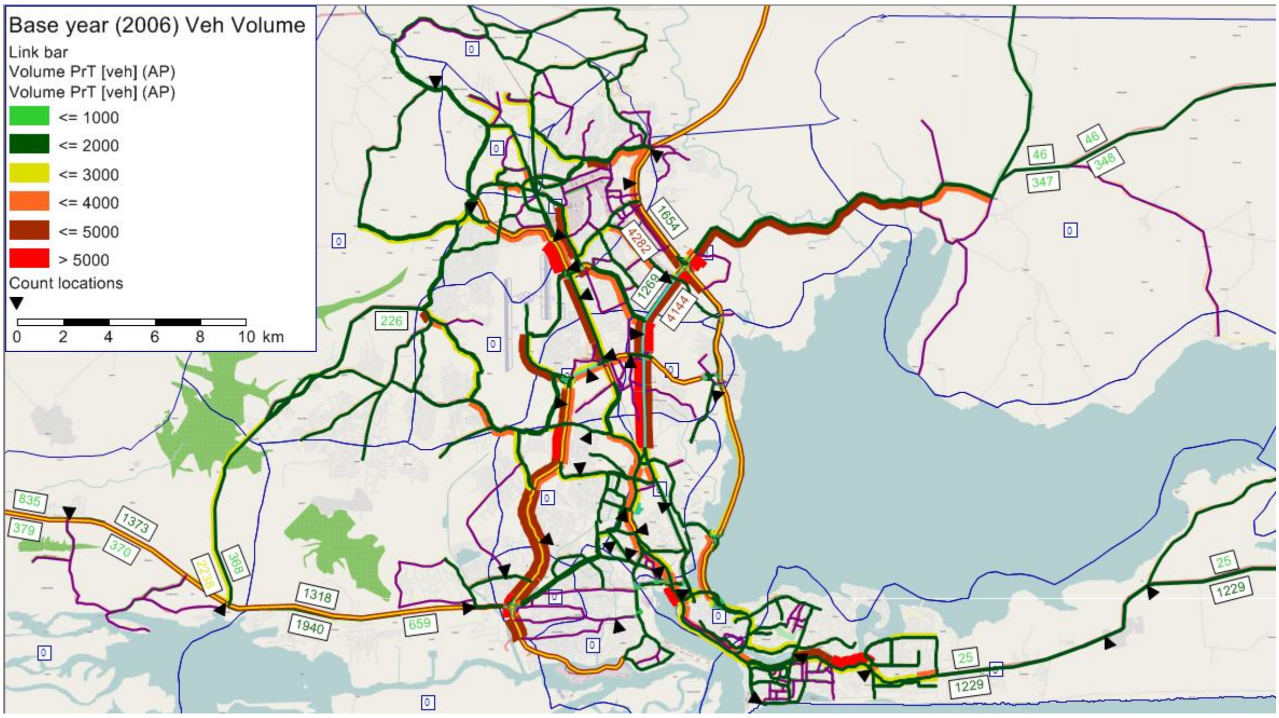
		LOS				
Free-Flow Speed	Criteria	A	B	C	D	E
60 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	40
	Average speed (mi/h)	60.0	60.0	59.4	56.7	55.0
	Maximum volume to capacity ratio (v/c)	0.30	0.49	0.70	0.90	1.00
	Maximum service flow rate (pc/h/ln)	660	1080	1550	1980	2200
55 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	41
	Average speed (mi/h)	55.0	55.0	54.9	52.9	51.2
	Maximum v/c	0.29	0.47	0.68	0.88	1.00
	Maximum service flow rate (pc/h/ln)	600	990	1430	1850	2100
50 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	43
	Average speed (mi/h)	50.0	50.0	50.0	48.9	47.5
	Maximum v/c	0.28	0.45	0.65	0.86	1.00
	Maximum service flow rate (pc/h/ln)	550	900	1300	1710	2000
45 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	45
	Average speed (mi/h)	45.0	45.0	45.0	44.4	42.2
	Maximum v/c	0.26	0.43	0.62	0.82	1.00
	Maximum service flow rate (pc/h/ln)	490	810	1170	1550	1900

C: Speed-Flow curves with LOS Criteria (HCM 2000)

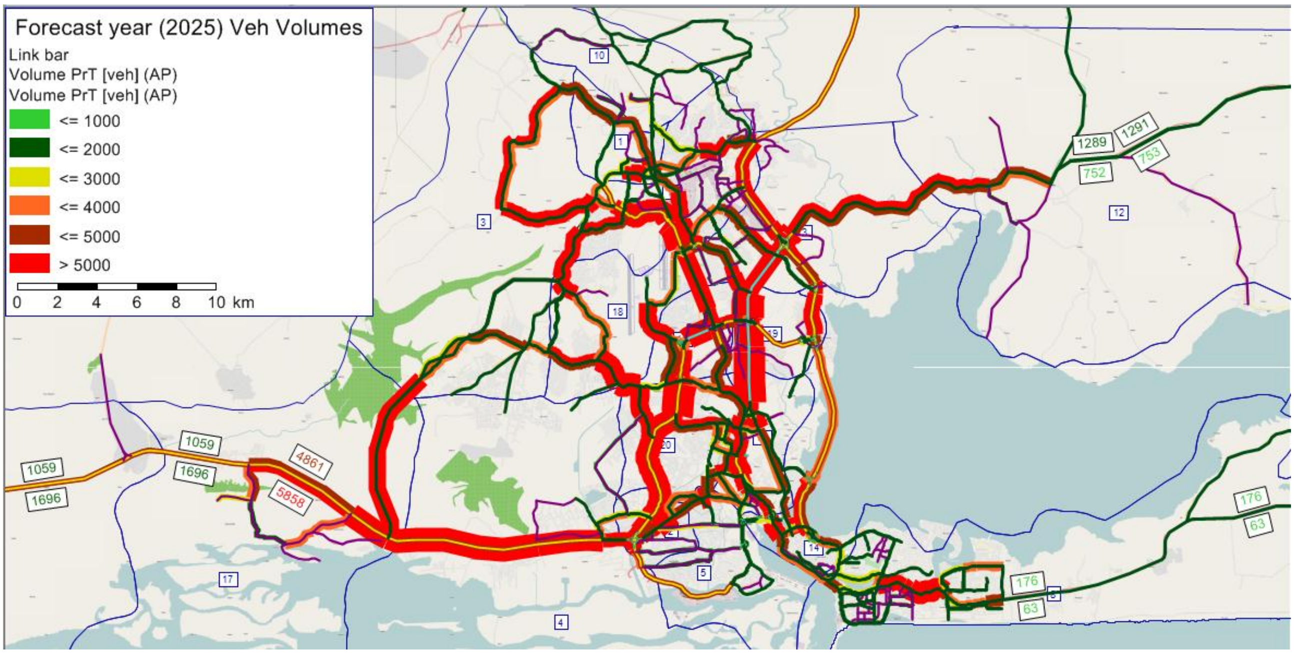


D: Assignment Output of Base & Future year

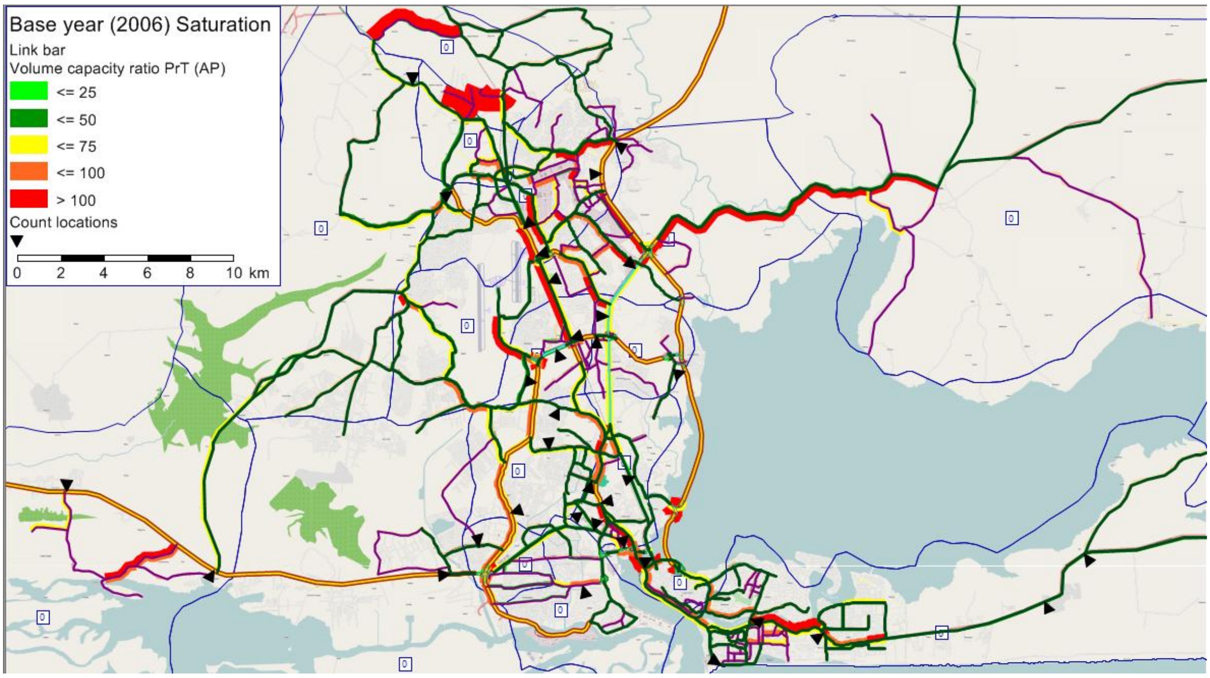
D-1 Base year (2006) Assigned Volumes



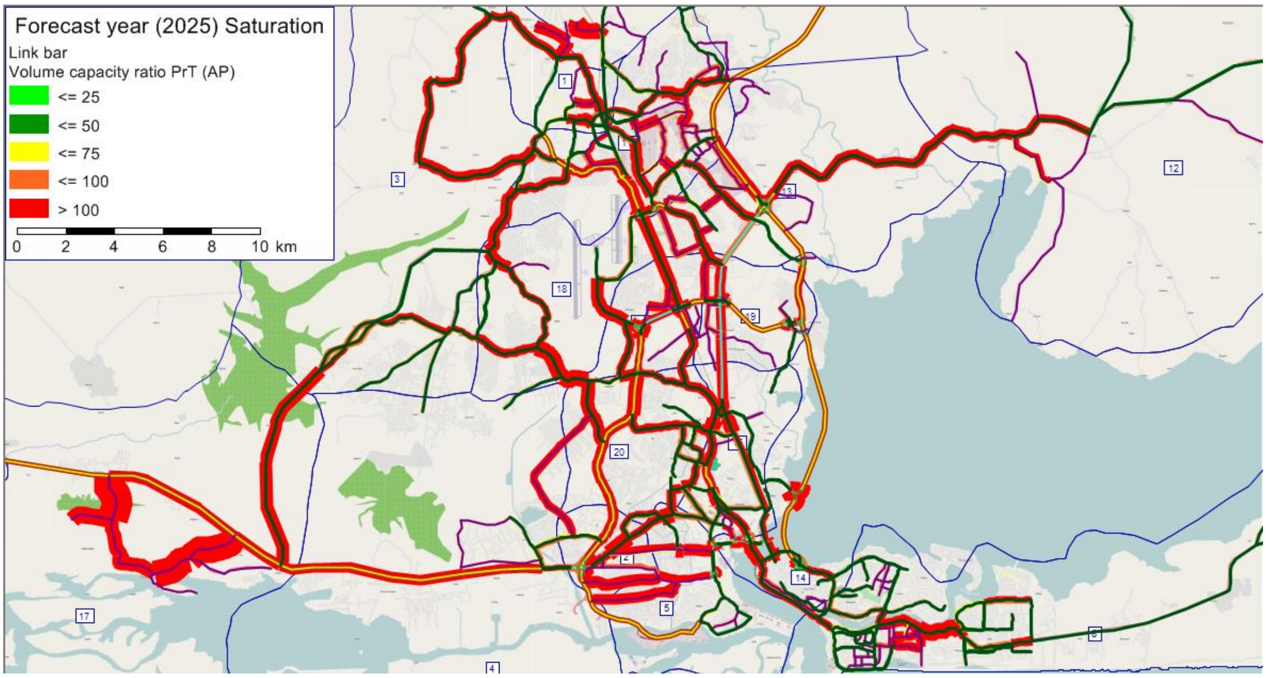
D-2 Forecast year (2025) Assigned Volumes



D-3 Base Year (2006) Saturation



D-4 Forecast Year (2025) Saturation



E: Distribution Output of Base and Forecast Year

E-1 Base year (2006) O-D Trip Matrix

Zones			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Name		Agege	Ajeromi-If	Alimosho	Amuwo O	Apapa	Badagry	Epe	Eti-osa	Ibeju lekk	Ifako-ijaiy	Ikeja	Ikorodu	Kosofe	Lagos Islar	Lagos Mai	Mushin	Ojo	Oshodi-Is	Somolu	Surulere
		Sum	1676	399	3990	6460	775	837	348	2024	1229	2483	4348	4168	9205	6213	5487	3124	1532	3446	1815	3323
1	Agege	4713	20	17	93	269	23	33	50	7	5	18	133	975	1936	38	562	121	45	114	141	114
2	Ajeromi-Ifelodun	1258	21	5	214	86	8	13	4	31	26	48	167	43	97	65	67	130	18	146	16	55
3	Alimosho	7121	94	60	320	962	119	82	58	62	82	102	644	378	452	68	1347	509	119	359	899	406
4	Amuwo Odofin	4870	34	18	585	222	36	33	22	115	109	97	120	360	1034	278	285	471	46	533	205	266
5	Apapa	597	5	2	112	40	3	7	2	22	14	8	14	30	65	36	36	68	9	76	11	38
6	Badagry	381	9	1	23	15	3	2	1	12	9	10	59	17	67	20	23	38	9	26	16	21
7	Epe	46	5	0	0	0	0	0	0	0	0	7	8	0	3	22	0	0	0	0	0	0
8	Eti-osa	6700	448	26	1034	557	71	106	28	324	310	1009	518	208	448	152	25	139	249	549	65	437
9	Ibeju lekki	25	2	0	4	3	0	0	0	1	0	3	3	1	2	1	0	1	1	2	0	2
10	Ifako-ijaiye	6785	16	20	91	259	33	32	101	103	81	12	126	1121	2847	1301	232	124	44	110	34	96
11	Ikeja	8045	89	108	431	1104	178	144	14	86	65	95	579	189	416	1155	1623	428	198	406	124	613
12	Ikorodu	1174	161	1	4	7	1	1	0	4	3	201	220	12	78	456	5	6	2	7	1	5
13	Kosofe	4620	564	2	21	43	4	3	7	764	52	535	586	94	271	1591	14	15	20	17	2	14
14	Lagos Island	854	21	9	40	181	20	31	0	126	29	9	31	6	16	93	9	15	50	40	2	127
15	Lagos Mainland	2438	58	18	240	147	26	13	7	3	5	137	476	99	218	12	196	236	83	275	37	154
16	Mushin	3113	9	18	38	652	23	148	14	4	8	10	48	193	425	267	442	225	113	204	71	201
17	Ojo	740	17	2	43	29	5	12	5	10	16	19	112	36	141	31	43	71	26	50	31	40
18	Oshodi-Isolo	5011	68	68	297	1258	170	78	22	69	182	104	312	266	374	81	320	260	228	225	106	522
19	Somolu	1923	17	8	71	360	12	60	2	156	138	39	145	30	66	351	69	70	158	81	12	78
20	Surulere	2468	19	16	329	266	39	40	8	125	95	20	49	112	248	194	188	199	117	225	41	135

E-2 Forecast year (2025) O-D Trip Matrix

Zones			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Name		Agege	Ajeromi-I	Alimosho	Amuwo O	Apapa	Badagry	Epe	Eti-osa	Ibeju lekk	Ifako-ijaiy	Ikeja	Ikorodu	Kosofe	Lagos Islar	Lagos Mai	Mushin	Ojo	Oshodi-Is	Somolu	Surulere
		Sum	8719	17449	36907	2090	2068	1059	753	7860	63	4366	3267	3710	7058	5919	3065	14659	7169	10624	8578	13578
1	Agege	9178	225	1573	1193	179	168	84	44	618	5	91	102	217	403	469	219	863	568	591	517	1051
2	Ajeromi-Ifelodun	16000	1261	792	5213	98	78	61	88	484	4	642	440	431	802	368	233	1463	408	1252	931	950
3	Alimosho	29153	911	4665	3390	532	612	162	163	2248	18	475	444	801	1491	1706	796	3141	1089	1499	1882	3129
4	Amuwo Odofin	2924	228	141	941	11	18	7	17	107	1	116	79	83	155	81	51	264	47	226	177	172
5	Apapa	2899	230	98	951	15	10	11	17	93	1	117	80	83	155	71	45	267	74	228	179	173
6	Badagry	1696	131	105	329	8	14	0	13	79	1	68	59	62	115	60	38	196	8	152	131	127
7	Epe	1291	72	154	342	22	16	13	0	60	0	31	23	2	27	41	21	105	90	93	50	128
8	Eti-osa	8447	620	540	2956	82	51	51	37	45	0	316	212	184	342	83	100	829	344	710	397	547
9	Ibeju lekki	176	13	11	62	2	1	1	1	1	0	7	4	4	7	2	2	17	7	15	8	11
10	Ifako-ijaiye	5274	104	917	711	104	98	50	22	360	3	35	59	110	205	270	127	503	338	346	301	612
11	Ikeja	4181	123	662	700	75	71	47	17	260	2	62	56	84	157	192	89	363	313	250	217	442
12	Ikorodu	4629	256	551	1224	78	59	48	1	216	2	111	83	14	97	146	73	375	324	334	181	456
13	Kosofe	7749	421	906	2013	128	97	79	18	356	3	183	136	86	222	238	121	616	532	549	297	750
14	Lagos Island	6731	485	443	2311	68	42	42	28	93	1	245	161	140	260	96	73	642	282	571	302	448
15	Lagos Mainland	3973	265	312	1261	48	33	29	16	122	1	134	88	76	142	93	57	350	198	312	165	271
16	Mushin	13915	763	1608	3636	183	201	113	57	738	6	389	266	279	519	542	250	1170	765	761	592	1078
17	Ojo	7846	604	483	1516	37	66	6	58	365	3	314	271	285	530	277	176	904	63	698	604	587
18	Oshodi-Isolo	10753	577	1420	1918	162	189	95	57	694	6	301	206	278	518	527	250	847	642	523	591	952
19	Somolu	9059	510	1034	2433	140	110	87	31	405	3	260	176	153	284	269	138	676	584	602	342	823
20	Surulere	13087	921	1035	3808	118	133	73	69	515	4	469	321	337	627	391	206	1069	492	915	715	868

E-3 Free-Flow Travel Time Skim Matrix (Minutes)

Zones			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Name		Agege	Ajeromi-If	Alimosho	Amuwo O	Apapa	Badagry	Epe	Eti-osa	Ibeju lekk	Ifako-ijaiy	Ikeja	Ikorodu	Kosofe	Lagos Islan	Lagos Mai	Mushin	Ojo	Oshodi-Is	Somolu	Surulere
		Sum	432.8	387.3	469.9	481.8	417.5	962.3	1263.0	598.2	1201.9	518.9	388.8	634.8	375.6	416.7	354.6	335.6	654.1	391.2	361.7	356.4
1	Agege	434.0	4.3	19.2	8.5	23.1	20.2	47.1	60.8	29.8	62.0	6.5	4.3	27.1	11.8	19.5	13.7	9.4	30.6	10.6	11.4	14.2
2	Ajeromi-Ifelodun	379.7	17.7	4.2	19.0	9.2	4.2	36.4	62.0	20.1	52.2	22.7	14.6	28.3	13.1	9.8	7.6	8.7	19.8	12.6	11.4	6.1
3	Alimosho	471.1	8.5	19.7	8.5	23.7	23.1	42.5	63.9	32.7	64.9	13.7	9.3	30.2	14.9	22.4	16.6	12.3	26.0	9.3	14.3	14.7
4	Amuwo Odofin	473.8	22.4	8.8	23.7	8.8	11.9	35.9	67.5	27.2	59.3	27.4	19.4	33.8	18.6	16.9	14.6	13.4	19.4	17.3	16.7	10.8
5	Apapa	465.9	22.3	4.2	23.6	11.9	4.2	41.0	67.2	25.4	57.5	27.3	19.2	33.6	18.3	15.1	12.8	13.3	24.4	17.2	16.6	10.7
6	Badagry	960.9	47.1	36.5	42.5	35.9	40.4	29.9	95.2	54.8	87.0	52.3	47.0	61.5	46.2	44.5	42.3	41.1	29.9	43.8	44.4	38.5
7	Epe	1259.2	60.8	61.8	63.7	68.2	62.7	95.4	38.5	72.4	104.5	63.8	56.8	38.5	50.1	60.8	55.8	54.5	78.9	58.8	53.9	59.3
8	Eti-osa	595.6	30.0	20.4	33.0	27.8	19.9	55.0	72.6	12.9	38.3	35.0	26.7	38.9	23.7	12.9	18.2	22.7	38.5	26.5	22.1	20.3
9	Ibeju lekki	1199.2	62.2	52.5	65.1	59.9	52.0	87.1	104.7	38.3	38.3	67.1	58.9	71.1	55.8	45.0	50.4	54.8	70.6	58.7	54.2	52.4
10	Ifako-ijaiye	520.7	6.5	24.1	13.7	28.1	25.1	52.3	64.1	34.8	66.9	6.5	9.1	30.4	15.2	24.3	18.6	14.3	35.8	15.6	16.3	19.1
11	Ikeja	391.2	4.3	16.1	9.3	20.1	17.1	47.2	56.8	26.7	58.9	9.1	4.3	23.1	7.8	16.1	10.2	6.3	30.7	7.6	8.3	11.1
12	Ikorodu	631.0	27.1	28.1	30.0	34.6	29.1	61.8	38.5	38.7	70.9	30.2	23.1	16.4	16.4	27.1	22.1	20.8	45.2	25.1	20.2	25.6
13	Kosofe	371.7	11.8	12.8	14.8	19.3	13.8	46.5	50.1	23.5	55.6	14.9	7.8	16.4	5.0	11.7	6.8	5.6	30.0	9.9	5.0	10.3
14	Lagos Island	405.2	18.8	9.7	21.7	17.1	9.2	44.3	61.0	12.9	45.0	23.6	15.1	27.3	12.1	6.3	6.3	11.3	27.8	15.6	10.5	9.5
15	Lagos Mainland	349.8	13.5	7.5	16.4	14.9	8.4	42.1	55.8	18.1	50.2	18.4	9.9	22.1	6.8	7.8	5.2	6.1	25.5	10.4	5.2	5.5
16	Mushin	340.1	9.5	10.2	12.4	14.2	13.0	41.4	54.5	22.7	54.8	14.4	6.4	20.8	5.6	12.0	6.1	3.8	24.9	4.4	3.8	5.2
17	Ojo	652.7	30.6	20.0	26.0	19.4	23.8	29.9	78.6	38.3	70.4	35.8	30.5	45.0	29.7	28.0	25.8	24.6	19.4	27.2	27.9	22.0
18	Oshodi-Isolo	392.2	10.6	13.2	9.3	17.2	16.7	43.8	58.9	26.4	58.5	15.8	7.8	25.2	10.0	16.1	10.5	4.4	27.2	4.4	8.1	8.2
19	Somolu	359.0	11.2	11.5	14.1	17.5	12.5	44.7	53.9	22.1	54.2	16.1	8.0	20.2	5.0	10.3	5.5	3.8	28.2	8.1	3.8	8.5
20	Surulere	350.0	13.5	6.8	14.7	10.8	10.0	38.0	58.5	20.3	52.4	18.4	10.4	24.8	9.6	10.0	5.5	4.5	21.5	8.3	7.7	4.5

F: Population Data

S/NO	LOCAL GOVERNMENT AREA	2006 POPULATION (millions)			FORECAST OF POPULATION (millions)									EXTENDED FORECAST (millions)									
	(Zones)	Male	Female	Total	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1	AGEGE	0.56	0.47	1.03	1.06	1.10	1.13	1.17	1.20	1.24	1.28	1.32	1.36	1.40	1.44	1.49	1.53	1.58	1.63	1.68	1.73	1.78	1.84
2	AJEROMI/IFELODUN	0.72	0.71	1.44	1.48	1.52	1.57	1.62	1.67	1.72	1.77	1.83	1.88	1.94	2.00	2.06	2.13	2.19	2.26	2.33	2.40	2.47	2.55
3	ALIMOSHO	1.10	0.95	2.05	2.11	2.17	2.24	2.31	2.38	2.45	2.53	2.61	2.69	2.77	2.86	2.94	3.03	3.13	3.22	3.32	3.42	3.53	3.64
4	AMUWO/ODOFIN	0.30	0.22	0.52	0.54	0.56	0.57	0.59	0.61	0.63	0.65	0.67	0.69	0.71	0.73	0.75	0.78	0.80	0.83	0.85	0.88	0.90	0.93
5	APAPA	0.26	0.26	0.52	0.54	0.55	0.57	0.59	0.61	0.63	0.65	0.67	0.69	0.71	0.73	0.75	0.77	0.80	0.82	0.85	0.87	0.90	0.93
6	BADAGRY	0.19	0.19	0.38	0.39	0.40	0.42	0.43	0.44	0.46	0.47	0.48	0.50	0.51	0.53	0.55	0.56	0.58	0.60	0.62	0.64	0.66	0.68
7	EPE	0.15	0.17	0.32	0.33	0.34	0.35	0.37	0.38	0.39	0.40	0.41	0.42	0.44	0.45	0.47	0.48	0.49	0.51	0.53	0.54	0.56	0.58
8	ETI-OSA	0.46	0.52	0.98	1.01	1.04	1.08	1.11	1.14	1.18	1.22	1.25	1.29	1.33	1.37	1.41	1.46	1.50	1.55	1.60	1.64	1.70	1.75
9	IBEJU-LEKKI	0.05	0.05	0.10	0.10	0.11	0.11	0.11	0.12	0.12	0.12	0.13	0.13	0.13	0.14	0.14	0.15	0.15	0.16	0.16	0.17	0.17	0.18
10	IFAKO/IJAIYE	0.38	0.36	0.74	0.77	0.79	0.82	0.84	0.87	0.89	0.92	0.95	0.98	1.01	1.04	1.07	1.10	1.14	1.17	1.21	1.24	1.28	1.32
11	IKEJA	0.33	0.32	0.65	0.67	0.69	0.71	0.73	0.75	0.78	0.80	0.83	0.85	0.88	0.90	0.93	0.96	0.99	1.02	1.05	1.08	1.12	1.15
12	IKORODU	0.36	0.32	0.69	0.71	0.73	0.75	0.78	0.80	0.83	0.85	0.88	0.90	0.93	0.96	0.99	1.02	1.05	1.08	1.12	1.15	1.19	1.22
13	KOSOFE	0.53	0.41	0.93	0.96	0.99	1.02	1.05	1.09	1.12	1.16	1.19	1.23	1.26	1.30	1.34	1.38	1.43	1.47	1.52	1.56	1.61	1.66
14	LAGOS/ISLAND	0.46	0.40	0.86	0.89	0.91	0.94	0.97	1.00	1.03	1.06	1.10	1.13	1.16	1.20	1.24	1.27	1.31	1.35	1.40	1.44	1.48	1.53
15	LAGOS/MAINLAND	0.33	0.30	0.63	0.65	0.67	0.69	0.71	0.73	0.75	0.78	0.80	0.83	0.85	0.88	0.91	0.93	0.96	0.99	1.02	1.05	1.09	1.12
16	MUSHIN	0.68	0.64	1.32	1.36	1.40	1.45	1.49	1.54	1.58	1.63	1.68	1.74	1.79	1.84	1.90	1.96	2.02	2.08	2.14	2.21	2.28	2.35
17	OJO	0.51	0.43	0.94	0.97	1.00	1.03	1.06	1.10	1.13	1.16	1.20	1.24	1.27	1.31	1.35	1.40	1.44	1.48	1.53	1.57	1.62	1.67
18	OSHODI/ISOLO	0.51	0.62	1.13	1.17	1.21	1.24	1.28	1.32	1.36	1.40	1.45	1.49	1.54	1.58	1.63	1.68	1.73	1.79	1.84	1.90	1.96	2.02
19	SHOMOLU	0.52	0.51	1.03	1.06	1.09	1.12	1.16	1.19	1.23	1.27	1.31	1.35	1.39	1.43	1.47	1.52	1.57	1.61	1.66	1.71	1.77	1.82
20	SURULERE	0.70	0.58	1.27	1.31	1.35	1.40	1.44	1.48	1.53	1.57	1.62	1.67	1.72	1.78	1.83	1.89	1.95	2.01	2.07	2.13	2.20	2.26
	TOTAL	**9.12**	**8.44**	**17.55**	**18.09**	**18.65**	**19.22**	**19.81**	**20.42**	**21.05**	**21.69**	**22.36**	**23.05**	**23.75**	**24.48**	**25.24**	**26.01**	**26.81**	**27.63**	**28.48**	**29.36**	**30.26**	**31.19**

G: Traffic Count

WEEKDAYS COUNTS ON DIFFERENT CLASSES OF ROAD IN 20 LOCAL GOVERNMENT AREAS, LAGOS STATE										
			EXPRESS WAY				MAJOR ROAD			
Zones No	**LGA**	**Road Name**	SUV	Car	Total Private Cars (Average Daily Traffic)	**Peak hour count (10% of ADT)**	SUV	Car	Total Private Cars (Daily Average)	**Peak hour count (10% of ADT**
1	Agege	Agege Motor Road W of Pen Cinema, S of Oba Agunji rd	836	2699	3535	**354**				
2	Ajeromi-Ifelodun	Mobil Rd - Over River					1735	7107	8842	**884**
		Kiri Kiri Rd - Over River					724	3034	3758	**376**
3	Alimosho	Igando Road - W of Lasisi Ige & E of Rasak Tijani St					1228	4138	5366	**537**
		Ipaja Road - West of Shittu Tijani Close					2533	4909	7442	**744**
		LASU Road - S of Obadore & N of New Covenant Church Rd					1352	3292	4644	**464**
		LASU Road W of Idimu Road					1625	6995	8620	**862**
		Abeokuta Expressway - Btw Iyana Ipaja & Iyana Egbeda	1971	6299	8270	**827**				
4	Amuwo Odofin	New Festac Road	2971	7643	10614	**1061**				
		Lagos Badagry Expressway - W of Junction with Eric Moore	3282	7766	11048	**1105**				
		Lag.Badagry Exp.Way end of Festac 1st gate	2770	11365	14135	**1414**				
5	Apapa	Gaskiya Road - Over River					259	2018	2277	**228**
		Dockyard Road - Parallel to Wharf Rd								
		East bridge Tincan Island	2123	5288	7411	**741**				
6	Badagry	Lag Badagry Exp.Way end of Badagry	630	12602	13232	**1323**				
		Lag Badagry Exp.Way west of Ijanikin	2522	8064	10586	**1059**				
		Lag Badagry Exp.Way end of Ijotun	615	7228	7843	**784**				
7	Epe									
8	Eti-Osa	Adeola Odeku St - Btw Idowu martins Str & Ologun Agbaje St					7371	12447	19818	**1982**
		Ring Road - Btw Bishop Oluwole & Ahmadu Bello Str	5335	11760	17095	**1710**				
		The palms,Admiralty Rd ,North of shoprite					10075	15729	25804	**2580**
		Ahmadu Bello Way - On bridge					8002	26602	34604	**3460**
		Osbourne Road E of Junction wt 3rd Mainland Bridge					9923	36754	46677	**4668**
		Awolowo Road- Btw Alhaji Ribadu Rd & keffi Str					3187	10128	13315	**1332**
		Falomo Bridge - On bridge	9393	16520	25913	**2591**				
		Lekki -Epe Expressway W of Admiralty Roundabout	8931	15057	23988	**2399**				
9	Ibeju-Lekki	Lekki Epe Expressway E of Estate entrance road, Ajah	6245	7214	13459	**1346**				
		Lekki Epe Expressway W of Ikota Bridge	10055	17950	28005	**2801**				
10	Ifako-Ijaiye	Abeokuta Expressway S of Junction with Agbado Ijaiye	1707	10209	11916	**1192**				
		Agbele Road - Between Omoleye St & Meiran road					1372	3815	5187	**519**
		Fagba Iju Rd					2832	6234	9066	**907**
11	Ikeja	Agege Motor Rd-N of Concorde Rd at Airport Junction	9588	30200	39788	**3979**				

		Agege Motor Road S of Junction with Abeokuta Exp	5688	21197	26885	**2689**				
		Agege Motor Road - S of Adekunle Fajuyi	3836	23588	27424	**2742**				
		Lateef Jakande					17343	21010	38353	**3835**
		Apapa Oworonshoki Exp.Btw Oshodi/Anthony	6593	29915	36508	**3651**				
		Babatunde Oki st.								
		Ikorodu Rd(Idiroko)	16714	33640	50354	**5035**				
		Lagos Ibadan Expressway - In front of Motorways centre	6433	44711	51144	**5114**				
		Berge -Ibadan Expressway on bridge, N with Isheri rd	6481	12946	19427	**1943**				
12	Ikorodu	Ikorodu Rd west of Oba	3271	7150	10421	**1042**				
13	Kosofe	Ikorodu Road North of Oregun Ogudu	1458	7075	8533	**853**				
		Ikorodu Road South of Oregun Ogudu	3610	5380	8990	**899**				
		Ikorodu Road-On bridge E of Mile 12	4233	8960	13193	**1319**				
14	Lagos Island	Eko Bridge On bridge	5889	16938	22827	**2283**				
		Third Mainland Bridge Nr LI	8245	7422	15667	**1567**				
		Carter Bridge On Bridge	2720	8388	11108	**1111**				
15	Lagos mainland	3rd MainLand Bridge North of Adekunle Access	9756	25523	35279	**3528**				
		Muritala Muhammed Way - Btw Pedgrave & St Hughes Av					1149	6066	7215	**722**
		Herbert Macaulay - Btw Pedgrave & Hughes Av					2459	11107	13566	**1357**
		Adekunle Access Before Meeting 3rd Mainland Bridge					4416	17459	21875	**2188**
16	Mushin	Agege Motor Road nr Fadeyi-Btw Ikeolu & Alh Lasisi St	4264	7126	11390	**1139**				
17	Ojo	Lagos Badagry Expressway E of Ijanikin	1188	8492	9680	**968**				
		Lagos Badagry E of LASU & Iyana Iba rd	1140	7312	8452	**845**				
18	Oshodi-isolo	Airport Rd.	6396	20752	27148	**2715**				
		Apapa Oworonsoki Expressway btw Airport rd & Agege Rd	4590	27198	31788	**3179**				
		Apapa Oworonsoki Expressway btw Isolo rd & Ladipo St	15852	25946	41798	**4180**				
		Isolo Rd					1351	7692	9043	**904**
19	Somolu	Apapa Oworonsoki Expressway W of Jun wt Awolokun	10636	27346	37982	**3798**				
		St. Finbarrs Rd - S of Moronfolu Str								
20	Surulere	Eric Moore - Btw Jimph Odutola St & Abede Village Rd					2307	6918	9225	**923**
		Western Avenue - South of Bode Thomas Street	6099	13956	20055	**2006**				
		Alhaji Masha Rd - Btw Ogunlana rd & Akerele Rd					2516	17688	20204	**2020**
		Apapa Oworonshoki Expressway- Btw Coker & Olanipekun Rd	4516	11081	15597	**1560**				
		Ijesha- N of Junction btw Apapa Oworonshoki Exp					1868	1653	3521	**352**
		Ojuelegba Road - Btw Western Avenue & Akitan Str					1272	6823	8095	**810**