QUICK RESPONSE TRAVEL DEMAND MODELLING:

A CASE STUDY OF ZARIA

BY

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DEDICATION

This work is dedicated to my loving and caring parents, Alh. & Hajiya Tanko Wambai,

My loving and caring wife, Mrs. Salamatu Lawal Nagogo.

DECLARATION

I hereby declare that this thesis has been composed by me and that it is a record of my own research. It has not been accepted in any previous application for a degree anywhere. However, as it is required by research laws and ethics, all sources of information are specifically acknowledged by means of references.

……..
RABIU USMAN SHEHU
JULY, 2011

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ABSTRACT

Internal Volume Forecasting Technique is one of the several methods of Quick Response Travel Demand technique. This thesis reviewed the various techniques used in travel demand modelling and demonstrated the application of the Internal Volume Forecasting technique towards deriving a travel demand model for Zaria. The study successfully validated the simplified travel demand model for application in the study area and by extension, others with similar characteristics. The method was applied to four zones (Zaria city, Sabon Gari, Tudun Wada and Samaru) all in Zaria Urban Area. The data used in the model include demographic and socio-economic data. These are population, employment, recreation and commercial activities. Appropriate combinations of production and attraction which was population and recreation only for the zones of study produced a final model of trip generation and distribution as; = . + . . The travel time exponent of 2.0 found in this study conform to the study conducted by the U. S. Department of Transportation in the year 2000. The result of the model can be used in future forecasting of traffic in Zaria after a further slight improvement to the model to carry out the assignment stage. A Microsoft excel sheet probability factors.xls has been created in the course of this work to ease the difficulty of determining the trip probability factors.

TABLE OF CONTENTS

Title page		i
Dedication		ii
Declaration		iii
Certification		iv
Acknowledgements		v
Abstract		vi
Table of contents		vii
List of tables		x
List of Figures		xii
Chapter One: Introduction		1
1.1	Preamble	1
1.2	Statement of the Problem	3
1.3	Aim and Objectives	4
1.4	Study Area	4
Chapter Two: Literature Review		8
2.1	Travel Demand and Forecasting	8
2.2	Units for Measuring Travel Demand	12
2.3	Measuring Existing Travel	13
2.4	Time Frame for Travel Survey	12
2.5	Traffic Volume and Passenger Counts	15
2.6	Forecasting Future Travel on Road Segments and / or Transit Lines	16
2.7	Direct Estimation of Traffic Volume by Trend Analysis	16

2.8 Stepwise / Sequential Procedure 16

2.9 Data Required for Travel Demand Model 17

2.10 Land Use Models 20

2.11 A Brief History of Land – Use and Travel Demand Modelling 21

2.12 Development of Travel Demand Models 22

2.13 The Need for Land Use Models 25

2.14 NCHRP Report 365 28

2.15 The Lowry Model and Derivatives 30

2.16 Model Calibration 32

2.17 Regression Analysis 33

2.18 Trip Generation Model: Aggregate Approach 33

2.19 Trip Generation Model: Disaggregate Approach 35

2.20 Applications of Travel Models 40

2.21 Theoretical Framework and Concepts 41

Chapter Three: Research Methodology 44

3.1 Introduction 44

3.2 Types of Data Required 44

3.3 Sources of Data 44

3.4 Data Collection Strategy and Methodology 40

3.5 Data Analysis 45

3.6 Model Development of IVF Technique 46

Chapter Four: Analysis and Discussion of Results 49

4.1 Introduction 49

4.2 Employment Status 49

4.3 Inter – Regional Traffic by Road 49

4.4 Road Network of Study Area 49

4.5 Traffic Analysis Zone 50

Chapter Five: Summary, Conclusion and Recommendations 69

5.1 Summary 69

5.2 Conclusion 70

5.3 Recommendations 70

References 72

Appendix I: Regression Analysis Result, All Land Uses (n=2) 80

Appendix II: Regression Analysis Result, Population and recreation only (n=2) 82

Appendix III: Regression Analysis Result, All Land Uses (n=1.5) 84

Appendix IV: Regression Analysis Result, Population and Recreation (n=1.5) 86

Appendix V: Regression Analysis Result, All Land Uses (n=2.5) 88

Appendix VI: Regression Analysis Result, All Land Uses (n=2.5) 90

LIST OF TABLES

Table		Page
4.1	Population of Study Area	51
4.2	Employment Status of Study Area	52
4.3	Hectare of Land Used For Recreation and Leisure of Study Area	52
4.4	Hectare of Land Used For Commercial Activities in the Study Area	52
4.5	Travel Time in Zaria City	53
4.6	Travel Time from Zaria City to Tudun Wada	54
4.7	Travel Time from Tudun Wada to Sabon Gari	55
4.8	Travel Time in Sabon Gari	56
4.9	Travel Time in Sabon Gari Travel Time from Sabon Gari to Samaru	57
4.10	Travel Time in Samaru	58
4.11	Travel Time in Tudun Wada	59
4.12	Trip Table Representing Travel Time in (min) in all The Zones	60
4.13	Rating of Employment Status In Study Zones	60
4.14	Rating of population in study zones	61
4.15	Trip Probability Factors For Population and Employment	61
4.16	Rating of Hectare of Land Used For Recreation	62
4.17	Trip Probability Factors For Population and Recreation	62
4.18	Rating Hectare of Land Used For Commercial Activities in the Study Area	62
4.19	Trip Probability Factors For Population and Commercial Rating (n=2.0)	62
4.20	Trip Probability Factors For Population and Population Rating	63

(n=2.0)

4.21 Link volumes of the study zones 63

4.22 Trip Probability Factors For Population and Employment Rating (n=1.5) 64

4.23 Trip Probability Factors For Population and Recreation Rating (n=1.5) 65

4.24 Trip Probability Factors For Population and Commercial Rating (n=1.5) 65

4.25 Trip Probability Factors For Population and Population Rating (n=1.5) 65

4.26 Trip Probability Factors For Population and Employment Rating (n=2.5) 66

4.27 Trip Probability Factors For Population and Recreation Rating (n=2.5) 66

4.28 Trip Probability Factors For Population and Commercial Rating (n=2.5) 67

4.29 Trip Probability Factors For Population and Population Rating (n=2.5) 67

4.30 Summary of travel time exponent 68

LIST OF FIGURES

Figures		Page
1.4	Study Area Map	5
3.1	Research Design	46
4.1	Map of Zaria Urban Area Showing Study Zones	50
4.2	Traffic Analysis Zones of the Study	51

CHAPTER ONE

INTRODUCTION

1.1 Preamble

Many urban activities are not situated in one place and there is an interesting need for people to travel to work, school, for shopping and to visit other places in the city, so as to satisfy their daily needs. To overcome the impedance from their activity they require particular means of mobility and those without personal vehicles must make use of public transport for such journeys in cities. Workers make trips daily from the residential areas to their workplaces generally characterizes the traffic. Traders too carry their wares from one part of the city to another, while others go to schools and business centres.

The demand for transport is inevitable within the context of socio-economic interaction in the society. For instance, it enhances city logistics relatively to land use, traffic and delivery characteristics. However, the Growth in Demand for urban transport in Nigerian cities like Zaria is largely influenced by the following factors;

i. Large increase in urban population, leading to a proportional increase in motorised trips.
ii. Spread of urban areas – longer journeys and more fuel consumption
iii. Greater availability of motorized transport, resulting in more motorized trips and increase in fuel consumption;
iv. Increase in household incomes, creating a greater propensity for travel
v. Increases in commercial and industrial activities; leading to increased volumes of service vehicles and freight traffic.

A thorough understanding of existing travel pattern is necessary for identifying and analyzing existing traffic related problems.

Detailed data on current travel pattern and traffic volumes are needed also for developing travel forecasting/prediction models. The prediction of future travel demand is an essential task of the long-range transportation planning process for determining strategies for accommodating future needs.

Travel demand models use current traffic and transit ridership characteristics along with population and employment forecasts to predict future travel demand in terms of mode choice, destination, temporal distribution, route choice, etc. Travel demand models were originally developed (Alan, 1993) to determine the impacts of major highway projects.

Traditional travel demand models employ an approach known as the Urban Transportation Modelling System (UTMS), which is also called the four-step planning model (Hogberg, 1976). The four-step planning model involves predicting the number of trips produced by and attracted to each zone (trip generation), creating origin-destination (O-D) matrices which link origins and destinations (trip distribution), determining the portion of travellers that will use each available mode (mode split), and assigning each trip to a particular route (trip assignment).

One of the most expensive and time-consuming tasks in the travel – demand modelling process is the collection of data on household, land use, and trip characteristics for calibration of the Urban Travel Demand (UTD) models. In most urban areas it is necessary to conduct a special home-interview survey to obtain the required data. Even

for a small city the data collection process can take more than a year at a cost of many thousands of dollars (Smith *et al*., 1978).

A travel demand model, the Internal Volume Forecasting model, which uses traffic counts rather than home – interview survey data for model calibration has been found to simplify the travel demand model process (Smith *et al*., 1978). The aggregate approach provided by this method makes estimation of zonal trip frequency quite convenient with a few regression variables. The method is also economical in terms of data collection, calibration and operation.

1.2 Statement of the Problem

Due to the growth in land development and population, residents of Zaria are faced with the problems of delay in accomplishing intra-city transport related tasks.

Prolonged routes and longer trip times in many cases have become unavoidable due to inadequacy of fundamental requirements such as:

- Effective regulatory control of transport operations.
- Transport infrastructure and facilities as alternative accessibilities between certain areas of the town such as a bypass to convey traffic from Sokoto, Zamfara, Katsina, Jos and Kaduna away from Kwangila.
- Adequate research data for planning and projection of the current and future transport demand.

These problems have resulted in increased frequency of accidents, traffic congestion during peak hours and the accompanying negative externalities.

Consequently, this research intends to focus on developing a travel demand model for Zaria through the use of a simplified travel demand analysis.

1.3 Aim and Objectives

1.3.1 Aim

The broad aim of this study is to develop a travel demand model of Zaria with a view to providing a platform for forecasting travel pattern of the area.

1.3.2 Objectives

The study has the following objectives

1. To delineate the study area into compact traffic zones and determine the population, employment, recreational and commercial uses in each of the identified traffic zones as well as the travel times.
2. To develop a model that will provide the basis for forecasting future development of the transport system in Zaria using simplified forecasting techniques.

1.4 Study Area

The modern urban area of Zaria consists of five nuclei of settlement centres all arranged successively along a major highway.

The urban area of Zaria is made up of four districts namely the old walled city, the colonial township (Tudun Wada and GRA), the Ahmadu Bello University (ABU) Samaru village area and Sabon Gari. Each of these units has characteristics associated with age in which it was built and with the culture of its builders and occupations.

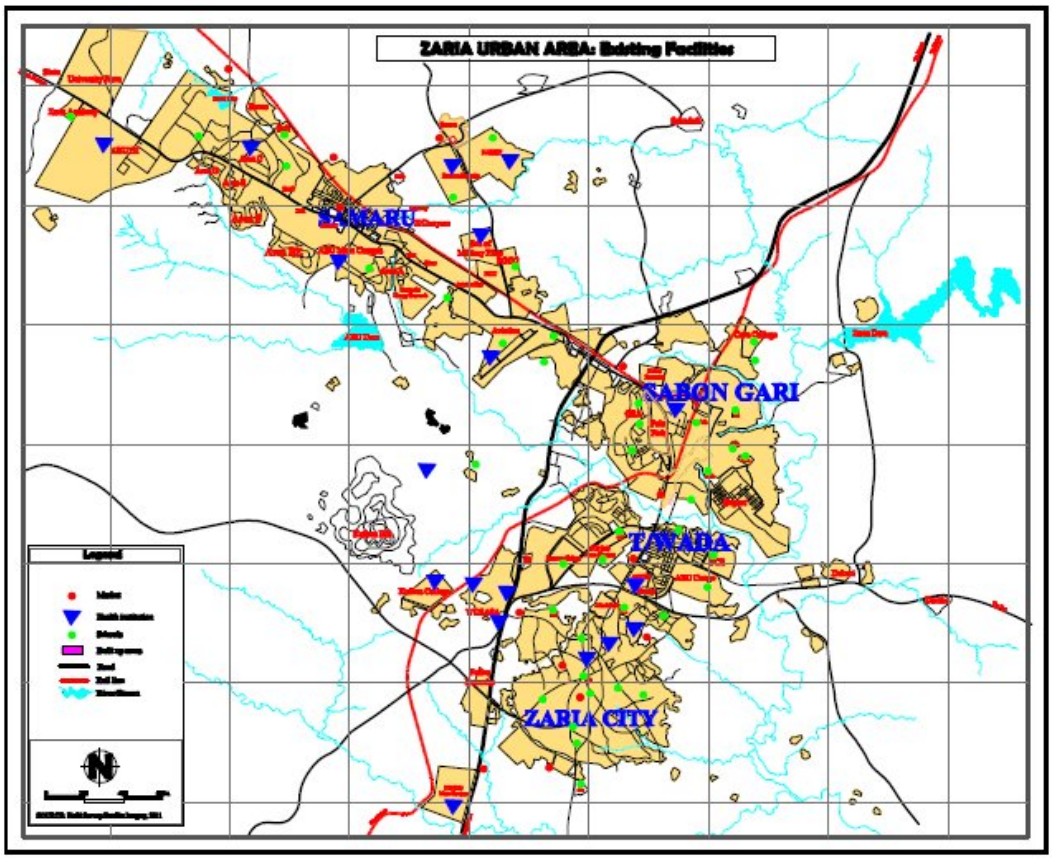


Fig. 1.1 Map of Zaria Urban Area Showing Study Zones (Source: Field survey and satellite imagery, 2011)

1.4.1 Birnin Zaria

The original Birnin (walled – city) retains much of physical character that matured during its evaluation. Briefly described, it is a complex maze of mud-walled compounds tightly arranged into groupings which are separated by – narrow footpaths that cut their ways through the city leading to the market areas, the Emir's Palace and adjacent Friday mosque which forms the focal point of the city. The population of the walled city was about 1300 people in 1918. The National Population Commission gave an estimated population of about 30,000 people in 1991.

1.4.2 Tudun Wada

The Tudun Wada area situated immediately north of the main gate of Zaria City that opens towards the North West is also being occupied by residential quarters and educational institute (tertiary institute and secondary school). The main market is located at the main road i.e. at the centre of the area. One of the main road networks include Wusasa to Congo via Gaskiya, in addition to the main road of Zaria that divide the area into two leading to Sabon Gari from Zaria City. Two other roads originate from the area and lead to other towns in Kaduna and Jos.

1.4.3 The Colonial Township

The colonial township founded in the first decade of the twentieth century is about three kilometres north of the city across the river Kubani from Tudun Wada. It serves as the centre of provincial administration, the Nigerian Railway corporation workshop and modern commercial activities and industries.

The Government Residential Area (GRA) which forms the largest part of the old European location is composed of extensive planting of ornamental trees and shrubs with a golf course separating the GRA from the residential compound.

1.4.4 Samaru

The nucleus of the fourth and most recent addition to Zaria urbanized areas was the Agricultural Research station founded in Samaru in 1924. The station attracted the School of Agriculture by 1945 which in turn precipitated the laying out of newly planned Samaru Village with the development of better road and the increased use of automobiles. Other government institutions were cited; these include the Zaria branch

of Nigerian College of Arts, Sciences and Technology which is currently the main campus of Ahmadu Bello University, the Industrial Development Centre, The Federal Ministry of Works and Housing and the Northern Nigerian Housing Corporation Housing Estate were cited near Samaru, while the Nigerian College of Aviation Technology is the second largest institution complex located at the outskirts near Samaru.

Ahmadu Bello University (ABU) is the first largest tertiary institution located in Samaru. It was established in 1963 thereby creating sources of income and revenue for both the people in the city and Government.

CHAPTER TWO

LITERATURE REVIEW

2.1 Travel Demand and Forecasting

Transportation forecasting is the process of estimating the number of vehicles or people that will use a specific transportation facility in the future. For instance, a forecast may estimate the number of vehicles on a planned road or bridge, the ridership on a railway line, the number of passengers visiting an airport, or the number of ships calling on a seaport. Traffic forecasting begins with the collection of data on current traffic. This traffic data is combined with other known data, such as population, employment, trip rates, travel costs, etc. to develop a ***traffic demand model*** for the current situation. Feeding it with predicted data for population, employment, etc. results in estimates of future traffic, typically estimated for each segment of the transportation infrastructure in question, e.g. for each roadway or railway station (Martin *et al*., 1998).

Traffic forecast are used for several key purposes in transportation policy, planning and engineering: to calculate the capacity of infrastructure, e.g. how many lanes a bridge should have; to estimate the financial viability of projects, e.g. using cost- benefit analysis and social impact assessment; and to calculate environmental impacts, e.g. air pollution and noise (Martin *et al*., 1998). Travel Demand Forecast Models (*TDFM*) produce projected travel demand based on the supplied land-use for a target year. The principal output from these models is traffic volumes. There are other important outputs in the process, but the basic outputs are still traffic volumes. These traffic volumes are used in many different applications including highway design, highway operations analysis, alternative selection, and project financial analysis. The accuracy of these

traffic projections can be very important in determining project feasibility as well as purpose and need. Often times the projections are used not only to develop potential toll revenue, but are also required for determining project financing and related bonding issues (Martin *et al*., 1998).

The model reflects the expected land-use, transportation network, and current travel behaviour at the time it is developed. These elements can change by the time the forecast year is reached.

Land-use is the most dynamic of these elements. Changes in the highway facility and regional economics result in unexpected development, especially in areas that do not have strong development and growth policies. Given this uncertainty, it is still important to produce accurate travel demand forecasts (Martin *et al*., 1998).

The travel demand forecasting model process is composed of four basic steps: trip generation, trip distribution, mode choice, and assignment. The traditional travel demand model, first divides the urban area into traffic zones, from which trips originate (trip production), and to which trips are destined (trip attraction).

The first step in the four step process is the trip generation model. The principle aim of trip generation models is to determine the number of trips originating in, or attracted to, the zones of an investigated area. The trip generation step utilizes a series of models in which zone-based information about employment and population is used to estimate the extent to which each zone is an origin and/or destination for trips. These projections can be disaggregated, depending upon data availability, to identify sub-sets of employment

and population types with different travel behaviour. Estimates can also be made separately according to the purpose of trip, e.g., home-to work, home-to-other, or other-to-other. The basic classification is expressed in the terminology of economics with the notions of trip production and trip attraction. The home is generally considered as a source of production and work as one of attraction. These trips are also called 'home-based' trips and count for around 80% of all trips. If trips occur, for example, between work and shop, i.e., 'non home-based' trips, then production and attraction change according to origin and destination respectively (Ortúzar and Willumsen, 1990). Despite this ambiguity, 'generation' is used as "trips are generated from their origins and attracted to their destinations" (Dasgupta et al., 1996). This mutual property between generation and attraction also determines the variables of the model. The following factors are regarded as the socio-economic variables for trip production: income, car ownership, household structure and family size, value of land, residential density, or accessibility (Ortúzar and Willumsen, 1990). Lohse and Lätzsch (1997) usually consider the number of inhabitants, number of working places (differentiated according to industry and other sectors) and number of vehicles or degree of motorisation as variables for transport planning; and despite these components the constraints for trip generation stem from the transport system and its design in relation to society, economy and environment. Dasgupta *et al*., (1996) used structural variables according to the land-use objectives and found a reasonable correlation between work trips and employment. They found it more difficult to establish similar relations for leisure and shopping activities where factors such as type of product, location or catchment area, should be considered.

Trip production estimation is the first step of the conventional four-step transportation demand forecasting process. Conventionally, trip generation models can be categorized into: aggregate or disaggregate approaches. The former is a direct estimation of trip frequency by zones: regression analysis methods are widely used in this approach. In contrast, the disaggregate approach estimate trip production from the household or person level and category analysis is common methodology. An aggregate approach provides a very convenient zonal estimation of trip frequency with a few regression variables, and it is very economical in terms of data collection, calibration, and operation. In contrast, a household – based or a person – based disaggregate approach can require a significant amount of data for model calibration and testing. However, a disaggregate approach can provide a more precise estimation on trip frequency, and it can respond better to the different travel needs due to the different socio-economic and demographic backgrounds of travellers.

The trip distribution steps links the trip origins and destinations for each type of trip through a gravity, or spatial interaction model, in which the demand for travel between any two points is positively correlated with the number of trip origins and destinations for the zone pair, and negatively correlated with the impedance between the two zones. The results are commonly called "trip tables". Typically travel time is used as a measure of impedance or accessibility. The gravity type of formulation is the same as that at the core of the Lowry land use model.

The mode choice step disaggregates trips between the highway and other modes. Mode choice models may include such factors as demographic group, cost, relative travel times, and trip purpose.

The assignment, or loading, of vehicle trips to specific links in the highway network and person trips to links in the transit network occurs in this step. The assignment algorithm is usually based on the assumption that people try to minimize travel time. There are several different approaches that can be used to determine the traffic assignment that results in the smallest travel times. For example, the model may repetitively assign a user-selected percentage of trips incrementally along the network paths that result in the minimum travel time. As certain links fill up with traffic, the speeds on them are reduced and travel time increases, until other links become more attractive. The process continues until all trips are assigned.

2.2 Units for Measuring Travel Demand

Travel demand is measured and expressed in different ways for different types of analysis.

Examples of different units of measurement are:

a) Trip (between two areas)

b) Trip end (in a given area)

c) Traffic volume (on a road segment)

d) Person trip and vehicle trip

e) Passenger vehicle and freight vehicle

f) Person-mile travelled and vehicle-mile traveled

The definition of each of these units should be understood clearly, and an appropriate unit of measurement should be used to match the case being analyzed. For example, for a parking study, “trip end” is the appropriate unit for expressing parking demand. For

estimating the number of lanes to be provided in a road segment, the demand should be expressed in terms of "traffic volume". As it was pointed out earlier, the appropriate unit of travel for estimating fuel consumption and/or air pollution attributable to transportation is Vehicle Miles Travelled (*VMT*).

2.3 Measuring Existing Travel

Detailed information on existing travel is needed for two purposes – 1) analyzing existing problems, and 2) developing mathematical models for forecasting travel. A variety of surveys can be performed for gathering information related to existing travel demand. However, travel surveys are expensive, and, therefore, care must be taken to identify the types of information that really would be useful for specific purposes, and then the most suitable procedures should be selected for gathering the information. Sampling techniques are useful, and adequate time and care must be devoted to developing sampling procedures. There are several different types of survey techniques, some of which are suitable for automobile travel, some for transit travel, and some for general passenger movement. Survey procedures for freight vehicles and commodity movements may be very different in certain respects from those of passenger travel.

2.4 Time Frame for Travel Surveys

Since travel demand varies during a given year according to the season (or month of year) and day of week, a decision must be made carefully to select a specific time frame of reference for surveys. For urban transportation studies it is a common practice to develop travel demand information for an average weekday in the 'fall' season (William *et al*, 1976). However, the time can be different based on the nature of the problem to be analyzed. For example, in the case of a tourist oriented urban area the major concern

may be traffic problems during weekend days or holidays, and surveys may be done to capture information for one of those days. A few major types of surveys are discussed in the following sections.

2.4.1 Origin-Destination (O-D) Surveys

The classification of trips into the three classes of internal, external-internal (and vice-versa), and through trips is useful for 'meso' scale and metropolitan level as well as small area studies. This classification scheme is useful for developing forecasting procedures/models as well as policies and strategies for accommodating travel because strategies for each of these classes of travel would be different. For example, through trips may require a by-pass facility. External-internal trips may have to be intercepted before they reach a heavily congested area such as the Central Business District (CBD).

The origins and destinations of trips along with some other characteristics such as trip purpose and mode of travel can be determined in different ways (William *et al*, 1976):

a) Home interviews (for internal travel)
b) Roadside interviews at cordon stations (for external-internal and through trips)
c) On-board survey on transit vehicles.

All of these three techniques involve "sampling' and require careful planning before their execution. Several years ago Federal Highway Administration and the former Urban Mass

Transportation Administration developed detailed guidelines for these survey procedures documented in reports titled *Urban Origin-Destination Surveys*, and *Urban Mass Transportation Travel Surveys* respectively. Full-scale origin-destination surveys

were widely used during 1960's and 1970's to develop a variety of information including "desire lines" of travel. Their use has decreased because of the cost and also due to the use of synthetic or borrowed disaggregate travel models, which require less survey data.

2.5 Traffic Volume and Passenger Counts

For determining the use of various roadway facilities and assessing their level of service, vehicle counts are taken at selected locations along roadways. Short-count techniques are useful provided appropriate expansion factors are developed based on previous or ongoing research on fluctuations of traffic by hour, by weekday, and by month.

For urban transportation studies 'screen lines' and 'cut-lines' are established in the study area to select traffic count locations and take counts in an organized manner so that the major travel movements can be measured and analyzed. These counts are also used for checking the results of travel forecasting models. Similarly traffic counts are taken at special traffic generators such as an airport and a large college/university to capture their unique travel generating characteristics.

For analyzing the use of a transit service, passenger counts are taken on-board transit vehicles and/or at selected stops or stations. These passenger counts usually are taken by observers who are assigned to specific transit vehicles and/or transit stops/stations according to a survey plan

2.6 Forecasting Future Travel on Road Segments and/or Transit Lines

A variety of forecasting procedures are available ranging from the extrapolation of past trends to complex mathematical models involving several steps. A transportation planner must recognize the advantages and disadvantages of each procedure.

2.7 Direct Estimation of Traffic Volume by Trend Analysis

If traffic volume data are available for a road segment or a transit line of interest for several years in the past, the historical trend can be identified and extrapolated to estimate future volumes. This approach, of course, is appropriate if the trend is expected to continue, which commonly is true for short-range forecasts. Trend based forecasts are appropriate also for aggregate values such as total VMT or transit rides in an urban area. However, major changes in the land development pattern and/or transportation network can cause substantial changes in the travel pattern, and if such changes are likely then trend extrapolation would not be appropriate. Therefore, for long-range forecasts of traffic volumes on individual segments of a road network or the number of passenger trips on individual transit routes, trend analysis is not used.

2.8 Stepwise/Sequential Procedure

A widely used travel estimation procedure for long-range forecasts of traffic volumes on a highway network uses several steps in a sequence. Each step requires a particular type of model or procedure, and there are different choices of models at each step. One of the major advantages of this procedure is its ability to reflect several types of changes, which may occur in the future:

a) Changes in trip making rates;

b) Changes in development pattern resulting in altered travel pattern;

c) Changes in transportation mode usage; and

d) Changes in transportation network.

Another advantage of the stepwise, or sequential, procedure is that it generates several types of useful information at the end of various steps. The disadvantage of the procedure is that it needs a large amount of data for model development. It also requires a sound knowledge of one of the available computer software that is specially designed for developing and applying these models. A great deal of research has been performed and is still being continued to improve this stepwise modeling procedure, Weiner (1992).

The stepwise procedure is popularly known as the four-step modeling process as this procedure includes four major steps: trip generation, trip distribution, mode choice, and traffic assignment. Additionally network analysis must be done to develop a few types of information that are needed for the other steps.

2.9 Data Required For Travel Demand Model

Typical travel demand models are data intensive. The basic types of input data required are land use, trip generation, travel impedance, trip friction, adjustment factors, highway and transit network. These are described below in sections 2.9.1 to 2.9.7.

2.9.1 Land use data

The trip generation step requires information about the socio-economic characteristics of each traffic analysis zone. This may include, for example, population, households,

employees, or schools. Any type of land use or economic characteristic that can be quantitatively related to the number of trips produced or attracted may be included. Some of this land use information, include, population, income levels, e.t.c.

2.9.2 Trip generation factors

The trip generation step also requires information about the number of trips associated with each socioeconomic characteristic of a traffic analysis zone, e.g., the number of trips per household in a given income category. The factors can be determined based on local surveys or, if data are lacking, standard technical guidance documents such as are published by the Institute of Transportation Engineers (ITE) of Britain.

2.9.3 Travel impedance factors

The trip distribution step and the modal choice step require information about the impedance, or difficulty of trips between each pair of zones. Impedance factors are usually expressed as either, time, distance, or cost, and are based upon local surveys.

2.9.4 Friction factors

The trip distribution step also requires information about the relative impact of a unit of impedance on the likelihood of trips between each pair of zones. These "friction factors" may differ according to the purpose of the trip. For example, drivers are more likely to choose to travel long distances or pay tolls for trips to work rather than trips to buy milk.

2.9.5 Adjustment factors

The mathematical relationships used in the trip distribution step often include an adjustment factor which modellers apply to make predicted travel distribution match common sense expectations or observed behaviour, i.e., the adjustment factors are used to calibrate the model. These factors are sometimes retained in future year forecasts of travel activity.

2.9.6 Highway network

The trip assignment step requires an abstract description of the highway network as nodes and links. A node typically is assigned to a specific physical point in the region, such as an intersection or a transit stop where a transfer can be made. Links define roadway segments between nodes and have associated speed, distance, capacity, and other attributes.

2.9.7 Transit network

The trip assignment step also requires an abstract description of the transit network. It includes the links to specific route travels and the nodes where stops are made.

The four stages of a travel demand model may include feedback at different stages. For example, the speeds calculated in the trip assignment step, which incorporate the slowing caused by traffic congestion on each link, may be fed back into the trip distribution and mode choice steps. Using the congested speeds, the model again determines the split of travel among available modes (e.g. drive-alone, transit) and then determines the most reasonable path in the network travel would take. The iterations continue until either all paths connecting a pair of zones have the same travel time so

there is no advantage in switching paths, or until a predetermined number of iterations have been made.

The use of feedback is almost always limited to the last three of the four stages described above, even when the model is used to predict future travel activity. Planning agencies generally do not feed the information on travel choices and ease of travel between zones produced by the four stage model back into either the trip generation step or the modelling of future land use patterns.

Transportation model outputs include vehicle volumes by link on the highway network, person trips on the transit network, congested speeds by link, trip origins and destinations and intrazonal trips by zone. These predictions can represent average daily or peak/off-peak period travel.

2.10 Land Use Models

Most operational urban land use models are derived, at least in part, from Lowry's (1964) "Model of Metropolis" for the city of Pittsburgh. The approach developed by Lowry (1964) links together two spatial interaction. One allocates employment to a set of land use zones on the basis of employment levels in industries that export products from the area (i.e., manufacturing and primary industries). The employment forecasts come from outside the model, often from a regional economic model. The Lowry model and those derived from it then project residential locations of the families of the employed workers on the basis of the employment locations, using a "gravity" type function. This is similar to the trip distribution step of the standard travel demand model, and uses a similar travel impedance variable.

A second spatial interaction module allocates employment in the service sector across zones on the basis of residential locations. The service sector employment generates a second set of families of employed workers to be allocated to residences. Residential and service locational processes are iterated until minimal additional employment is projected, i.e., equilibrium is approximated. Estimates of either land area occupied or floor space used within each zone is derived from residential and employment activity projections, combined with activity-to-floor space rates. Totals are constrained by physical limits and planning restrictions within a zone. Modelling urban form, as represented by location (land use) models, was initiated by Lowry in his Model of Metropolis (1964).

2.11 A Brief History of Land-use and Travel Demand Modelling

In recognition of the complex dynamics of an urban system, urban planners in the 1950s and ’60s initiated the development of integrated Land Use-Transport (LU-T) models. The first of these models to gain popular notice was Lowry’s model of Metropolis in 1964. Since then there have been several integrated LU-T models developed worldwide such as ITLUP (Putman, 1983), MEPLAN (Echenique, 1985), MUSSA (Martínez, 1992), and UrbanSim (Waddell, 2002). While the land-use components of these LU-T models have been rapidly evolving from simple aggregate representations to complex economic and econometric models of the market processes, the 4-step model continues to represent the transport modelling component.

Meanwhile, however, the travel demand model has evolved greatly from the simple 4-step models of the 1960s. On the one hand, advances in econometric modelling led to

the adoption of disaggregate choice models within the 4-step modelling framework. Further enhancements were due to conceptual advances such as the recognition of the linkages between trips, which resulted in tour-based 4-step models.

2.12 Development of Travel Demand Models

2.12.1. Aggregate Models

The earliest travel demand models were simple mathematical models, such as a gravity model or an entropy model that quantified travel as a function of the size of a zone. These were essentially aggregate level trip-based models. The number of trips generated from a zone was considered to be proportional to the population in the zone, while the number of trips 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 referred to as 'impedance'), Hogberg, P., (1976)

2.12.2 Disaggregate trip-based models

Advances in modelling techniques resulted in a shift away from these aggregate models and led to the development of disaggregate trip-based models. These models 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. However, in practice, due to data limitations and modelling constraints, disaggregate trip-based models are sometimes (even to this day) implemented in an aggregate manner with aggregate zonal socio-demographic data, (Mugler et al, 1999).

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 (Mugler et al, 1999) to address this limitation.

2.12.3. Tour-based models

Most travel demand models currently in operation use a tour-based 4-step modelling approach. This approach divides all individual travel into tours based at home and trips not based at home. 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. All the remaining non-home based trips, such as a trip from the work place to lunch, or a trip from one shopping location to another, or a business trip from work, are classified under two purposes – non-home based employer's business and non-home based 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 known as combined tour distribution and mode choice step, Ortuzar and Willumsen (1990). And finally, the network assignment procedure allocates the tours to the transport network.

Tour-based models, although popular in practice, are still rather limited. They suffer from a lack of behavioural realism on several counts, many of which they share in common with the trip-based approach. First, tour-based models continue to neglect linkages between trips. For instance, if a person drives from home to work and then stops at the grocery store on the way back home, this would be viewed by tour-based models as one home-based work trip and one non-home based 'other' trip. Second, tour-based models often neglect trips made specifically to serve passengers (example, pick-up or drop-off children at school). Third, tour-based models do not consider potential trade-offs across travel purposes. For instance, an individual with limited time on her hands may decide against shopping for the day and choose to eat out instead. Fourth, tour-based models do not consider the effects of household interactions on travel. Fifth, tour-based models do not consider the effects of in-home activities on travel. Clearly, the key shortcoming of tour-based models is that they are not behaviourally realistic.

2.12.4. Activity-based models

The solution to the limitations of the trip and tour-based approaches is the activity-based paradigm (Bhat *et al*., 2003), for a detailed discussion of the differences between trip/tour-based and activity-based models. Activity-based models acknowledge the fact that the travel needs of the population are determined by their need to participate in

activities spread out over time and space. Consequently, an individual's activity patterns, both in-home and out-of-home, influence the individual's travel patterns. For instance, if a person participates in e-shopping over the internet at home, the in-home activity may satisfy her shopping needs and she may, as a result, not make a trip to the local mall. In order to accurately quantify the travel needs of the population, it is therefore important to model the activity-travel patterns of the population. The activity-travel pattern of an individual is defined (Bhat *et al*., 2003) as a complete string of activities undertaken by the person over the course of a day characterised by location, time of day, and mode of travel between locations). Further, it is important to acknowledge that human beings are not islands and that they interact with each other extensively. Therefore an individual's activity-travel patterns are influenced by those of other individuals within the population, and particularly by the activity-travel patterns of other household members.

There are a few operational activity-based models in use today, such as the BB System (Bowman and Ben-Akiva, 2000) and the Albatross model (Arentze and Timmermans, 2004). On the other hand, there are several state-of-the-art (prototype) activity-based modelling systems that approach behavioural realism in their representation of travel-related choices but are not yet ready to become operational (for example, PCATS by Kitamura and Fuji: 1998, AMOS by Pendyala *et al*., 1998, SIMAP by Kulkarni and McNally, 2001, CEMDAP by Bhat *et al*., 2004).

2.13 The Need for Land Use Models

What is the function of land use models or more precisely what does the Transportation-Land Use Interaction model do? Land use models deal with describing activities of land

consuming actors and their competition for land in an urban setting. These actors are households, firms and retail establishments, each with particular requirements for space and access to jobs, schools and markets.

Describing the spatial distribution of these activities at present and projecting future land uses are the main two aspects of these models. These models also consider interaction among these activities through the transportation network.

Land use transportation interaction models overcome the deficiencies in the existing traditional four-step models. Consider the addition of a new facility in a metropolitan area. As the result of the addition of this facility, there will be some route changes, even possibly some mode switching and possibly some destination changes where travellers can satisfy, say, their shopping trip needs (Dasgupta *et al*., 1991).

What the existing transportation models are not capable of capturing is the projection of relative changes in household location and employment location of the land consuming actors (Dasgupta *et al*., 1991).

The reason for the deficiencies of the existing traditional four-step transportation models is that land use activities considered in the trip generation phase have a fixed spatial pattern. It is known that improving transportation facilities or even anticipation of a new transportation facility creates a secondary effect. These changes in population and employment location are due to the fact that some of these zones in the study area become more accessible and therefore households and firms start to relocate to take

advantage of the new facility, even anticipating these changes. These secondary effects are not considered in the traditional four-step transportation models.

In traditional land use planning, the future transportation system is also assumed to be fixed, while the increase in population or activity in zones might require further facility enhancement.

However, often these are not considered in the assumed transportation network which is being used for land use projection.

Over time, this disjointed planning framework creates imbalances between transportation and land use. The imbalances show themselves as congestion, overloaded networks in some part, and under-utilized facilities on the other. Famous examples of these imbalances are the overloaded Shirley Highway in Washington, DC or the London Orbital Highway in England. These facilities became prematurely overloaded few years after their opening. Ordinarily these highways were assumed to have a 30-year service life-span, U.S. Department of Transportation, Federal Highway Administration (1976).

Not all imbalances show themselves in congested facilities. An under-utilized facility such as the Sawgrass Expressway built by the Broward County Expressway Authority in Florida is the other side of the imbalance. The Sawgrass Expressway when opened in 1986 realized only a portion of the traffic projected on the facility.

Modelling urban form, as represented by location (land use) models, was initiated by Lowry, (1964) in his Model of Metropolis (1964). Lowry, (1964) considered the City of Pittsburgh, where the location of steel mills and other large industries, because of their

size requirement and distant markets, are independent of local employee location. These were considered as basic employment. The model is based on the assumption that, everything else being equal, the place of employment determines the place of residence. Place of work (basic employment location) implies the place of residence (Population and dwelling units). The resident population requires "services", therefore, place of service employment is determined by resident population. The service employees themselves require housing in relation to their place of work. This additional population requires further services which will be fulfilled by additional service employment. The new service employees require housing in relation to their place of work. This round of reasoning continues until there are very few service employees or households to be located, (Sosslau et al, 1978).

Households and employment are constrained by regional employment and household totals. The heart of the model for placing households is a gravity model relating homes to employment using an impedance function of power form. One of the derivatives of Lowry's model is the Time Oriented Metropolitan Model (Crecine, 1994) which introduces an element of time in the model. The original Lowry formulation, as Lowry, (1964) puts it, generates an "instant metropolis".

2.14 NCHRP Report 365

In 1998, NCHRP Report 365, *Travel Estimation Techniques for Urban Planning*, was published to update NCHRP Report 187, *Quick-Response Urban Travel Estimation Techniques and Transferable Parameters*. NCHRP Report 365, 1998 provides a thorough review of the four-step travel demand process and transferable parameters that

can be used in simple planning analysis. It is particularly useful to planners in smaller urban areas that cannot afford to develop area-specific parameters.

Based on Modlin's work, NCHRP Report 365 (1998) selected and reprinted a set of his regression models to serve as the through trip estimation technique in small urban areas. The models are shown as below.

Through Trip Generation Model

$$Y_i = 76.76 + 11.22 \times I - 25.74 \times PA - 42.18 \times MA + 0.00012 \times ADT_i + 0.59 \times PTKS_i - 0.48 \times PPS_i - 0.000417 \times POP \quad (2.1)$$

where

Y_i = percentage of the ADT at external station i , that are through trips;

I = interstate (0 or 1);

PA = principal arterial (0 or 1);

MA = minor arterial (0 or 1);

ADT_i = average daily traffic at external station i ;

$PTK_i S$ = percentage trucks excluding vans and pickups at external station i ;

PPS_i = percentage of vans and pickups at external station i ;

POP = population inside the cordon area.

This model was actually the one Modlin, (1974) developed in 1974 and simplified by ignoring low functional roadways (i.e., major collector, minor collector and local routes). In Equation 2.1, an external station can be only one of the three functional classifications which represent the major routes for a study area. For that classification, the value of the variable is 1; for the other two, the value will be 0.

The methodology provided by NCHRP Report 365 has the same deficiencies as Modlin's models published in *Transportation Research Record 842*. It can be used only for small urban areas with population less than 50,000. It is based on old survey data collected 30 to 40 years ago that do not reflect current through travel patterns, Sosslau *et al*, (1976).

2.15 The Lowry Model and Derivatives

The land use model developed by Lowry, 1964 was a spatial interaction model designed to simulate patterns of residential and service location in the Pittsburgh, Pennsylvania, region. The impetus for building the model was to be able to simulate the effects of urban renewal and slum clearance programs on the distribution of activities within the region. The model borrowed from economic base theory, divides a region's employment into basic and nonbasic services. Basic industries are assumed to export much of their product outside the region, generating additional income that can then support additional nonbasic services. Nonbasic industries then serve households (e.g., retail activities) and other industries within the region. Lowry, (1964) model assumed that the location of basic industries was fixed. This required an initial allocation of basic employment to zones within the region. Households were then allocated to zones from the initial basic employment locations, using a function similar to the deterrence function used in the trip distribution step of most trip-based travel forecasting models (Horowitz, 2004):

Several models extended the basic Lowry, (1964) framework in new directions. For example, the Time Oriented Metropolitan Model (TOMM) described by Crecine (1964) disaggregated the population into socioeconomic groups to improve the model's

representation. It also differed from the Lowry, (1964) model in that only some of the nonbasic activities in a region would be reallocated between model iterations, reflecting a certain degree of inertia in location.

Garin (1966) recast the original Lowry, (1964) model by proposing a matrix representation for the model's components and substituting a production-constrained, gravity-type interaction model as the basis for allocation. Garin, (1966) version also allocated all activities at each iteration, an improvement over Lowry, (1964) formulation since it improved the coupling between allocation and generation (Timmermans, 2003). Another land use model designed by Goldner (1971) allocated activities according to an intervening opportunity model, a special case of the gravity model (Wilson 1971). The design of the model also sought to improve realism by using different dispersion parameters for each of the nine counties of the San Francisco Bay area, where it was calibrated and tested.

Two other spatial interaction-based models merit attention, since they have been extensively applied and tested. The first is the Leeds Integrated Land Use (LILT) model, developed by Mackett (1983, 1991). LILT combines a Lowry-type land use model with a conventional, four-step travel model. Forecasts of change in population are allocated to zones according to accessibility functions derived from work trips and zonal attractiveness functions. Other salient features of LILT include the ability to handle demolition, changing occupancy rates and vacancies, and a car ownership submodel, which estimates vehicle ownership as a function of network travel times and costs (Timmermans, 2003). The IRPUD model (Wegener, 1982) was developed by Wegener and colleagues at the University of Dortmund in Germany. IRPUD is quite

complex and contains seven interlinked submodels of aging, firm relocation, residential and non-residential construction, rehabilitation and demolition, change of job, change of residence, and car ownership/travel demand. IRPUD is somewhat unusual in that it contains a micro - simulation model of land use, in which land uses are allowed to change through aging. Another desirable feature of IRPUD's design is that it allows different sub-models to take place at different spatial scales (intra-regional location takes places at a meso-scopic scale, while land development takes places at a micro/tract level). These features are emulated in some of the newer, emerging urban microsimulation models. As a practical matter, the IRPUD model can be classified along with other spatial interaction models, since it uses gravity models to allocate the distribution of land use. The first generation of land use and integrated transportation and land use models based on spatial interaction formulations produced a multitude of models that were tested and applied in numerous settings. Some models, such as the METROPILUS planning support system package, continue the legacy of these models to the present. However, very few examples of this type of model framework remain.

2.16 Model Calibration

Calibration is a procedure used to develop estimates of the parameters of model equations which best fit the general model structure to a specific observed data set. The model parameters then represent an estimate of the relationship between input variables and model outcomes; that is, a representation of underlying behaviour. Model calibration is typically the most resource intensive part of a modelling exercise.

Note that successful model calibration only indicates that the structure of the model includes the important variables that influence behaviour (or correlate well with

variables that influence behaviour) under the conditions prevailing for the calibration data set.

2.17 Regression Analysis

The functions of trip making are calculated by regression analysis which can be either linear or non-linear; the latter is more difficult to handle but allows a greater flexibility. The application of regression analysis is only valid (i) if the circumstances remain stable, (ii) if the variables have similar normal distributions and form a coherent correlation ellipse, and (iii) if the 'independent' variables are statistically independent (Lohse & Lätzsch 1997).

The regression analysis is only applied to trip production or trip attractions, but not to the area as a whole (Lohse & Lätzsch 1997). It can only explain variations in travel behaviour between zones.

Regression analysis is the most widely used statistical technique for investigating and modeling the relationship between variables. The basic idea of regression analysis is to use data on a quantitative independent variable to predict or explain variation in a quantitative dependent variable. In most applications, as with this research, there is more than one independent variable that helps explain the dependent variable

2.18 Trip Generation Model: Aggregate Approach

Multiple regressions is the most common methodology used in the aggregate approach for trip generation, and it attempts to discover a (typically) linear relationship between the number of trips produced in a zone and the socioeconomic characteristics of the

residents in the zone. A hypothetical regression form for a zonal trip generation model is (adopted from Ortuzar and Willumsen, 1990):

$$Y_i = \theta_o + \theta_1 X_{1i} + \theta_2 X_{2i} + \ldots . + \theta_k X_{ki} + E_i$$

Where

θ_k : Coefficients to be estimated

X_{ki} : variable k for zone i

E_i : error term

This approach facilitates estimation of total trip production or attraction based on some common variables among residents of each zone. However, some zones that have extreme values of the common variables must be excluded from the analysis process, or they would increase the variation of the estimates. For example, an industrialized zone which does not have any residential variables will not predict any home – based trips, and the inclusion of such a zone will arbitrarily influence the overall trip estimation accuracy.

Ortuzar and Willumsen (1990) suggest the use of trip rates instead of zonal total trip so the effect of the zone size can be eliminated (the error will not depend on the size of the zone). Therefore, the original zonal total trip estimation can be changed into a zonal trip mean estimation, and the calibration process is implemented with zonal average characteristics attribute instead of residents in each zone. The original equation becomes:

Using trip rates instead of the number of trips:

$$y_i = \theta_o + \theta_1 x_{1i} + \theta_2 x_{2i} + \ldots . + \theta_k x_{ki} + e_i$$

Where the y_i , x_{ki} , e_i are normalized by H_I

H_i : *the number of households in zone i*

$y_i = {}^{y_i}/_{H_i}$, *trips per household*

$x_{ki} = {}^{x_{ki}}/_{H_i}$, *attributes o household*

$e_i = {}^{e_i}/_{H_i}$, *error term*

This approach suggests the development of a disaggregate trip generation model in which trips are directly estimated more precisely at the household or person level. The variation over households (or persons) in terms of socioeconomic or demographic characteristics is then used to reflect different intensities of travel demand.

2.19 Trip Generation Model: Disaggregate Approach

A disaggregate approach for a trip generation model is used to estimate trip frequencies at the household or person level instead of total trips by zones. The example models described are similar in that both use a multiple classification methodology and the trip frequencies are estimated at household level. Although regression analysis can be used to estimate trip rates for households or persons using socioeconomic or demographic variables, category analysis appears to be more widely applied and is less restrictive in terms of its assumptions.

A household level cross – classification approach is described first. The 1995 trip generation model used by the Los Angeles County Metropolitan Transportation Authority (MTA) is the trip generation model developed and utilized by Southern California Association of Governments (SCAG). The trip production rates are cross-tabulated by two housing types and three vehicle ownership levels, and the trip attraction end uses a regression equation of zonal population and employment to balance the trip attractions.

The Portland METRO model, which is also categorized as disaggregate household level generation approach, uses a multiple classification analysis to derive home-based trip rates (Lawton et al, 1994). However, the difference between METRO and MTA models is that the METRO model employs a regression approach to estimate the zonal total non-home-based trips, which makes the METRO model a mixture of aggregate and disaggregate approaches.

This disaggregate household level trip production estimation process requires some so called "re-generation" models to determine the portions of households with different numbers of workers, auto ownership and children (Lawton *et al*. , 1994). Kalenoja (1999), studied the spatial differences in the trip generations and travel behaviour for the Tampere region of Helsinki, Finland and concluded that "individual qualities for example age, gender, household size, car ownership and income remain the most significant explainers for trip generation and travel behaviour. However, spatial factors and accessibility measures can offer valuable complementary information of the trip generation and trip chaining for transport models".

Osula (1991) developed a trip generation models for land uses in Nigeria. The model was used to estimate the present number of daily trips generated from Trans – Ekulu Housing Estate for work trips and, non-work trips and auto trips in the three zones of his study area.

Smith and McFarlene, (1978) evaluated an internal volume forecasting (IVF) model and Khisty and Zahrani, (2000) produced a replacement for conventional urban travel

demand models in small and medium sized areas. The model used interzonal trip probability factors as a measurement of the magnitude of the trip between zones. The trip probability factors were calculated as a function of production and attraction variables of zones, interzonal travel time impedance and related exponential factors. Instead of conducting surveys and home interviews for estimating productions and attractions for each zone, the model used production and attraction variables such as population, employment and rating for commercial and recreational use of each zone. The model was applied to calibrate a travel demand model for the county of Fond du Lac in Central Wisconsin (1978) and the city of spokane (Khisty et al, 2000) a linear regression model was derived for the relationship between link volumes and trip probability factors from observed traffic counts, as given below:

$$V = 181 + 0.031 \times P_i P_j \qquad (2.2)$$

Where, P_i is the population of zone i and P_j is the population of zone j.

The model was used to forecast traffic volumes for future years using trip probability factors, which were calculated from forecasted changes in production and attraction variables. The model used linear regression method for calibration.

Other non-linear models have been proposed by Hogberg, 1976. Also, the model did not consider intrazonal travel time impedance. The inclusion of origin-zone accessibility was recommended by the study. The major advantage of this approach was the elimination of conducting extensive surveys for collecting socioeconomic data for estimating zonal productions and attractions, and using ground traffic counts for calibration.

The study concluded that routinely collected traffic counts in a base year can be used to estimate traffic volumes in a horizon year with reasonable accuracy. Khisty and Al-Zahrani, 2000 further suggested the model to be used in cities of less developed and developing countries because of its simplicity and low cost.

McPherson, Heimbach and Goode, 1983, set forth a computerized method for updating data bases for travel demand forecasting. The study focused on development of a computerized system capable of monitoring and recording changes in urban activities that could be used to update transportation planning data bases periodically. Two major analytical techniques were used to develop the model, as follows:

i. *Computerized Geocoding:* This technique provided the mechanism for linking together a variety of diverse data sources that may have only one common link (e.g., street addresses). The process provided a convenient framework for continuous monitoring and updating transportation planning data.
ii. *Income Model Construction Using Harmonic Analysis:* Harmonic analysis was used to express income-estimating model as a Fourier series.

The study expressed the necessity of developing an income model because of confidentiality requirements by law prohibited state and federal revenue agencies from releasing income tax return files to other agencies. Conclusions of this study were supported by the findings from the system implemented and tested in Greensboro, North Carolina.

Rutherford and Pennock, 1985 discussed the features and application of the software 'Quick Response Microcomputer System' (QRMS) developed by Comsis Corporation, to incorporate the techniques of travel demand forecasting presented in NCHRP 187, 1978. The software could be used for rapid calculation of zonal productions and attractions. Some of the limitations of the original software were:

- Maximum number of TAZs was limited to 50,

- Maximum number of assignment links was limited to 800, and
- Maximum travel time allowed was 40 minutes,

The socioeconomic data, such as number of dwelling units, income, auto-ownership, retail and non-retail employment were input to the trip generation procedure. The travel times were calculated from zone type's coordinates of zone centroids, map scale and a circuity factor to convert airline distance to over-the-road distance. Rutherford and Pennock believed that the mode choice model of the software was not a particularly useful tool, as it required inputs which might be less than logical.

Goulias and Kitamura, 1992 presented a model for forecasting travel demand based on microanalytic simulation and dynamic analysis of travel characteristics. The system consisted of two components: a microsimulator of household socioeconomic and demographic data and a dynamic model system of household auto ownership and mobility. Each component comprised interlinked models formulated at the household level. The interactions and causal paths that underlie life cycle evolution of individual households were replicated in the socioeconomic and demographic microsimulator. Simulation units evolved from year to year, experiencing changes in urban activities. Employment, income, education level, household size was among the variables that were generated in the microsimulation. The parameters of the model for generating the socioeconomic and demographic data were estimated from observed data from Dutch National Mobility Panel Data. The model system provided a flexible tool for forecasting travel demand; however, the process was complex and required a large amount of data for estimating the parameter which triggered the simulation process.

Neumann, Halkias and Elrazaz (1983) proposed a method for estimating trip rates from traffic counts on the links of a network. The socioeconomic variables causally related to trip production, such as zonal population and dwelling units, were distributed by gravity model and assigned to the links of the network. Regression analysis was carried out to build a linear regression model for estimating traffic counts on the links from assigned socioeconomic variables on each link, using observed link counts as the dependent variable and socioeconomic variables as independent variables. Trip rates by purpose were calculated from the estimated proportion of trips by purpose of the study area.

2.20 Applications of Travel Models

Travel forecasting models help assess the effectiveness of each alternative in reducing traffic congestion. Since traffic congestion of serious nature usually occurs on major highways – primarily arterials – the travel forecasting procedure usually pays more attention to these highways. Typically local roads and some minor collectors are not included in the network used for traffic assignment. For the design of a new highway and/or the widening of an existing highway, the estimated traffic volume for the facility is main item of interest that highway design engineers expect from travel forecasting models. For other related information such as the proportion of design hourly volume with respect to average daily traffic, directional split, and truck percentage, highway design engineers use other sources of information. However, this situation changed when more and more urban areas had to assess the air quality impact of highway networks as more detailed and accurate information related to travel was needed for air quality analysis.

2.21 Theoretical framework and concepts

Quick-Response techniques have been successfully applied to perform trip generation in small urban community travel models (Michael, 2002). Among several of these methods is the Internal Volume Forecasting Model (IVF) as presented below;

In the IVF model interzonal trip – probability factors perform the trip generation and trip distribution functions of the UTD models. The interzonal trip – probability factors are;

$$f_{ijk} = \frac{P_i A_j}{t_{ij}^n} \quad \text{.....} \qquad 2.3$$

In which f_{ijk} = interzonal trip – probability factor between zones *i* and *j* for the kth set of P_i and A_j characteristics; P_i = characteristics of internal zone *j* related to trip attraction; t_{ij} = interzonal travel impedence such as travel time; and n = exponent related to the importance of travel impedence.

A relationship between the trip probability factors and link volumes on a transportation network was determined by assigning the matrices of trip probability factors to the network and then estimating a regression equation of the form:

$$V = a_o + a_1F_1 + a_2F_2 + \ldots + a_kF_k + \ldots a_mF_m \quad \text{.....} \qquad 2.4$$

In which V = observed internal volume on a link; a_k = kth computed regression coefficient; and F_k = link loading of the trip probability factors based on the kth set of p_i and A_j characteristics.

Because the trip probability factors were only computed between zones within the study area, the volume used as the dependent variable must be the internal traffic volume on the link. To obtain internal traffic volumes from observed counts, a trip table of external

trips is built and assigned to the network. The resulting volumes are then subtracted from total counts to leave internal volumes.

2.21.1 Calibrating the Model

This follows a three – step process of calibrating the trip generation, trip distribution and traffic assignment models. The explanatory power of the regression equation, R^2, is the primary means of selecting among alternatives at each step.

2.21.2 Trip Probability Factors

Because traffic on a link is composed of trips for different purposes, it will be hypothesized that traffic on a link might best be explained by an equation using trip probability factors related to each trip purpose. The following five pairs of production and attraction variables will be tested: (1) P_i and E_j (2) P_i and R_j (3) P_i and C_j (4) P_i andP_j, in which P_i is the population in zone i, E_j is the employment in zone j, R_j is the recreational rating of zone j, C_j is the commercial use rating of zone j, The travel time exponent, n will be assumed initially to be 2. The P_iE_j factor will be assumed to correspond to work trips, the P_i R_j factor to recreational trips, the P_i C_j factor to shopping trips, and the P_iP_j factor to all trips. A rating of each activity on a scale of **one (1) to four (4)** for each zone will be used to measure these variables.

The resulting five trips – probability factor matrices will then be assigned to the identified Zaria network separately so that each link had associated with it a dependent variable, V, the internal traffic volume on the link, and four independent variables representing the links loadings of the different trip probability factors. The correlation matrix is then used to check the correlation of the independent variables with one

another and to select the independent variable that is appropriate for use in the regression equation.

2.21.3 Travel time exponent

Two exponents of 1.5 and 2.5 were tested on either side of the exponent of 2.0 which had been used in the initial analysis. The effects of varying the exponent of travel time are to alter the distribution of trips by trip length. A larger exponent results in trip interchanges with shorter trip length becoming relatively more important. Conversely, a smaller exponent causes more trips to be estimated between interchanges having a greater separation.

2.21.4 Assignment stage

In this stage, a base year equation for estimating the simulated link volumes is derived. This equation can be used to estimate a future year traffic volume is derived. The root mean square (*rms*) error shall be used to measure the error of the estimated link volumes calculated using.

$$rms = \frac{\sum_{i=1}^{nj}(V_{oi} - V_{si})^2}{n_j - 1} \quad \ldots\ldots \quad 2.5$$

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This section examines the types of data required for the study, sources of data, method of data gathering and the data analysis method.

The methodology for this study is organized as follow:

a) Types of data required

b) Sources of data

c) Data collection strategy and methodology

d) Data analysis

3.2 Types of Data Required

In line with the objectives outlined, data required are in respect of the following information. Traffic zones of the study area as well as the population, employment, recreational and commercial use in each of the identified traffic zones and finally, the travel times.

3.3 Sources of Data

Data was obtained from field survey. Visual site observation, traffic census and photographs were used with secondary data from published statistics.

Series of pilot surveys was first initiated. The time of day and day of week representative of actual situations was taken cognizance of, as well as the logistics needed for effective administration.

Relevant and secondary data was extracted from published statistics from various levels of Government commissioned studies and projects reports. Such Government Agencies that are relevant to the study include: Statistical year book of Kaduna State, Kaduna State Ministry of Public Transportation, Federal Office of Statistics, Zaria and Sabon Gari Local Governments, Zaria Zonal office of National Population Commission, Kaduna State Ministry of Commerce and Tourism, Kaduna Agricultural Development Programme (KADP) and others.

All these organizations are located within the city and some of' their officials were also interviewed separately and in groups. Perusal of publications in journals, project reports from academic institutions, periodicals and journals also revealed additional information used in this study.

3.4 Data Analysis

Descriptive inferences and statistical techniques such as cross-tabulation and tables were used to analyze the data collected during the field survey. Regression analysis and the Internal Volume Forecasting technique were also used for the model calibration.

3.5 Data Collection Strategy and Methodology

The data collection strategy and methodology is summarized in figure 3.1, which shows the research design.

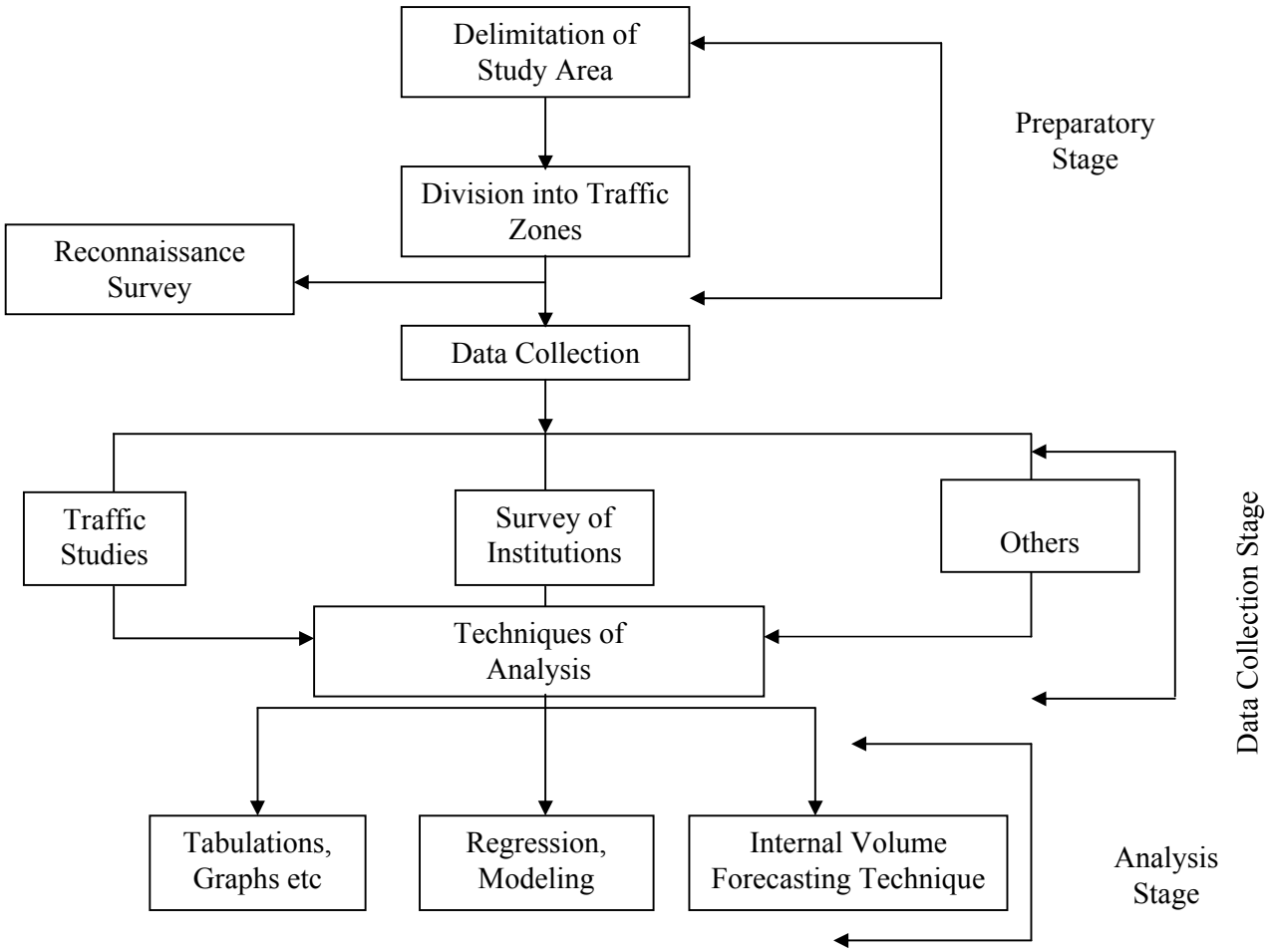


Fig.3.1 Research Design

3.6 Model Development of the Internal Volume Forecasting Technique

In the IVF model interzonal trip – probability factors perform the trip generation and trip distribution functions of the UTD models. The interzonal trip – probability factors are;

$$f_{ijk} = \frac{P_i A_j}{t_{ij}^n} \qquad 3.1$$

In which f_{ijk} = interzonal trip – probability factor between zones *i* and *j* for the kth set of P_i and A_j characteristics; P_i = characteristics of internal zone *j* related to trip attraction; t_{ij} = interzonal travel impedance such as travel time; and n = exponent related to the importance of travel impedance.

A relationship between the trip probability factors and link volumes on a transportation network was determined by assigning the matrices of trip probability factors to the network and then estimating a regression equation of the form:

$$V = a_o + a_1F_1 + a_2F_2 + \ldots . + a_kF_k + \ldots . a_mF_m \qquad 3.2$$

In which V = observed internal volume on a link; a_k = kth computed regression coefficient; and F_k = link loading of the trip probability factors based on the kth set of p_i and A_j characteristics.

3.6.1 Calibrating the model

This follows a three – step process of calibrating the trip generation, trip distribution and traffic assignment models. The explanatory power of the regression equation, R^2, is the primary means of selecting among alternatives at each step.

3.6.2 Trip Probability Factors

Because traffic on a link is composed of trips for different purposes, it will be hypothesized that traffic on a link might best be explained by an equation using trip probability factors related to each trip purpose. The following five pairs of production and attraction variables will be tested: (1) P_i and E_j (2) P_i and R_j (3) P_i and C_j (4) P_i andP_j, in which P_i is the population in zone i, E_j is the employment in zone j, R_j is the recreational rating of zone j, C_j is the commercial use rating of zone j, The travel time exponent, n will be assumed initially to be 2. The P_iE_j factor will be assumed to correspond to work trips, the P_i R_j factor to recreational trips, the P_i C_j factor to shopping trips, and the P_iP_j factor to all trips. A rating of each activity on a scale of **one (1) to four (4)** for each zone will be used to measure these variables.

The resulting five trip – probability factor matrices will then be assigned to the identified Zaria network separately so that each link had associated with it a dependent variable, V, the internal traffic volume on the link, and four independent variables representing the links loadings of the different trip probability factors. The correlation matrix is then used to check the correlation of the independent variables with one another and to select the independent variable that is appropriate for use in the regression equation.

3.6.3 Travel time exponent

Two exponents of 1.5 and 2.5 were tested on either side of the exponent of 2.0 which had been used in the initial analysis. The effects of varying the exponent of travel time are to alter the distribution of trips by trip length. A larger exponent results in trip interchanges with shorter trip length becoming relatively more important. Conversely, a smaller exponent causes more trips to be estimated between interchanges having a greater separation.

3.6.4 Assignment stage

In this stage, a base year equation for estimating the simulated link volumes is derived. This equation can be used to estimate a future year traffic volume is derived. The root mean square (*rms*) error shall be used to measure the error of the estimated link volumes calculated using.

$$rms = \frac{\sum_{i=1}^{n_j}(V_{oi} - V_{si})^2}{n_j - 1} \quad \text{..... 2.5}$$

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter was geared towards presentation, interpreting and analysis of the data collected.

This following section analyzed the location and distribution of the main land use types; residential, commercial and employment as it affect trip generation and distribution in four zones in Zaria.

4.2 Employment Status

It is estimated that nearly 70% of Zaria's inhabitants 18 years and above are engaged in some form of income-producing activity. Of these labour force participants, 85% are engaged on a regular full-time basis, and 15% on a casual or part-time basis. The total labour force in Zaria is estimated to be about 115,000. This category includes all non students who are not engaged primarily in house hold duties (Odumosu, 2008).

4.3 Inter-Regional Traffic by Road

Zaria township area experiences a heavy flow of through traffic because of its location as a total point between Kaduna, Jos, Kano Sokoto and Katsina.

4.4 Road Network of Study Area

The study area map from which the traffic analysis zones are derived is presented below on figure 4.1.

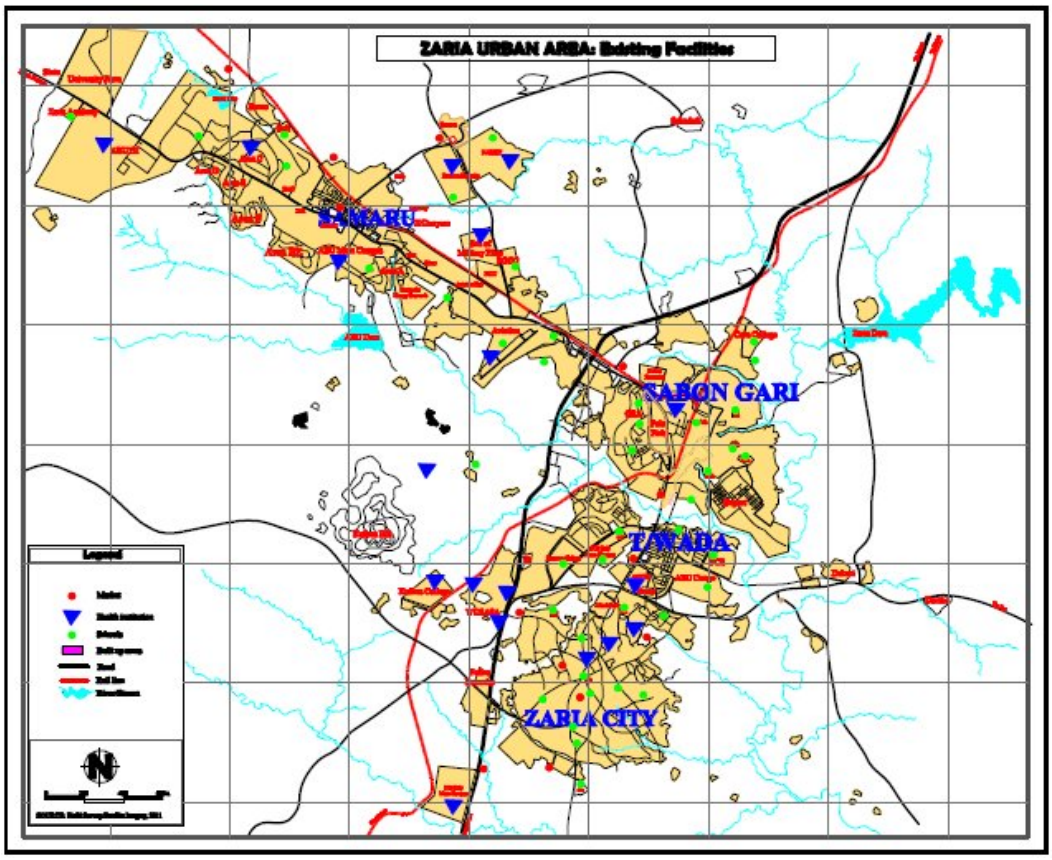


Fig. 4.1 Map of Zaria Urban Area Showing Study Zones (Source: Field survey and satellite imagery, 2011)

4.5 Traffic Analysis Zone

In order to select the traffic analysis zones, the zonal boundaries were determined by the transport network, which acts as watersheds of traffic generation enclosing the main traffic bus stops and corridor movements with principal roads within the metropolis bisecting the zones. These are: Zaria City, Tudun Wada, Sabon Gari and Samaru

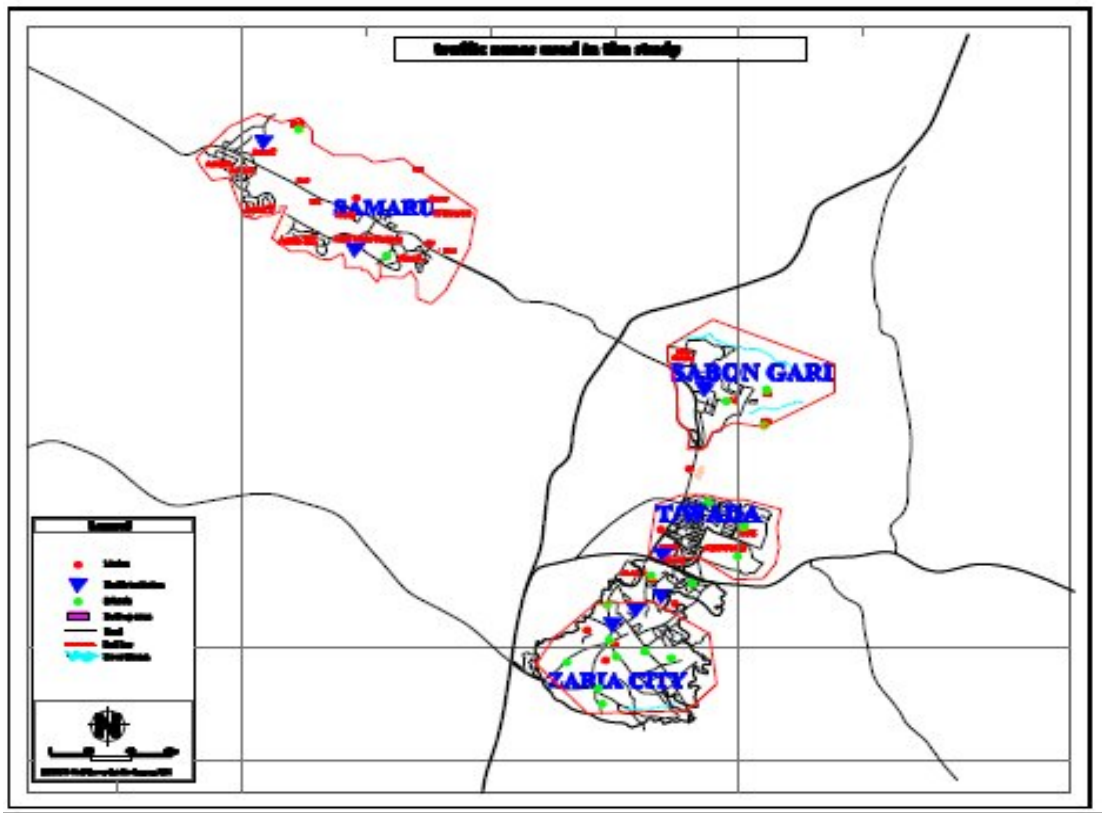


Fig. 4.2 Traffic Analysis Zones of the Study Area

Table 4.1: Population of Study Area

*The projected population is based on 3.5% National Average Growth Rate

S/N	ZONES	POPULATION 1991	*PROJECTED POPULATION 2011
1	ZARIA CITY	24,979	49,702
2	TUDUN WADA	46,921	93,363
3	SABON GARI	35,183	70,004
4	SAMARU TOWN	8,831	17,571

Sources: National Population Commission, 1991

Table 4.2: Employment Status of Study Area

S/N	ZONES	Employment status (No)
1	ZARIA CITY	34,791
2	TUDUN WADA	65,354
3	SABON GARI	49,003
4	SAMARU TOWN	12,299.7

Sources: Kaduna state statistical year book, 2011

Table 4.3: Hectare of Land Used For Recreation and Leisure of Study Area

S/N	ZONES	Hectares of land
1	ZARIA CITY	30.345
2	TUDUN WADA	27.37
3	SABON GARI	74.97
4	SAMARU TOWN	208.845

Sources: Zaria Master Plan, 2011

Table 4.4: Hectare of Land Used For Commercial Activities in the Study Area

S/N	ZONES	Hectares of land
1	ZARIA CITY	6.699
2	TUDUN WADA	18.821
3	SABON GARI	140.39
4	SAMARU TOWN	95.7

Sources: Zaria Master Plan, 2011

Table 4.5: Travel Time in Zaria

Run Direction / Number	Travel Time (Min) (T_e/T_w)	No. of Vehicles Travelling in Opposite Direction (N_e)	No of Vehicles That Overtook Test Vehicle (O_e)	No of Vehicles Overtaken by Test Vehicle (P_e)
Eastward				
1	18.45	567	10	4
2	19.46	548	14	8
3	19.23	598	15	7
4	19.49	579	8	5
5	19.23	549	9	9
6	20.22	589	23	8
7	19.34	547	19	7
8	19.43	500	3	6
Average	19.36	559.63	12.63	6.75
Westward				
1	19.21	534	20	12
2	18.45	540	23	2
3	19.23	555	10	18
4	19.45	564	9	19
5	19.34	578	13	20
6	19.34	563	12	17
7	19.45	508	10	15
8	18.45	538	11	10
Average	19.12	547.50	13.50	14.13

Sources: Field survey, 2011

$$V_w = \frac{(559.63 + 13.50 - 14.13)60}{19.36 + 19.12} = 872\ vph$$

$$V_e = \frac{(547.50 + 12.63 - 6.75)60}{19.36 + 19.12} = 864\ vph$$

$$Average\ volume = \frac{872 + 864}{2} = 868\ vph$$

$$T_e = 19.36 - \frac{(12.63 - 6.75)60}{864} = 18.9\ mins$$

$$T_W = 19.12 - \frac{(19.12 - 14.13)\,60}{872} = 19.2\ mins$$

$$Average\ travel\ time = \frac{18.9 + 19.2}{2} = 19.00\ mins$$

where;

Moving away from zaria city is East bound and coming to zaria is westbound

T_e = The time it takes to travel east in Zaria

T_w= The time it takes to travel west in Zaria

N_e= The number of vehicles travelling west in the opposite lane while I am travelling east

O_w= The number of vehicles that overtook my test car while travelling in the westbound

P_w The number of vehicles that my car passes while travelling in the westbound direction

Table 4.6: Travel Time from Zaria City to Tudun Wada

Run Direction / Number	Travel Time (Min) (T_e/T_w)	No. of Vehicles Travelling in Opposite Direction (N_e)	No of Vehicles That Overtook Test Vehicle (O_e)	No of Vehicles Overtaken by Test Vehicle (P_e)
Eastward				
1	12.34	483	10	6
2	15.44	499	10	9
3	12.19	489	5	8
4	16.23	481	7	5
5	12.14	480	8	7
6	12.00	478	10	9
7	12.22	499	10	8
8	14.22	490	7	7
Average	13.35	487.38	8.38	7.38
Westward				
1	16.11	469	10	5
2	13.22	473	10	4
3	12.17	486	8	3
4	10.45	492	10	7
5	10.23	466	5	2
6	13.45	487	6	8
7	14.11	497	9	6
8	14.27	499	10	6
Average	13.00	483.63	8.50	5.13

Sources: Field survey, 2011

$$V_e = \frac{(483.63 + 8.38 - 7.38)\,60}{13.35 + 13.00} = 1104\ vph$$

$$V_w = \frac{(487.38 + 8.50 - 5.13)\,60}{13.35 + 13.00} = 1118\ vph$$

Average link Volume = (1104+1118)/2 = 1111vph

$$T_e = 13.35 - \frac{(8.38 - 7.38)60}{1104} = 13.3\ mins$$

$$T_w = 13.00 - \frac{(8.5 - 5.13)60}{1110} = 12.8\ mins$$

$$Average\ travel\ time = \frac{13.3 + 12.8}{2} = 13.05\ mins$$

Table 4.7: Travel Time from Tudun Wada to Sabon Gari

Run Direction / Number	Travel Time (Min) (T_e/T_w)	No. of Vehicles Travelling in Opposite Direction (N_e)	No of Vehicles That Overtook Test Vehicle (O_e)	No of Vehicles Overtaken by Test Vehicle (P_e)
Eastward				
1	14.23	700	7	4
2	15.24	693	8	6
3	16.34	645	5	7
4	14.12	660	8	8
5	15.22	690	4	9
6	17.11	685	5	5
7	12.00	679	8	7
8	12.22	680	9	8
Average	14.56	679.00	6.75	6.75
Westward				
1	14.11	670	4	6
2	16.26	690	5	7
3	18.50	670	10	4
4	14.23	700	6	5
5	16.23	685	7	8
6	14.22	690	5	9
7	15.11	669	8	8
8	16.00	671	9	7
Average	15.58	680.63	6.75	6.75

Sources: Field survey, 2011

$$V_e - \frac{(680.63 + 6.75 - 6.75)60}{14.56 + 15.58} - 1355\ vph$$

$$V_w = \frac{(679.00 + 6.75 - 6.75)\ 60}{14.56 + 15.58} = 1352\ vph$$

$$Average\ link\ volume = \frac{1355 + 1352}{2} = 1354\ vph$$

$$T_e = 14.56 - \frac{(6.75 - 6.75)60}{1355} = 14.6\ mins$$

$$T_W = 15.58 - \frac{(6.75 - 6.75)\ 60}{1352} = 15.6\ mins$$

$$Average\ travel\ time = \frac{14.6 + 15.6}{2} = 15.1\ mins$$

Table 4.8: Travel Time in Sabongari

Run Direction / Number	Travel Time (Min) (T_e/T_w)	No. of Vehicles Travelling in Opposite Direction (N_e)	No of Vehicles That Overtook Test Vehicle (O_e)	No of Vehicles Overtaken by Test Vehicle (P_e)
Eastward				
1	23.46	900	4	2
2	24.56	899	5	4
3	25.34	867	8	5
4	26.12	845	9	8
5	25.34	867	4	5
6	26.46	845	7	6
7	27.22	830	8	12
8	25.00	800	9	8
Average	25.44	856.63	6.75	6.25
Westward				
1	23.22	845	10	1
2	24.36	896	20	1
3	29.45	888	29	0
4	18.10	856	17	0
5	19.35	834	18	0
6	24.32	875	19	0
7	26.34	859	9	0
8	23.22	899	10	1
Average	23.55	869.00	16.50	0.38

Sources: Field survey, 2011

$$V_e = \frac{(869.00 + 6.75 - 6.250)\,60}{25.44 + 23.55} = 1066 vph$$

$$V_W = \frac{(856.63 + 16.5 - 0.38)\,60}{25.44 + 23.55} = 1070\ vph$$

$$T_e = 25.44 - \frac{(6.75 - 6.25)\,60}{1066} = 25.4\ mins$$

$$T_W = 23.55 - \frac{(16.50 - 0.38)60}{1070} = 22.6\ mins$$

$$Average\ travel\ time = \frac{1070 + 25.4}{2} = 24.00\ mins$$

Table 4.9: Travel Time from Sabon Gari to Samaru

Run Direction / Number	Travel Time (Min) (T_e/T_w)	No. of Vehicles Travelling in Opposite Direction (N_e)	No of Vehicles That Overtook Test Vehicle (O_e)	No of Vehicles Overtaken by Test Vehicle (P_e)
Eastward				
1	32.33	1679	20	4
2	30.11	1870	10	8
3	39.23	1680	15	6
4	31.15	1638	19	7
5	29.35	1789	10	5
6	39.33	1699	12	8
7	33.33	1730	20	9
8	30.32	1660	25	5
Average	33.14	1718.13	16.38	6.50
Westward				
1	33.23	1700	10	6
2	30.23	1643	11	7
3	37.23	1760	15	8
4	35.23	1723	9	5
5	38.25	1689	10	8
6	34.00	1610	14	9
7	36.10	1790	15	9
8	30.00	1734	17	2
Average	34.28	1706.13	12.63	6.75

Sources: Field survey, 2011

$$V_e - \frac{(1706.13 + 16.38 - 6.5)60}{33.14 + 34.28} - 1527\ vph$$

$$V_w = \frac{(1718.13 + 12.63 - 6.75)\,60}{33.14 + 34.28} = 1535\ vph$$

$$Average\ link\ volume = \frac{1527 + 1535}{2} = 1531\ vph$$

$$T_e = 33.14 - \frac{(16.38 - 6.5)\,60}{1527} = 32.8\ mins$$

$$T_W = 34.28 - \frac{(12.63 - 6.75)\,60}{1535} = 34.1\ mins$$

$$Average\ travel\ time = \frac{32.8 + 34.1}{2} = 33.45\ mins$$

Table 4.10: Travel Time in Samaru

Run Direction / Number	Travel Time (Min) (T_e/T_w)	No. of Vehicles Travelling in Opposite Direction (N_e)	No of Vehicles That Overtook Test Vehicle (O_e)	No of Vehicles Overtaken by Test Vehicle (P_e)
Eastward				
1	28.80	880	20	5
2	29.58	891	10	7
3	30.25	843	11	8
4	27.56	856	12	10
5	33.08	812	10	11
6	34.45	800	12	15
7	29.49	890	14	12
8	27.22	877	10	11
Average	30.05	856.13	12.38	9.88
Westward				
1	32.34	810	10	5
2	30.20	834	12	6
3	23.00	823	16	8
4	30.45	844	12	9
5	33.33	823	10	5
6	35.25	881	11	7
7	30.22	840	13	8
8	29.55	860	14	9
Average	30.54	839.38	12.25	7.13

Sources: Field survey, 2011

$$V_w = \frac{(856.13 + 12.25 - 7.13)60}{30.05 + 30.54} = 853\ vph$$

$$V_e - \frac{(839.38 + 12.38 - 9.88)60}{30.05 + 30.54} - 834\ vph$$

$$Average\ volume = \frac{853 + 834}{2} = 844\ vph$$

$$T_e = 30.05 - \frac{(12.38 - 9.88)60}{834} = 29.9\ mins$$

$$T_W = 30.54 - \frac{(12.25 - 7.13)\ 60}{853} = 30.2\ mins$$

$$Average\ travel\ time = \frac{29.9 + 30.2}{2} = 30.5\ mins$$

Table 4.11: Travel Time in Tudun Wada

Run Direction / Number	Travel Time (Min) (T_e/T_w)	No. of Vehicles Travelling in Opposite Direction (N_e)	No of Vehicles That Overtook Test Vehicle (O_e)	No of Vehicles Overtaken by Test Vehicle (P_e)
Eastward				
1	18.50	905	10	6
2	19.56	901	15	8
3	21.33	911	13	7
4	20.56	901	20	9
5	19.34	900	10	12
6	18.45	905	13	3
7	23.24	905	19	8
8	20.12	901	12	4
Average	20.14	903.63	14.00	7.13
Westward				
1	19.36	904	17	6
2	20.00	896	13	7
3	20.24	834	16	3
4	21.15	844	19	9
5	18.46	911	15	8
6	19.34	875	11	6
7	18.45	897	17	7
8	19.55	858	12	8
Average	19.57	877.38	15.00	6.75

Sources: Field survey, 2011

$$V_w = \frac{(903.63 + 15.00 - 6.75)60}{20.14 + 19.57} = 1378\ vph$$

$$V_e - \frac{(877.38 + 14.00 - 7.13)60}{20.14 + 19.57} - 1337\ vph$$

$$Average\ volume = \frac{1378 + 1337}{2} = 1357\ vph$$

$$T_e = 20.14 - \frac{(14.00 - 7.13)60}{1337} = 19.8\ mins$$

$$T_W = 19.57 - \frac{(15.00 - 6.75)\,60}{1378} = 19.2\ mins$$

$$Average\ travel\ time = \frac{19.8 + 19.2}{2} = 19.5\ mins$$

Table 4.12: Trip Table Representing Travel Time in (min) in all The Zones

t_i / t_j	1	2	3	4	TOTAL
1	19	13.05	28.15	67.55	127.75
2	13.05	19.5	15.1	48.55	96.2
3	28.15	15.1	24	33.45	100.7
4	67.55	48.55	33.45	30.05	179.6
TOTAL	127.75	96.2	100.7	179.6	504.25

Sources: Field survey, 2011

Table 4.13: Rating of Employment Status in Study Zones

S/N	ZONES	Employment status (No)	Rating (A_j)
1	ZARIA CITY	34,791	1
2	TUDUN WADA	65,354	3
3	SABON GARI	49,003	2
4	SAMARU TOWN	12,299.70	4

Sources: Field survey, 2011

Table 4.14: Rating of Population in Study Zones

S/N	ZONES	POPULATION 1991	PROJECTED POPULATION 2011	Rating (P_i)
1	ZARIA CITY	24,979	49,702	2
2	TUDUN WADA	46,921	93,363	4
3	SABON GARI	35,183	70,004	3
4	SAMARU TOWN	8,831	17,571	1

Sources: Field survey, 2011

Trip probability factors for the study zones were derived using the formula below. The trip production used is the population rating for my study zone while the trip attracted is the employment rating. The interzonal travel time used here is the travel time and is derived from table 4.9. The travel time exponent used in the first stage of this analysis is 2 as is the practice in estimating such models.

$$f_{ijk} = \frac{P_i A_j}{t_{ij}^n}$$

TABLE 4.15 Trip Probability Factors for Population and Employment (n=2.0)

Production (f_i) / Attraction (f_j)	1	2	3	4
1	-	0.035231426	0.005047812	0.001753232
2	0.023487618	-	0.03508618	0.006787995
3	0.003785859	0.039471953	-	0.010724795
4	0.000219	0.001273	0.001787	-

Sources: Field survey, 2011

Table 4.16: Rating of hectare of land used for recreation and leisure of study area

S/N	ZONES	Hectare of land	Rating
1	ZARIA CITY	30.345	2
2	TUDUN WADA	27.37	1
3	SABON GARI	74.97	3
4	SAMARU TOWN	208.845	4

Sources: Zaria Master Plan, 2000

Table 4.17: Trip Probability Factors For Population and Recreation (n=2.0)

Production (f_i) / Attraction (f_j)	1	2	3	4
1	-	0.011743809	0.007571718	0.001753232
2	0.046975235	-	0.052629271	0.006787995
3	0.007571718	0.013157318	-	0.010724795
4	0.000438	0.000424	0.002681	-

Sources: Field survey, 2011

Table 4.18: Hectare of Land Used For Commercial Activities in the Study Area

S/N	ZONES	Hectare of land	Rating
1	ZARIA CITY	6.699	1
2	TUDUN WADA	18.821	2
3	SABON GARI	140.39	4
4	SAMARU TOWN	95.7	3

Sources: Zaria Master Plan, 2000

Table 4.19: Trip Probability Factors For Population and Commercial Rating (n=2.0)

Production (f_i) / Attraction (f_j)	1	2	3	4
1	-	0.023487618	0.010095624	0.001314924
2	0.023487618	-	0.070172361	0.005090996
3	0.003785859	0.026314635	-	0.008043596
4	0.000219154	0.000848499	0.003574932	-

Sources: Zaria Master Plan, 2000

TABLE 4.20: Trip Probability Factors For Population and Population (n=2.0)

(f_i) / (f_j)	1	2	3	4
1	-	0.046975235	0.007571718	0.000438308
2	0.046975235	-	0.052629271	0.001696999
3	0.007571718	0.052629271	-	0.002681199
4	0.000438308	0.001696999	0.002681199	-

Sources: field survey, 2011

Table 4.21: Link Volumes of the Study Zones

Link	Volume (vph)
Sabon gari - Samaru	1531
Tudun Wada- Sabon gari	1354
Zaria City –Tudun Wada	1111

Sources: Field Survey, 2011

The resulting trip probability factors were assigned to the Zaria Network separately so that each link had associated with it a dependent variable V, the internal traffic volume on the link (Table 4.30), and four independent variables representing the link loadings of the different trip probability factors. This is shown below.

$$V = a_o + a_1 F_{pE} + a_2 F_{pR} + a_3 F_{pC} + a_4 F_{pJ}$$

So that for Sabon gari to samaru link we have the following

$$1531 = a_o + a_1 \times 0.010725 + a_2 \times 0.010725 + a_3 \times 0.008044 + a_4 \times 0.002681$$

For tudun wada to sabon gari we have

$$1354 = a_o + a_1 \times 0.035082 + a_2 \times 0.052629 + a_3 \times 0.070172 + a_4 \times 0.052629$$

For Zaria to tudun wada we have

$$1111 = a_o + a_1 \times 0.035231 + a_2 \times 0.011744 + a_3 \times 0.023488 + a_4 \times 0.046975$$

Running the regression analysis, only population and recreation as well as population and employment were found to be the real predictors in the model.

Yielding

$$V = 1654.370 + 5880.149 \times F_{PR} - 17383.166 \times F_{PE}$$

For which $R^2 = 1$ and se = 0

The negative sign in the F_{PE} is illogical

Thus running the regression again with only population and recreation yields

$$V = 1316.740 + 0.009 \times F_{PR}$$

With R^2 adjusted = 0.99 and se= 297.4917

Now that an adequate combination of production and attraction has been selected (population and recreation), the next step is to select a suitable trip exponent (n). The trip exponent used in the first instance was 2. The purpose is to alter the distribution of tips by trip length. The exponent of 1.5 was tested next.

Table 4.22: Trip Probability Factors For Population and Employment (n=1.5)

Production (f_i) / Attraction (f_j)	1	2	3	4
1	-	0.127272766	0.026781962	0.014409601
2	0.084848511	-	0.136340401	0.047297276
3	0.020086472	0.153382951	-	0.062027898
4	0.001801	0.008868	0.010338	-

Sources: Field Survey, 2011

Table 4.23: Trip Probability Factors For Population and Recreation (n=1.5)

Production (f_i) / Attraction (f_j)	1	2	3	4
1	-	0.042424255	0.040172943	0.014409601
2	0.169697021	-	0.204510601	0.047297276
3	0.040172943	0.05112765	-	0.062027898
4	0.003602	0.002956	0.015507	-

Sources: Field Survey, 2011

Table 4.24: Trip Probability Factors For Population and Commercial Rating (n=1.5)

Production (f_i) / Attraction (f_j)	1	2	3	4
1	-	0.084848511	0.053563924	0.010807201
2	0.084848511	-	0.272680801	0.035472957
3	0.020086472	0.102255301	-	0.046520923
4	0.0018012	0.00591216	0.020675966	-

Sources: Field Survey, 2011

Table 4.25: Trip Probability Factors For Population and Population Rating (n=1.5)

Production (f_i) / Attraction (f_j)	1	2	3	4
1	-	0.169697021	0.040172943	0.0036024
2	0.169697021	-	0.204510601	0.011824319
3	0.040172943	0.204510601	-	0.015506974
4	0.0036024	0.011824319	0.015506974	-

Sources: Field Survey, 2011

So that for Sabon Gari to Samaru link we have the following

$$1531 = a_o + a_1 \times 0.062028 + a_2 \times 0.062028 + a_3 \times 0.046521 + a_4 \times 0.01550?$$

For Tudun Wada to Sabon Gari we have

$$1354 = a_o + a_1 \times 0.136340 + a_2 \times 0.204511 + a_3 \times 0.272681 + a_4 \times 0.204511$$

For Zaria to Tudun Wada we have

$$1111 = a_0 + a_1 \times 0.127273 + a_2 \times 0.042424 + a_3 \times 0.084849 + a_4 \times 0.169697$$

Yielding

$$V = 1782.790 + 0.767 \times F_{PR} - 1.132 \times F_{PE}$$

For which $R^2 = 1$ and se = 0

The negative sign in the F_{PE} is illogical

Therefore running the regression for population and recreation only produced

$$V = 1282.870 + 0.20 \times F_{PR}$$

With R^2 adjusted = 0.92 and se = 292.1709

Testing the exponent of 2.5 the following results were obtained.

Table 4.26: Trip Probability Factors For Population and Employment (n=2.5)

Production (f_i) / Attraction (f_j)	1	2	3	4
1	-	0.009752702	0.000951402	0.000213318
2	0.006501802	-	0.009029166	0.000974197
3	0.000713551	0.010157811	-	0.001854347
4	0.0000267	0.0001827	0.0003091	-

Sources: Field Survey, 2011

Table 4.27: Trip Probability Factors For Population and Recreation (n=2.5)

Production (f_i) / Attraction (f_j)	1	2	3	4
1	-	0.003250901	0.001427103	0.000213318
2	0.013003603	-	0.013543748	0.000974197
3	0.001427103	0.003385937	-	0.001854347
4	0.0000533	0.0000609	0.000464	-

Sources: Field Survey, 2011

Table 4.28: Trip Probability Factors For Population and Commercial Rating (n=2.5)

Production (f_i) / Attraction (f_j)	1	2	3	4
1	-	0.006501802	0.001902804	0.000159988
2	0.006501802	-	0.018058331	0.000730648
3	0.000713551	0.006771874	-	0.00139076
4	0.0000267	0.000121775	0.000618116	-

Sources: Field Survey, 2011

Table 4.29: Trip Probability Factors For Population and Population Rating (n=2.5)

Production (f_i) / Attraction (f_j)	1	2	3	4
1	-	0.013003603	0.001427103	0.0000533
2	0.0130036	-	0.0135437	0.0002435
3	0.0014271	0.0135437	-	0.0004636
4	0.0000533	0.0002435	0.0004636	-

Sources: Field Survey, 2011

So that for Samaru to Sabon Gari link we have the following

$$1531 = a_o + a_{1\times} 0.001854 + a_2 \times 0.001854 + a_3 \times 0.001391 + a_4 \times 0.000464$$

For Sabon Gari to Tudun Wada we have

$$1354 = a_o + a_1 \times 0.009029 + a_2 \times 0.013544 + a_3 \times 0.018058 + a_4 \times 0.013544$$

For Tudun Wada to Zaria we have

$$1111 = a_o + a_1 \times 0.009753 + a_2 \times 0.003251 + a_3 \times 0.006502 + a_4 \times 0.013004$$

Yielding

$$V = 1599.631 + 0.594 \times F_{PR} - 1.173 \times F_{PE}$$

For which $R^2 = 1$ and se = 0

The negative sign in the F_{PR} is illogical

Running the regression again with only population and recreation yields

$$V = 1335.932 - 0.19 \times F_{PR}$$

With R^2 adjusted = 0.99 and se= 298.1499

The negative sign in the equation above implies that the exponent of 2.5 did not predict the IVF model in zaria.

Table 4.30: Summary of Travel Time Exponent

Tested exponent	R^2	Standard error
2.0	99	297.4917
1.5	92	292.1709
2.5	99	298.1499

Since the exponent 2.5 produced a negative coefficient for population and recreation, the exponent was not used. The travel time exponent with the explanatory power n= 2.0 was selected because it produced the highest percentage of R^2. Coincidentally, the selection of exponent 2.0 agreed with U.S. Department of Transportation's 2000 work on the gravity model which found that an exponent of 2.0 worked best when distributing intercity trips.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The results from the model derived in this thesis demonstrated that it is sufficient to conduct a travel demand study of Zaria and other similar areas with only demographic and socio-economic data of the zones. Using the demographic data of the four zones along with the commercial, recreational and employment data, a model $V = 1316.740 + 0.009 \times F_{PR}$ was derived. This model represents the generated and distributed trips in zones studied in Zaria as a function of the trip probability factors of the zones using population and recreation probability factors only. The calibrations of the model consist of three steps. First, was a selection of an appropriate combination of production and attraction with the R^2 value of the regression being the major factor in the selection among the alternatives. Subsequently a combination of population and recreation of the study zones produced the best result leading to a link volume with population and recreation probability factor of $V = 1316.740 + 0.009 \times F_{PR}$ with R^2 adjusted = 0.99 and se= 297.4917. Secondly, a rigorous effort was made to select the best travel time exponent. This process led to a test of exponents 2.5 and 1.5 alongside the earlier exponent of 2.0 earlier used. The exponents of 2.0, 1.5 and 2.5 produced an explanatory power of the regression equation as 99%, 92% and 99%. As a result, the travel exponent with the highest explanatory power 99% which was generated by the 2.0 exponent was selected. The 2.5 exponent also produced a high explanatory power but was not selected because of the negative coefficient of population and recreation it produced. The analysis produced a final model of trip generation and distribution relating population and recreation of zones as;

$V = 1316.740 + 0.009 \times F_{PR}$. The travel time exponent found in this study conform to the study conducted by the U. S. Department of Transportation in the year 2000.

A Microsoft excel sheet trip probability factors.xls has been created in the course of this work to ease the difficulty of determining the trip probability factors.

5.2 Conclusion

The primary objective of the IVF model was to reduce the costs of estimating highway link volumes by eliminating the need for expensive home interview surveys. The two steps of the model calibration of the Internal Volume forecasting model have been demonstrated. The two steps are sufficient for the traditional trip generation and distribution steps of travel demand forecasting.

5.3 Recommendations

The Internal Volume Forecasting Technique can be used to generate and distribute link volumes in Zaria and other similar cities in Nigeria using the equation $V = 1316.740 + 0.009 \times F_{PR}$.

Also it is recommended that

- ✓ More zones should be adopted for future refinement of the model.
- ✓ Further research work should be conducted on the full implementation of the IVF model in Zaria and other similar cities in Nigeria. Since, large population is an impediment to the IVF model; the research should focus on disaggregating larger cities with a view to applying the IVF model in heavily populated cities.

Further, the research should figure out ways to bring together disaggregate cities in the IVF model.

- ✓ More land uses should be incorporated in any future refinement of this model
- ✓ Government should enact policies that will ease the sourcing of data for research purposes in Nigeria.

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APPENDIX I

Regression Analysis Result

All Land Use (Travel Time Exponent = 2)

Output Created		02 Sep 11 13:10:42
Comments		
Input	**Data**	C:\usman thesis all land uses.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	3
Missing Value Handling	**Definition of Missing**	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT v /METHOD=ENTER fpc fpe fpp fpr .
Resources	**Memory Required**	1892 bytes
	Additional Memory Required for Residual Plots	0 bytes
	Elapsed Time	0:00:00.00

Variables Entered/Removed(b)

Model	Variables Entered	Variables Removed	Method
1	FPR, FPE(a)	.	Enter
a Tolerance = .000 limits reached.			
b Dependent Variable: V			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000(a)	1.000	1.000	.
a Predictors: (Constant), FPR, FPE				

ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	88926.000	2	44463.000	.	.(a)
	Residual	9.873E-12	0	.		
	Total	88926.000	2			

a Predictors: (Constant), FPR, FPE

b Dependent Variable: V

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1654.370	.000		.	.
	FPE	-17383.166	.000	-1.163	.	.
	FPR	5880.149	.000	.667	.	.

a Dependent Variable: V

Excluded Variables[(b)]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	FPC	.(a)	.	.	.	.000
	FPP	.(a)	.	.	.	.000

a Predictors in the Model: (Constant), FPR, FPE

b Dependent Variable: V

APPENDIX II

Regression Analysis Result

Population and Recreation (Travel Time Exponent = 2)

Output Created		02 Sep 11 13:27:07
Comments		
Input	**Data**	C:\usman thesis all land uses.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	3
Missing Value Handling	**Definition of Missing**	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT v /METHOD=ENTER fpr .
Resources	**Memory Required**	1188 bytes
	Additional Memory Required for Residual Plots	0 bytes
	Elapsed Time	0:00:00.00

Variables Entered/Removed(b)

Model	Variables Entered	Variables Removed	Method
1	FPR(a)	.	Enter
a All requested variables entered.			
b Dependent Variable: V			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.069(a)	.005	-.990	297.491674
a Predictors: (Constant), FPR				

ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	424.704	1	424.704	.005	.956(a)
	Residual	88501.296	1	88501.296		
	Total	88926.000	2			

a Predictors: (Constant), FPR

b Dependent Variable: V

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1316.740	279.332		4.714	.133
	FPR	609.604	8799.928	.069	.069	.956

a Dependent Variable: V

APPENDIX III

Regression Analysis Result

All Land Use (Travel Time Exponent = 1.5)

Output Created		02 Sep 11 21:51:30
Comments		
Input	**Data**	C:\usman thesis all land uses.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	3
Missing Value Handling	**Definition of Missing**	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT v /METHOD=ENTER fpc fpe fpp fpr .
Resources	**Memory Required**	1892 bytes
	Additional Memory Required for Residual Plots	0 bytes
	Elapsed Time	0:00:00.70

Variables Entered/Removed(b)

Model	Variables Entered	Variables Removed	Method
1	FPR, FPE(a)	.	Enter
a Tolerance = .000 limits reached.			
b Dependent Variable: V			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000(a)	1.000	1.000	.
a Predictors: (Constant), FPR, FPE				

ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	88926.000	2	44463.000	.	.(a)
	Residual	1.975E-11	0	.		
	Total	88926.000	2			

a Predictors: (Constant), FPR, FPE

b Dependent Variable: V

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1782.790	.000		.	.
	FPE	-5887.853	.000	-1.132	.	.
	FPR	1828.556	.000	.767	.	.

a Dependent Variable: V

Excluded Variables(b)

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	FPC	.(a)	.	.	.	.000
	FPP	.(a)	.	.	.	.000

a Predictors in the Model: (Constant), FPR, FPE

b Dependent Variable: V

APPENDIX IV

Regression Analysis Result

Population and Recreation (Travel Time Exponent = 1.5)

Output Created		02 Sep 11 22:02:26
Comments		
Input	**Data**	C:\usman thesis all land uses.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	3
Missing Value Handling	**Definition of Missing**	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT v /METHOD=ENTER fpr .
Resources	**Memory Required**	1188 bytes
	Additional Memory Required for Residual Plots	0 bytes
	Elapsed Time	0:00:00.95

Variables Entered/Removed(b)

Model	Variables Entered	Variables Removed	Method
1	FPR(a)	.	Enter
a All requested variables entered.			
b Dependent Variable: V			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.200(a)	.040	-.920	292.170851
a Predictors: (Constant), FPR				

ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3562.194	1	3562.194	.042	.872(a)
	Residual	85363.806	1	85363.806		
	Total	88926.000	2			

a Predictors: (Constant), FPR

b Dependent Variable: V

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1282.870	293.766		4.367	.143
	FPR	477.051	2335.302	.200	.204	.872

a Dependent Variable: V

APPENDIX V

Regression Analysis Result

All Land Use (Travel Time Exponent = 2.5)

Output Created		02 Sep 11 22:37:02
Comments		
Input	**Data**	C:\usman thesis all land uses.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	3
Missing Value Handling	**Definition of Missing**	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT v /METHOD=ENTER fpc fpe fpp fpr .
Resources	**Memory Required**	1892 bytes
	Additional Memory Required for Residual Plots	0 bytes
	Elapsed Time	0:00:00.03

Variables Entered/Removed(b)

Model	Variables Entered	Variables Removed	Method
1	FPR, FPE(a)	.	Enter
a Tolerance = .000 limits reached.			
b Dependent Variable: V			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000(a)	1.000	1.000	.
a Predictors: (Constant), FPR, FPE				

ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	88926.000	2	44463.000	.	.(a)
	Residual	.000	0	.		
	Total	88926.000	2			

a Predictors: (Constant), FPR, FPE

b Dependent Variable: V

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1599.631	.000		.	.
	FPE	-56641.969	.000	-1.173	.	.
	FPR	19624.134	.000	.594	.	.

a Dependent Variable: V

Excluded Variables(b)

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	FPC	.(a)	.	.	.	.000
	FPP	.(a)	.	.	.	.000

a Predictors in the Model: (Constant), FPR, FPE

b Dependent Variable: V

APPENDIX VI

Regression Analysis Result

Population and Recreation (Travel Time Exponent = 2.5)

Output Created		02 Sep 11 22:43:49
Comments		
Input	**Data**	C:\usman thesis all land uses.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	3
Missing Value Handling	**Definition of Missing**	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT v /METHOD=ENTER fpr .
Resources	**Memory Required**	1188 bytes
	Additional Memory Required for Residual Plots	0 bytes
	Elapsed Time	0:00:00.47

Variables Entered/Removed(b)

Model	Variables Entered	Variables Removed	Method
1	FPR(a)	.	Enter
a All requested variables entered.			
b Dependent Variable: V			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.019(a)	.000	-.999	298.149949
a Predictors: (Constant), FPR				

ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	32.608	1	32.608	.000	.988(a)
	Residual	88893.392	1	88893.392		
	Total	88926.000	2			

a Predictors: (Constant), FPR

b Dependent Variable: V

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1335.932	267.900		4.987	.126
	FPR	-632.463	33022.380	-.019	-.019	.988

a Dependent Variable: V