Travel Demand Modeling of Addis Ababa East – West Light Rail Transport

A Thesis Submitted to Addis Ababa University, Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering.

Railway Engineering

By

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Addis Ababa, Ethiopia
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ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY

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D E C L A R A T I O N

I hereby declare that the thesis entitled "**Travel Demand Modeling of Addis Ababa East – West Light Rail Transport**" has been carried out by me under the supervision of Dr. Bikila Teklu, Addis Ababa Institute of Technology, Addis Ababa University, Addis Ababa during the year 2014-2016 for the partial fulfillment of the requirements for the Degree of Master of Science in Railway Engineering, Civil. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

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C E R T I F I C A T E

This is to certify that the thesis entitled "**Travel Demand Modeling of Addis Ababa East – West Light Rail Transport**" is an authentic work carried out by Assaye Melaku Gabre under my guidance and supervision. This is the actual work done by Assaye Melaku Gabre for the partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering, Railway Engineering, from Addis Ababa University, Addis Ababa.

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Abstract

In recent years Ethiopia has achieved sustainable economic development. In order to maintain healthy economy, diversified and well managed transportation system needs in place. As part of the first GTP, the Federal government has built international and national railway networks. The city of Addis Ababa has gain an opportunity to have 34km of Light Rail Transport line. In order to keep any transportation systems fully functional during its service years, appropriate transport planning and modeling needed. The first step of transport planning and modeling it is to identify the needs for transportation, usually called travel demand modeling. The main objective of this research is to determine Addis Ababa East - West Light Rail travel demand by using the conventional statically oriented and trip based approach of the four step travel demand modeling technique. This modeling principle needs data of, transportation network, city level socio-economic indicators, transportation cost, travel time cost, available means of transport, and other relevant data that dictate mobility and choice of transportation mode. In order to facilitate modeling procedures TransCAD 4.5 modeling tool was utilized. In the course of modeling, Addis Ababa Transport Master Plan study serve as a basic platform for modeling by updating its input variable with 2012 base year data. The 99 Kebels of Addis Ababa used as TAZ's, transportation network developed, regression equations of trip production and attraction with updated variables used. The balanced trip production of the four trip categories, Home Based Work, Home Based Education, Home Based Others, and Non Home Based trips distributed over TAZ's. By deducting percentage of none public transport users, total number of traffics split over the three modes of public transports; Taxi, Bus and Medium Bus; and assigned over the network. By considering LRT as the fourth means of transport in the East - West corridor, traffic modal share recalculated using generalized cost, and percentage share of the four means of transport identified. As the modeling results showed, 3.5 million people reside in Addis Ababa, total number of traffic in the study corridor is 644,400, with 25.9 percentage share 167,200 passengers use LRT per day. Of all the segments, Mexico, Coca, Torhayloch and Stadium area has the highest number LRT user. These and other findings of this research compared with design document of LRT and it is concluded that the base year of 2012 traffic by itself surpass both initial and short term expected design traffic. Therefore, it is highly recommended a quick review of LRT traffic forecast is needed in order to alleviate the current over crowded in East – West LRT line.

Key word: Travel demand, Transport modeling, TransCAD, Light Rail, GIS

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List of Abbreviations

AABoFED	Addis Ababa Bureau of Finance and Economic Development
AACG	Addis Ababa City Government
AACRA	Addis Ababa City Road Authority
BoFED	Beraue of Finance and Economic Development
CDP	City Development Master Plan
CSA	Central Statistics Agency
ERA	Ethiopian Road Authority
GDP	Gross Domestic Product
GIS	Geographic Information System
GIS-T	Geographic Information System in Transportation
GTP	Growth and Transformation Plan
LRT	Light Rail Transport
MDG	Millennium Development Goals
MoFED	Ministry of Finance and Economic Development
MoT	Ministry of Transportation
PASDEP	Plan for Accelerated and Sustained Development to End Poverty
SDPRP	Sustainable Development and Poverty Reduction Program
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CHAPTER I
INTRODUCTION

1.1 Background

Ethiopia is in dynamics of economic and social development. This is due to government laid policies and strategies. In the last twenty-four years the Federal Democratic Republic of Ethiopia had laid at last three policies of which leads the country to achieve sustainable economic growth. Sustainable Development and Poverty Reduction Program (SDPRP) implemented in the years 2002/03 − 2004/05, Plan for Accelerated and Sustained Development to End Poverty (PASDEP) implemented in the years of 2005/06 to 2009/10 and Growth and Transformation Plan I (GTP I) between the years of 2010/11 – 2014/15. SDPRP aim was poverty reduction and food security and that of PASDEP was medium term development perspective with goals set in parallel with Millennium Development Goals (MDG's) with an objectives set to achieve at its minimum that of the goals set by MDG's. During PASDEP implementation period high and sustained economic growth and significant social and human development were realized. During this same period the economy grew an average of 11 % per annum (MoFED, 2010). The performance of GTP is under investigation and it is expected that different phases of GTP's will implement the coming years till Ethiopia achieves long term goal of becoming middle income country by the year 2020/23.

The GTP emphasis on agricultural and rural development, industry, infrastructure, social and human development, good governance and democratization. Also special emphasis was given to infrastructure investments and social and human development sectors. The development of these key economic and social sectors like; agriculture, industry, mining, tourism, education and health heavily relied on transportation infrastructure. Such kind of transformative social and economic development in Ethiopia will leads to an increase need of efficient and versatile modes of transportation system in major economic city centers to deliver goods and services to and from centers of social and economic centers within the city or outside city center's geographic area. Since Addis Ababa is financial, political, economic and transportation hub of the country, transportation demand in Addis Ababa is expected to increase tremendously along with the economic development of the country and the city in the coming GTP implementation periods.

Transportation system availability and efficiency affect development patterns and it can be a boost or a barrier to economic growth of a nation. Transportation has affected economic development from the very beginning of human civilization. Economic development focused on the confluence of transport systems as transportation systems links production and consumption of good and services by bridging the gap of geographical distances. That is why early cities grew up on natural bays and ports on rivers and lakes where transportations were available.

As the concept of equilibrium is central to the supply - demand analysis of economics, the same principle is similarly applicable in transportation engineering. In economics, the plot of the supply and demand curve as a function of cost and their intersection shows the equilibrium point. In transportation engineering, the demand for travel *T* is a function of cost *C*, *T* would be produced at a market price of *C*. Since transport demand is a derived demand, and the benefit of transportation could be in non-monetary terms as well (e.g. time), the supply function takes the form of which *C* is the unit cost associated with meeting a demand *T*. Therefore, the supply function encapsulates response of the transport system to a given level of demand. In other words, supply function will answer the question what will be the level of service of the transportation system. The most common supply functions are, travel time, capacity...etc. of these functions relates the system/segment/link volume and travel time. Therefore, in order to keep transportation system in equilibrium, we need to keep up good operation and performance of the transportation system permanently throughout its life time which intern it means there is the need for continuous planning and decision making process.

In order to keep equilibrium between the demand for transportation and the supply of transportation, estimation of travel demand is important for transportation planners, traffic engineers, and policy makers, and more precisely by road and railway authorities to help plan, build, and maintain transportation infrastructures at City, Woreda (County), Regional, and National levels. In this thesis, the study area of the city of Addis Ababa; the capital city of Ethiopia; selected to determine Light Rail travel demand in East – West corridor, with the aim to develop travel demand model and compare its result (passenger volume) with that of the passenger volume calculated for construction purpose.

1.2 Statement of the Problem

Phase I of standard gauged (1.435m) and double track of East − West line of Addis Ababa Light Rail Transport (LRT) transit system is 17.410km long (with 2.63km of shared line with North – South) start from the western loop line of Tor Hailtoch hospital, and pass through Mexico Square, Mesekel Square and Megenagna until it reaches the final destination of Ayat. The East – West line has a total of 22 stations with 6 elevated, 5 common station, and 11 ground stations. The maximum and minimum station spacing are 1.26km, and 0.5km with average station spacing of 0.813km. With a single train passenger carrying capacity of around 300 people East – West line is expected to transport maximum daily passenger flow of 29,600 persons/ day in initial stage; 60,400 persons/ day in short period and 4,300 persons /day in long term with morning rush hour of 2,679 persons / hour, 5,502 persons/hour, and 7,696 persons / hours for respective periods (Schematic Design, 2012).

As the design document ‘Schematic Design (2012)’ showed clearly, Addis Ababa’s long term transportation travel demand model is not updated and utilized in the design process, rather corridor based data collected and analyzed to determine travel demand of the East – West Light Rail line. Therefore, due to the luck of application of standardized travel demand modeling approaches to determine the above mentioned number of traffics the reliability of the design document is highly questioned. Therefore, it is crucial to evaluate critically the design document based on the principles of travel demand modeling. Therefore, this study intended to fill the gap of utilization of standardized travel demand modeling for the development of transportation infrastructures like rail and road ways.

1.3 Research Objective

1.3.1 General Objectives

The general objective of this research is to determine the travel demand of East – West LRT., for the base year and for the coming 20 years’ period by using a modeling tool of TransCAD modeling software. Developing a model during this period of the project will help to revise values of input data using operational data later on and maintain up to date travel demand model. And also similarly, whenever needed infrastructure capacity improvement measures will be able to take for future years of operation based on travel demand results.

1.3.2 Specific Objectives

The specific objectives of this thesis are the basic procedural steps those help us to achieve the main objectives of the research objectives and those are;

- Study area socio economics description and identification, and updating
- Traffic analysis zones identification and descriptions,
- Transportation network development,
- Development of sub – model of trip generation,
- Development of sub – model of trip distribution
- Development of sub model of modal choice
- Development of sub – model of traffic assignment
- And development of sub – model of mode choice for LRT.

1.4 Thesis Organization

This thesis is organized in 5 chapters. In chapter 1 Introduction, we discussed back ground information about performance of Ethiopian economy and the need for travel demand modeling, problem statement, the importance of this kind of study, motives and objectives of the research were discussed. Chapter 2 presents literature review, which comprise of a brief over view of types of travel demand, Geographic Information System in transportation, TransCAD capabilities in travel demand modeling, and previous studies of travel demand modeling and train capacity. Chapter 3 presents data used in the research and methods of analysis applied. Chapter 4 discuss about finding of the research and the interpretation of results. And finally Chapter 5 presents conclusions and based on research findings and gives recommendations for future researchers.

CHAPTER II
LITRATURE REVIEW

2.1 Introduction

Movements of people, goods and information have always been fundamental components of human societies. Contemporary economic processes have been accompanied by a significant increase in mobility and higher levels of accessibility. Societies have become increasingly dependent on their transport systems to support a wide variety of activities.

Transportation systems links production and consumption of good and services by bridging the gap of geographical distances. Transportation of people and goods from one place to another takes place using transport means of road, rail, and ships/ferry. Transport means, transport services and transportation infrastructural facilities; those of moving and parked vehicles such as railway tracks, stations, roads, parking lots, bicycle lanes and bicycle parking's …etc. combined with operational time tables and control equipment (traffic lights, signs …etc.) makes the transportation system. The transportation science investigates the characteristics of the system and its various subsystems. The system characteristics of transportation refer to design, use, maintenance and operations of the system and its elements. Transportation includes its infrastructure, administration, vehicles and users and can be viewed from its various aspects, which include engineering, economics and social issues (Ortuzar & Willumsen, 2011).

Transportation system can be simplified as a single driver/vehicle with its second by second interactions with the road/rail (fixed infrastructure) and the vehicle (moving infrastructure). A system can be defined as a regional transportation infrastructure with its year by year interaction with the regional economy, the community of transportation users and owners and its control components such as administration and legislation (Myer, 2004).

As the concept of demand and supply are fundamental to economic theory, it is widely applied in the field to transport engineering too. In transportation engineering, the need for travel demand and the supply of transport infrastructures are similar notions of demand and supply of good and services in economics. However, we must be aware of the fact that the transport demand is a derived demand of economic activity; people travel not for the sake of travel but to practice in activities in different spatial locations; and not a need by itself and we cannot store it and the mobility occur over transport infrastructures having a fixed capacity (with in fixed operation period) which is the provided transportation supply. Thus, the supply function encapsulates response of the transport system to a given level of demand. In other words, supply function will answer the question what will be the level of service of the transportation system, if the estimated demand is loaded to the system. The most common supply function is the link travel time, capacity...etc. with functions which relates the link volume and travel time (Myer, 2004).

In transport planning, travel demand (as sometimes call it traffic demand) modelling is an integral component of transportation planning process and its primary aim is forecasting the ability of infrastructure to accommodate future traffic growth. Travel demand modelling or forecasting is an exercise used to determine future travel patterns under given or hypothetical conditions to plan the provision of public transport services or the need to build or expand road, rail, ropeway, bicycle lane … etc. of infrastructure networks (Lowe, 2002). A travel forecast estimates, the number of vehicles on a planned highway, bridge, a railway line, the number of passengers in rail line, an airport, or the number of ships on a seaport. It begins with the collection of data on current traffic and together with data on population, employment, trip rates, travels costs … etc., and these traffic data are used to develop traffic demand model. Feeding of future socio economic data (population, employment, etc.) into the model gives an output for future traffic demand of the transportation infrastructure, in question, e.g., each roadway segment or each railway station.

Depending of the problem type and areal extent travel demand modeling is applicable in microscopic, mesoscopic, and macroscopic level of transport planning; In addition to these classifications forecasting models can be categorized into; (a) deterministic vs. stochastic, (b) static vs. dynamic, (c) macroscopic (or aggregate) vs. microscopic (or disaggregate), and (d) analytical vs. simulation models. The combination of macro-level transport demand forecasting models, typically based on variants of the four-stage planning model, with microscopic or mesoscopic traffic simulation approaches, has been a common practice in urban area traffic management and planning in recent years (Holyoak & Stazic, 2009).

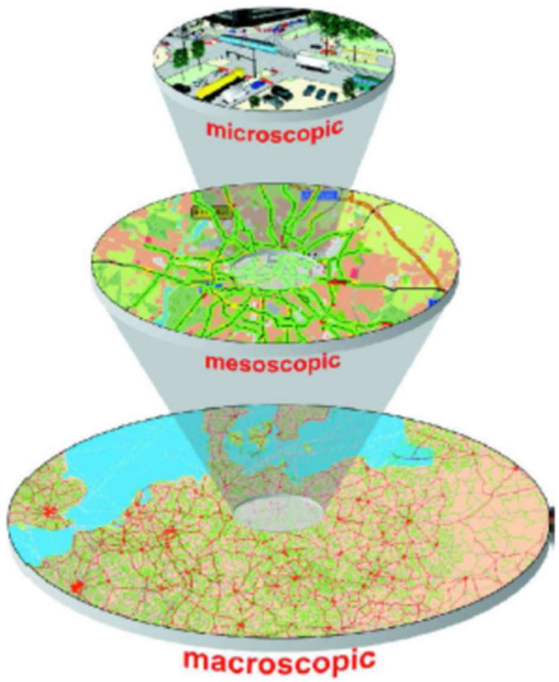


Figure. 1 Types of transport planning / transport modeling.
Source: (Jan Kašík, 2011)

Based on current and planned social, and economic structure of the city, travel demand models produce quantitative information about travel demand and transportation system performance that can be used to evaluate alternatives and make informed decisions. A travel demand model is an analysis tool that provides a systematic framework for representing how travel demand changes in response to different input assumptions. Travel demand models may take many different forms, some travel models seek to comprehensively represent multiple, inter- related aspects of regional travel behavior, such as what activities people engage in, where and when these activities occur, and how people get to these activities. Other models are more limited in scope, addressing a smaller transportation market such as airport-related travel, travel within a corridor or a particular district of a city. The type of travel model that is appropriate to use is dependent on the particular questions on researcher's hand.

2.2 Types of Travel Demand Models

There are a number of travel demand modeling techniques used in the transportation planning. Sketch planning, strategic planning, trip based and activity based modeling techniques are the very commons (Myer, 2004).

2.2.1 Sketch Planning Models

Sketch-planning models are the simplest types of travel models. These tools are designed to produce rough estimates of travel demand where order-of-magnitude information is all that is required. These models are typically simple and easy to implement, require less data, and often are implemented using common desktop software tools such as spreadsheets and geographic information systems (GISs). However, although these tools are less expensive to develop and apply, they may not provide the level of detail required to analyze certain types of policy and investments decisions, and may not provide detailed output information. As a result, sketch-planning models may be appropriate for specific targeted analyses, but cannot inform large-scale longer-term policy and investment decision making.

2.2.2 Strategic Planning Models

Strategic-planning models are often narrow in scope but incorporate significant detail in specific areas of analysis. These models often are used when there is a desire to analyze many scenarios quickly and implemented using basic software and hardware tools; these models are less expensive to develop and apply. Strategic-planning models are useful for testing a wide range of large-scale policy and investment alternatives but may be less appropriate for analyzing detailed project alternatives.

2.2.3 Trip Based Models (*Statistically-Oriented*)

Trip-based travel models have evolved over many decades ago. As their name suggests, trip-based models use the individual person trip as the fundamental unit of analysis. Trip-based models are widely used in practice to support regional, sub-regional, and project-level transportation analysis and decision making. Trip-based models are often referred to as “4-step” models because they commonly include four primary components. The first trip generation components estimate the numbers of trips produced by and attracted to each zone (these zones collectively represent the geography of the modeled area). The second trip distribution step connects where trips are produced and where they are attracted to. The third mode choice step determines the travel mode, such as automobile or transit, used for each trip, while the fourth assignment step predicts the specific network facilities or routes used for each trip.

Trip based travel demand modeling considered as the first generation of travel demand models. In the development of trip based models, which predicted traffic flows between traffic zones, i.e. aggregate models and its main satisfactory goal was the development of infrastructures. These models assumed the result (number of traffic on rail or road way) is the subsequent decisions of trip generation, trip distribution, mode choice and route choice. In this modeling technique, the derived nature of transport is understood and accepted, but not reflected in the structure. Therefore, the models have less accuracy of forecasting. This is especially true when the aim of travel demand modeling is the development of the need for transportation of a single rail or road user, which is disaggregate planning. Due to these, transport researchers came up with two new approaches to travel demand modellings; which are disaggregate trip based demand models and activity based travel demand models.

Therefore, the current usually termed trip based modeling actually is disaggregated trip based models and also known as the second generation travel demand models or discrete choice models. The model has been applied in many projects world-wide, even though it has maintained a fundamental error of the aggregate models in their structure, i.e. it analyzes each trip independently of other trips made by the same individual.

And finally it should be noted that; in trip based disaggregate demand models it is only the mode choice model that is estimated on disaggregate data (also referred to as discrete or individual based data), and other steps of modeling remain to be in aggregate level. (Jovicic, G. and C.O. Hansen, 2001).

2.2.3.1 Trip Generation

Trip generation is the first step of four step travel demand modeling and its aim is to acquire the number of trip/traffic generated (O_i) and attracted (D_j) form each TAZ within the study area. Trip generation is intended to address the question of how many trips of each type begin in each location with corresponding to the places where different activities occur according to land use and socioeconomic data. Productions and attractions are estimated for each TAZ by trip purpose, and then balanced at the regional level so that total productions and attractions are equal. The resulting productions and attractions by trip purpose and TAZ are subsequently used by the Trip Distribution model to estimate zone-to-zone travel patterns. It is expected that all the trips originate in certain transport zone, will arrive in one of the zones with in the study area.

The core point of a trip, is the motive for that intended trip. Trip motives could be home-based work trip, i.e., a trip that originates in a household's residential area, and arrives in that household's work area, or non- home based trips, recreational and social motives, shopping and other changing of activities could be the motive for trips. Among these the work and education trips are often referred as mandatory trips and the rest as discretionary trips. Therefore, generally trips classified by trip purpose, trip time of the day, and by person type.

The second way of classification is based on the time of the day when the trips are made into peak trips and off peak trips. The third way of classification is based on the type of the individual who makes the trips. This is important since the travel behavior is highly influenced by the socio economic attribute of the traveler.

Based on different trip intentions, productions and attractions consist of absolute counts, denoting the number of trips that depart from and arrive in each zone. Because of this, productions and attractions are in fact trip ends and both productions and attractions could be associated with socio economic trip factors using techniques based on growth factors and regression analysis. Growth factor modes tries to predict the number of trips produced or attracted by a house hold or zone as a linear function of explanatory variables, whereas regression analysis develop an equation with multiple variable with their coefficients obtained by doing simple and multiple regression analysis.

2.2.3.2 Trip Distribution

Trip distribution is the second step performed in four step modeling. Trip distribution uses the TAZ productions and attractions output from trip generation, and assigns each production to a destination and each attraction to an origin for all possible zones in the study area. In trip distribution, these two known sets of trip ends are connected together, without specifying the actual route and sometimes without reference to travel mode, to form a trip matrix between known origins and destinations. Trip distribution requires explanatory variables that are related to the cost (including time) of travel between zones, as well as the amount of trip-making activity in both the origin zone and the destination zone. The outputs of trip distribution are production-attraction zonal trip tables by purpose. In order to do this several formulations of trip distribution have come up in to use. In general trip distributions methods in travel demand modeling methods lies in two categories; Growth factor methods, and Synthetic methods.

Growth factor methods assume that in the future the trip-making pattern will remain substantially the same as today but that the volume of trips will increase according to the growth of the generating and attracting zones. These methods are simpler than synthetic methods and for small towns where considerable changes in land-use and external factors are not expected, they have often been considered adequate. The following are the important growth factor methods; Uniform factor method, Average factor method, Fratar method, and Furness method.

In synthetic models of trip distribution, an attempt is made to distinguish the underlying causes of movements between places, and relationships are established between trips and measures of attraction, generation and travel resistance. Synthetic models have an important advantage that they can be used not only to predict future trip distribution but also to synthesis the base-year flows. The necessity of having to survey every individual cell in the trip matrix is thus avoided and the cost of data collection is reduced. The following are the important Synthetic Methods; Gravity model, Tanner model, Intervening opportunities model and Competing opportunities model.

Due to number of criticism of Growth Factor Methods, the Synthetic Methods are dominating trip distribution sub-modeling, the major disadvantages of the growth factor methods are; trip distribution matrix has to be obtained first, and in order to do that large scale origin and destination studies with high sampling sizes are needed so as to estimate the smaller zone-to-zone movements accurately consequently the error in original data collected on zone-to-zone movements gets magnified. Another major disadvantages of growth factor methods are none of the available growth factor methods incorporates a measure of the resistance to travel and all simply assume the resistance to travel will remain constant by neglecting the effect of changes in travel pattern by the construction of new facilities and new network. Despite the above shortcomings, the growth factor methods are relatively simpler to use and understand therefore they can be used for studies of small areas and for updating stable and uniform data.

Therefore, due to those mentioned reasons, gravity model is used for trip distribution. Gravity model generated from an analogy with Newton's gravitational law. The gravity model was originally motivated by the observation that flows decrease as a function of the distance separating zones, just as the gravitational pull between two objects decreases as a function of the distance between the objects. As implemented for planning models, the Newtonian analogy has been replaced with the hypothesis that the trips between zones i and j are a function of trips originating in zone i and the relative attractiveness and/or accessibility of zone j with respect to all zones. The model was generalized by assuming that the effect of distance or 'separation' could be modelled better by a decreasing function, to be specified, of the distance or travel cost between the zones, and expressed as;

$$T_{ij} = A_i O_i B_j D_j f(c_{ij})$$

Where

O_i and D_j are total trip ends

A_i and B_j sets of balancing factors

fc_{ij} is a generalized function of the travel costs

2.2.3.3 Modal Split

In the four step demand modeling, the third step is modal split. The key aim of mode choice analysis is to distinguish the travel mode that travelers use in traveling between an origins location to a destination location. In the travel demand model, the choice is for travel between a particular origin zone and a particular destination zone. Thus, the trips that are distributed from each origin zone to each destination zone in the trip distribution model are further split into distinct travel modes. The input to the mode choice model is the total travel demand between each Origin-Destination pair, and commonly used approach to distribute the total travel demand for a given O-D pair over the available modes.

Mode choice model estimation and application could be done at either a dis-aggregate or aggregate zonal level. Aggregate models seek to predict the zonal shares of trips by mode. Aggregate models are typically estimated using mode shares by origin-destination pair and average zonal demographics. Disaggregate models are based on individual-level data obtained from surveys. At the individual level, choice is discrete: a person picks one from a set of modal alternatives. Logit models are frequently estimated on individual-level data, and then forecasts are made based upon aggregate, explanatory variables.

The mathematical formulation of traveler's choice behavior for alternative transport modes best explained by model applications of the Logistic Probability Unit, or Logit model. Logit model gain its popularity due to the fact that the formula possesses the ability to model complex traveler's behaviors of any population size with simple mathematical techniques. It should be noted that the mathematical framework of logit models is based on the theory of utility maximization (Ben-Akiva & Lerman, 1985). Logit models are generally classified into two main categories namely binary and multinomial logit models. Binary choice models are capable of modelling with two discrete choices only, i.e. the individual having only two possible alternatives for selection, whereas the multinomial logit models imply a larger set of alternatives.

$$P_i = \frac{e^{v_i}}{\sum_{j=1,n} e^{vj}}$$

Where;

P_i is the probability of using mode i

V_i utility of mode i

V_j utility of mode j

n is number of modes

The data for mode choice models usually include socio-economic characteristics of travelers; income and auto ownership; and the service characteristics of the alternative modes; travel time and cost. Good practice in model building includes identifying likely causal variables that explain mode choice and then testing the statistical significance of these variables empirically.

For modeling the share of public transit trips, it is important to consider variables such as access to transit stops and similarly other factors that could influence transit utilization.

Implementation of modal splits has two option in four step demand modeling, the first is application of modal split before trip distribution, and it is called pre distribution model or trip end model; and the second option is after trip distribution, usually termed as post distribution model or trip interchange model. Trip end model best utilized when there is significant number of transit network and users in the mode choice, whereas trip interchange model used on the reverse conditions. Because of the availability of transit network in the study area limited to the two North – South and East – West corridor, it is expected interchange model will represent to model the reality.

2.2.3.4 Trip Assignment

The process of allocating given set of trips to the specified transportation system is referred as traffic assignment. The fundamental aim of the traffic assignment process is to show the pattern of vehicular movements on the transportation system. Therefore, the major aim of traffic assignment is to estimate the volume of traffic on the links of the network, to estimates of travel costs, total distance covered by the vehicle, total system travel time, zone-to-zone travel costs(times) and to identify heavily congested links.

In order to solve these mentioned traffic network problems, different types of traffic assignment models are developed and most commons are; All-or-nothing assignment, STOCH assignment, Incremental assignment, Capacity restraint assignment, User equilibrium assignment (UE), Stochastic user equilibrium assignment (SUE), and System optimum assignment (SO), etc.

All-or-nothing assignment, method use the trips from any origin zone to any destination zone are loaded onto a single, minimum cost, path between them. This model is unrealistic as only one path between every zone to zone pair is utilized even if there is another path with the same or nearly same travel cost. Also, traffic on links is assigned without consideration of whether or not there is adequate capacity or heavy congestion; travel time is a fixed input and does not vary depending on the congestion on a link. However, this model may be reasonable in sparse and uncongested networks where there are few alternative routes and they have a large difference in travel cost. This model may also be used to identify the desired path, the path which the drivers would like to travel in the absence of congestion. In fact, this model's most important practical application is that it acts as a building block for other types of assignment techniques. It has a limitation that it ignores the fact that link travel time is a function of link volume and when there are congestion multiple paths are used to carry traffic volume.

STOCH assignment distributes trips between zones of origin – distribution pairs among multiple alternative paths that connect the pairs. The proportion of trips that is assigned to a particular path equals the choice probability for that path, which is calculated by a logit route choice model. Generally speaking, the smaller the travel time of a path, compared with the travel times of the other paths, the higher its choice probability would be. STOCH Assignment, however, does not assign trips to all the alternative paths, but only to paths containing links that are considered "reasonable." A reasonable link is one that takes the traveler farther away from the origin and/or closer to the destination. The link travel time in STOCH assignment is a fixed input and is not dependent on link volume. Consequently, the method is not an equilibrium method.

Incremental assignment is a process in which fractions of traffic volumes are assigned in steps. In each step, a fixed proportion of total demand is assigned, based on all-or-nothing assignment. After each step, link travel times are recalculated based on link volumes. When there are many increments used, the flows may resemble an equilibrium assignment; however, this method does not yield an equilibrium solution. Consequently, there will be inconsistencies between link volumes and travel times that can lead to errors in evaluation measures. Also, incremental assignment is influenced by the order in which volumes for zone to zone pairs are assigned, raising the possibility of additional bias in results.

Capacity Restraint assignment attempts to approximate an equilibrium solution by iterating between all or-nothing traffic loadings and recalculating link travel times based on a congestion function that reflects link capacity. Unfortunately, this method does not converge and can flip-flop back and forth in loadings on some links.

The User Equilibrium assignment is based on Wardrop's first principle (Wardrop, 1952) , which states that no driver can unilaterally reduce his travel costs by shifting to another route. If it is assumed that drivers have perfect knowledge about travel costs on a network and choose the best route according to Wardrop's first principle, this behavioral assumption leads to deterministic user equilibrium. This problem is equivalent to nonlinear mathematical optimization program.

The System Optimum assignment is based on Wardrop's second principle, which states that drivers cooperate with one another in order to minimize total system travel time. This assignment can be thought of as a model in which congestion is minimized when drivers are told which routes to use. Obviously, this is not a behaviorally realistic model, but it is useful to manage the traffic to minimize travel costs and therefore achieve an optimum social equilibrium.

Traffic assignment mathematical procedures bases on link performance functions, which are mathematical descriptions of the relationships between travel time and link volume. This formulation is one of the most-commonly used link performance functions in use and it update travel times iteratively, which makes it applicable except in All-or-nothing and STOCH assignments methods.

$$t = t_f \left[1 + \alpha \left(\frac{v}{c}\right)^{\beta}\right]$$

Where;

t = Congested link travel time

t_f = Link free-flow travel time

v = Link volume

c = Link capacity

α , β = Calibration parameters

Even though different formulations of traffic assignment functions have been suggested over the years, this one is very well suited for use in most traffic assignment models. With a suitable choice of parameters, this function can represent a wide variety of flow-delay relationships and is therefore used by the traffic assignment models in this work.

2.2.4 Activity Based Models (*Behaviorally-Oriented*)

The theory behind the activity based travel demand models is based on works of Hägerstrand (1970) and Chapin (1974). Hägerstrand's time-geography theory focuses on personal and social constraints when explaining our need for activity participation. Chapin's theory, on the other hand, is more concerned with opportunities and choices than the constraints. The theory postulates that the activity demand is motivated by basic human desires, such as the desires for survival, social encounters and ego gratification. Therefore, simply the fundamental premise for activity-based travel models becomes, travel demand derives from people's needs and desires to participate in activities. In some cases, these activities may occur within their homes, but in many cases these activities are located outside their homes, resulting in the need to travel. Activity-based models are based on behavioral theories about how people make decisions about activity participation in the presence of constraints, including decisions about where to participate in activities, when to participate in activities, and how to get to these activities.

Because they represent decisions and the resulting behavior more realistically, activity-based models are often better at representing how investments, policies, or other changes will affect people's travel behavior. Activity-based models are distinguished from trip-based models by a number of features. Activity-based models represent each person's activity and travel choices across the entire day, considering the types of activities the individual needs to participate in and setting the priorities for scheduling these activities (such as prioritizing work activities over shopping activities). As any individual's schedule becomes filled, the time available to participate in and travel to additional activities diminishes.

Activity-based models are more widely used now a day, and usually termed as third generation modeling technique. Activity-based models share some similarities to traditional 4-step models: activities are generated, destinations for the activities are identified, travel modes are determined, and the specific network facilities or routes used for each trip are predicted.

However, activity-based models incorporate some significant advances over 4-step trip-based models, such as the explicit representation of realistic constraints of time and space and the linkages among activities and travel, for an individual person as well as across multiple persons in a household. These linkages enable more realistically representation of the effect of travel conditions on activity and travel choices.

Activity-based models also have the ability to incorporate the influence of very detailed person-level and household-level attributes and the ability to produce detailed information across a broader set of performance metrics. These capabilities are possible because activity-based models work at a disaggregate person-level rather than a more aggregate zone-level trip-based model.(Castiglione, et al., 2015).

Currently the above two major types of travel demand forecasting approaches are widely in use; the traditional four-step travel demand model (statistically-oriented), and the activity-based model (behaviorally-oriented), which simulates individual and household activities at much more detailed levels. Activity-based approach has gain more attention on researchers and practitioners due to its advanced methodologies than the traditional four-step model (Bhat & Koppelman, 2003)..

Since the primary criticism of the traditional four-step method has been the lack of consideration and understanding of why people travel, and this criticism took shape after the adoption of activity based method.(Ben-Akiva & Lerman, 1985). Researchers such as Vovsha and Bradley (2006) and Bhat and Koppleman (2003) discuss at length the need to refine traditional models to advanced activity-based models. The major challenge with activity approaches is the necessity for plentiful amounts of travel data.

2.3 Geographic Information Systems

Geographic Information Systems (GIS) is an integrated collection of computer, software and data, used to view and manage information about geographic places, analyze spatial relationships, and model spatial processes. A GIS provides a framework for gathering and organizing spatial data and related information so that it can be displayed and analyzed. GIS have become an increasingly important means for understanding and dealing system processing problems of transportation in particular and in civil engineering in general. Typically, application of GIS technology in transportation system termed as GIS-T.

Structurally, GIS consists of a computer environment that joins graphical elements (points, lines, polygons, pixels) with associated tabular attribute descriptions. This characteristic sets GIS apart from both computer-aided design software (geographic representation) and databases (tabular descriptive data). For example, in a GIS view of road networks, the graphical elements would represent the location and shape of the roads, whereas the attributes might describe the road or street name, length, and traffic flow. The nature of the data representation has a strong influence on the analysis that can be applied.

Spatial data in GIS are most often organized into vector and raster (or surface) data structures. In the vector structure, geographic features or objects are represented by points, lines, and polygons that are precisely positioned in a continuous map space, similar to traditional hardcopy maps that identify landmarks, buildings, roads, streams, water bodies, and other features by points, lines, and shaded areas. In addition, each object in the vector structure includes topologic information that describes its spatial relation to neighboring objects, in particular its connectivity and adjacency. This explicit and unambiguous definition of and linkage between objects makes vector structures attractive and allows for the automated analysis and interpretation of spatial data in GIS environments (Meijerink, et al., 1994).

On the other hand, surface, or raster (from display technology), data structures divide space into a two-dimensional (2-D) grid of cells, where each cell contains a value representing the attribute being mapped. A raster is an x, y matrix of spatially ordered numbers. Each grid cell is referenced by a row and column number, with the boundary of the grid being registered in space to known coordinates. Raster structures arise from imaging sources such as satellite imagery and assume that the geographical space can be treated as though it were a flat Cartesian surface (Burrough, 1986). A point is represented by a single grid cell, a line by a string of connected cells, and an area by a group of adjacent cells.

The simplicity of data processing in raster structures has contributed to its popularity. But both vector and raster structures are valid representations of spatial data. The complementary characteristics of both structures have been recognized, and modern GIS can process both structures, including conversions between structures and overlays of both structures. Of the two ways of representing spatial data are the vector and raster formats; a good example for these formats are: digital photos; JPGE, .TIFF corresponding to raster format and road networks; .SHP, Coverage, represent vector format. Data structure choice between raster and vector, is generally one of the first major decisions to be made in establishing GIS based model.

Concerning to GIS-T, this decision is fairly straightforward since transportation system involved with networks and administrative boundaries; those could easily model through vector data formats. However, there are situations in which raster data format is used for transportation applications, since raster data modeling provides fast processing speed at the expense of the excellent precision provided by the vector model with its higher data needs.

2.4 TransCAD Capabilities

TransCAD is a geographic information system software package designed specifically for the planning, managing, and analyzing of transportation systems. The software provides a set of tools for travel demand modelling as well as capabilities for geographic database management, presentation graphics and transportation models. The software provides tools which can be used in all phases of travel demand model development processes; trip generation, trip distribution, mode split, and trip assignment.

TransCAD can be used for all modes of transportation, at any scale or level of detail. TransCAD provides; powerful GIS engine with special extensions for transportation, mapping, visualization, and analysis tools designed for transportation applications, application modules for routing, travel demand forecasting, public transit, logistics, site location, and territory management.

TransCAD applications has capability of building transportation information and decision support systems (DSS). TransCAD runs on readily available hardware under Microsoft Windows and embraces virtually all desktop computing standards.

TransCAD includes common GIS features such as polygon overlay, buffering, and geocoding, and most importantly it has an open system architecture that supports data sharing on local- and wide-area networks. TransCAD is the software package that fully integrates GIS with demand modeling and logistics functionality. This makes it possible for models to be much more accurate and efficient. For example, network distances and travel times are based on the actual shape of the road network and as correct representation of highway interchanges. Also, with networks, you can specify complex road attributes such as truck exclusions, delays at intersections, one-way streets, and construction zones. Further, data preparation is greatly facilitated and the database and visualization capabilities catch errors before they cause problems.

Another important feature of TransCAD is its Add-ins. Add-ins are macros or dialog boxes that are launched within TransCAD. One can create from simple to sophisticated add-ins using the GISDK to provide users access to existing software functions; to add new capabilities to the GIS engine; or to create links to one's own applications. The simplest add-ins are macros that run when they are selected by the user. The most flexible and powerful add-ins are custom toolboxes that provide users with push-button access to tools that you have programmed. These toolboxes look like the standard toolboxes used in all Windows applications.

TransCAD works using some specific GIS files which are called layers, all the layers are stored under one database (the extension is .dbf), the database and map layer (which displays the map) are contained in a Worksheet file. In addition, being a pioneer in T-GIS software package because of the above mentioned versatile advantages of TransCAD, it has been leading as number one travel demand modeling package for the last fifty years (Caliper Corporation, 2002).

2.5 Earlier Studies in Travel Demand Modeling of Addis Ababa

In the course of this literature review, three previous studies have been encountered regarding travel demand studies of Addis Ababa.

The first important study was conducted by Mekdim T. (2007), in –titled "*Logit Model of Work Trip Mode Choice for Bole Sub – City Residents*" for the partial fulfillment of Master Science degree from Addis Ababa University, Technology Faculty. The study's main focus was mode choice determination for Bole sub-city using logit model by understanding travelers' behavior of the residents. Due to objective limitations the study doesn't cover the scope of travel demand modeling for entire Addis Ababa.

The second study was conducted by Binyam B. (2007) in-titled "*Simplified Travel Demand Modeling for Developing Cities: in the case of Addis Ababa*" for the partial fulfillment of

Master Science degree from UNESCO-IHE, Delft, the Netherlands. This study focuses on the simplification of travel demand modeling process, by minimizing the required input data for the purpose of road network prioritization and planning for the city of Addis Ababa without the use of modeling software.

The third very important study was, "Urban Transport Study and Preparation of Pilot Project for Addis Ababa, 2005", which had carried out by M/S Consulting Engineers Services (India) P.L.C in association with SABA Engineering Private Limited. The client for this study was Ethiopian Road Authority, and it was sponsored by The World Bank. The main objective of the study was to develop medium to long term transportation framework/ mater plan, which include identification and prioritization of investment programs, development of transportation data base, and capacity building of Addis Ababa Road and Transport Authority. As part of transportation mater plan, medium to long term travel demand of Addis Ababa was determined. The conventional four step modeling procedure was applied and models for trip generation, distribution, mode split and traffic assignments were developed, and each sub model were calibrated with the help of intensively collected house hold, road side, and traffic surveys data, which includes Origin – Destination, and traffic counts. This study covers long ranges of detailed transport planning area, with the plan of to serve at least up to the year 2020.

CHAPTER III
MATERIALS AND METHODOLOGY

3.1 Data

There were always significant data demands for travel demand modeling studies which requires socio-economic status of transport infrastructure users, and the available transportation systems for current and forecasted service years. The primary need of such kind of data is to define traveler behavior, and the data is gathered via variety of techniques from variety of responsible organizations with in the study area. The conventional four – step travel demand modeling requires socio economic data, like general population, stratified population, employment, income, car ownership …etc. in house hold or aggregated level and spatial data those of land use, and transportation networks.

3.1.1 Study Area Description

The city of Addis Ababa is the political, and financial capital of Ethiopia, which is founded by Emperor Menelik II and his wife Empress Taytu Bitul in 1886. Addis Ababa located between 38° 39' 3" − 38° 54' 20" Longitude and 8° 50' 13" − 9° 06' 5" Latitude of geographical coordinates and its areal coverage reaches approximately 560 km^2. Addis Ababa lies at an altitude ranges from 2050 – 3000m above sea level, with an average altitude of 2500m and its run from rolling to escarpment being rolling the dominant topographic feature. Most of its mountainous and escarpments sections located in the norther part of the city; around Mount Entoto and in its surrounding areas; and the dominant rolling topography located in the central part of the city. Due to its mountainous topography and ample cloud covers Addis Ababa is reach in rain falls and river networks. All rivers of Addis Ababa flows from North to South towards Lake Aba Samuel.

The administrative structure of Addis Ababa City Administration contains ten Sub-Cities and 99 Kebeles. In the pioneer study of travel demand modeling for Addis Ababa, "Urban transport study and Preparation of Pilot Project for Addis Ababa" (2005), these Kebeles were used as a basic units of traffic analysis zones even though some Kebeles seems too large or too small to be single traffic zone in a conventional four step travel demand modeling, developing a new TAZ other than Kebeles will lead to no chance of using available socio- economic data which based mostly sub – cities or Kebeles. Therefore, for this study Kebeles are taken as TAZ of the study area, and the total number of traffic analysis zones has become 99 as shown in the figure. 2.

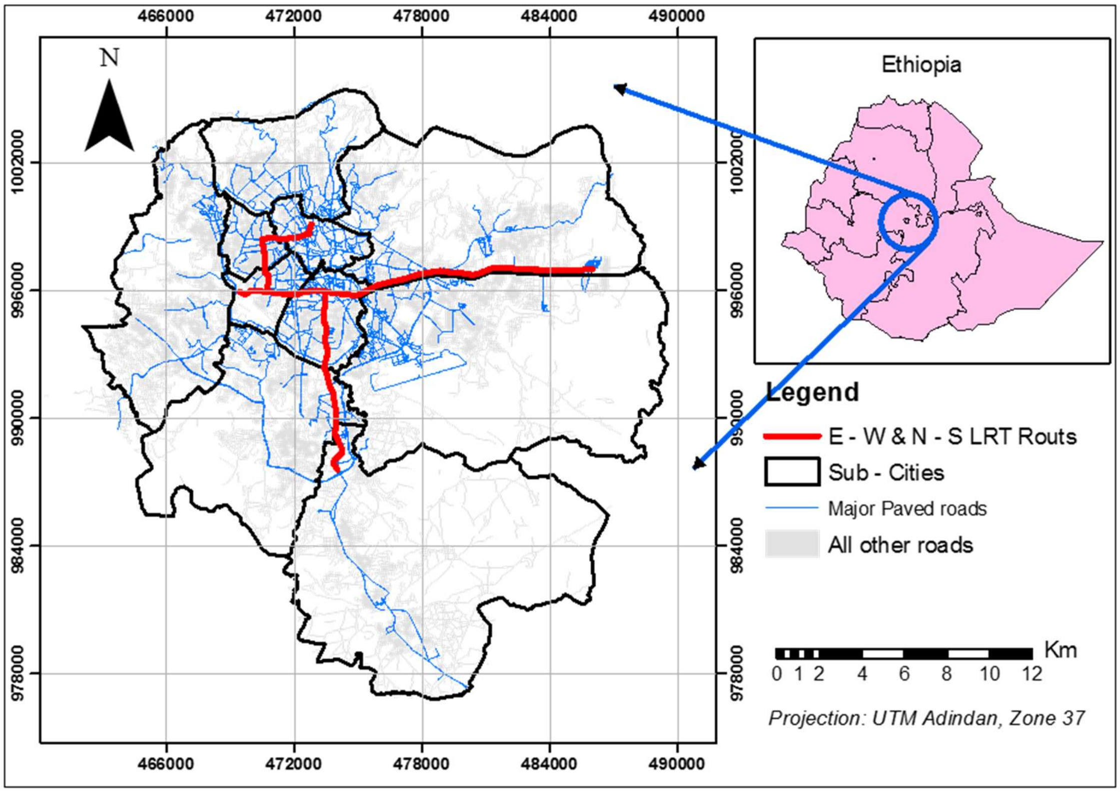


Figure. 2 Location map of the study area

3.1.2 Land Use

One of the most important input for travel demand modeling is land used data set. The importance of land use comes in to picture of travel demand modeling is from conceptual base of; travel is derived from the need to participate in daily activities. Activity centers like that of school, shopping center, social and administrative centers and others which are spatially distributed according to the land use development plan of the city under study. Land uses of different kinds needs different class of road based on the amount and type of traffic it possibly generates or attract.

Addis Ababa City Administration's City Development Master Plan (CDP) 2001 – 2010 has adopted decentralized, multi-nuclei, mixed use land use development strategies. According to CDP structural land use plan, there are nine major and twenty three minor land use structures and those are; Mixed use (existing and proposed), City centers (main and sub centers), Green Area (Forest, Green along rivers, Parks, and Agricultures), Social and Municipality Services (Stadium, Festive sites and Slaughter, Cemetery), Manufacturing and Storage (Industry, Storage, Rail Depot, Fright Terminals, Treatment Plant), Terminals (Other transport Terminals, and Airport Terminals), Reserved Area (areas not yet decided what kind of land use it best be), Restricted Area (Historic sites, water field and its surroundings, Aviation Zone) and Potential Mining and quarry sites.

It is important to note that future land use development trend of the study area in necessary for travel demand modeling. The third master plan preparation is near to be completed in the near future, but due to limited territorial boundary of Addis Ababa the total available land areal extent is not expected to change, and the principle of mixed area urban development will continue. The major land use development plan expected to be introduced in the third master plane is the re-construction and housing development which is expected to be vertical than horizontal that leads to the densification of Mixed Use land use areas specifically. As of the earlier master plans, the third master plan is expected to serve for the coming ten years' time.

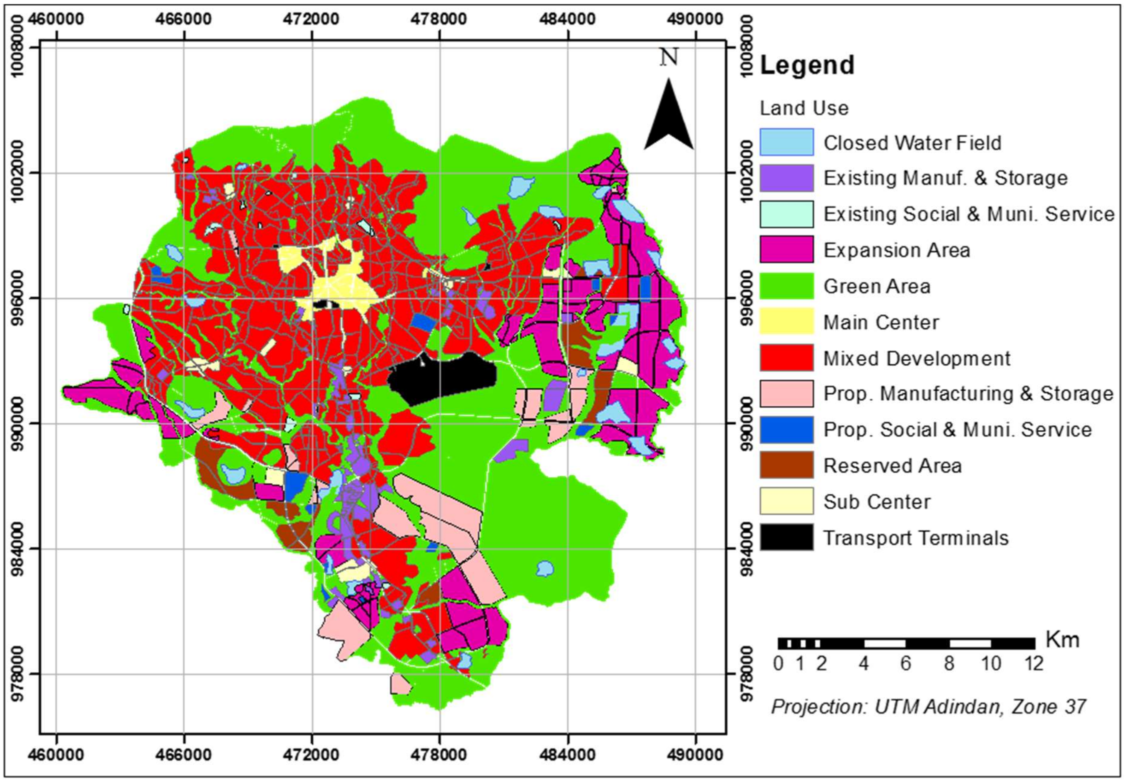


Figure. 3 Land use map of Addis Ababa according to 2002-2012 master plan

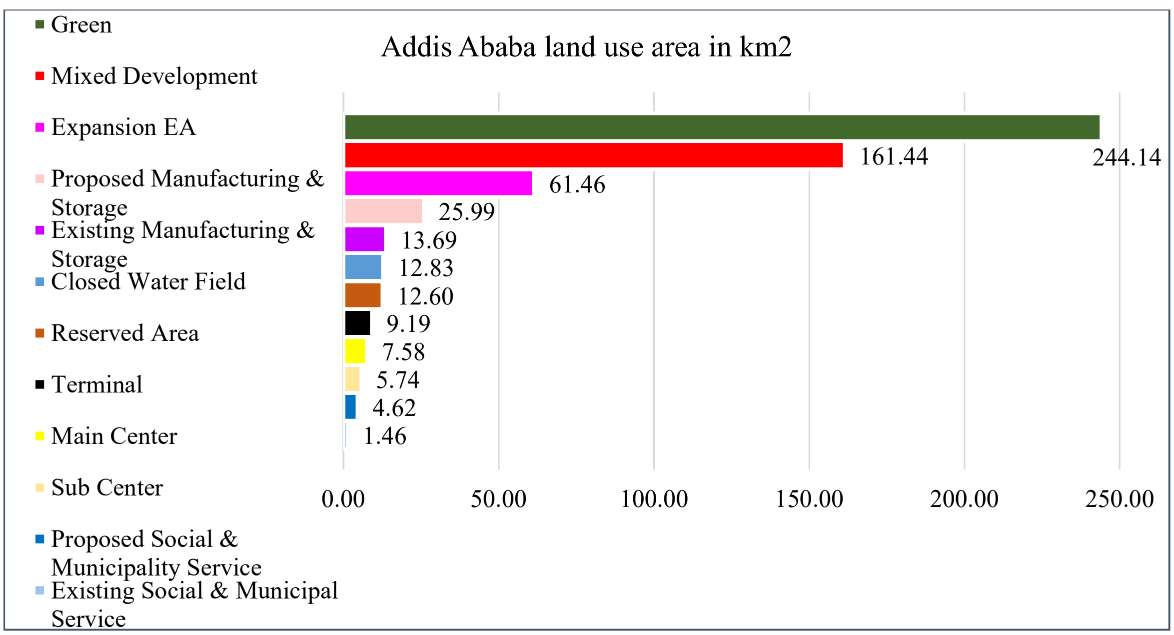


Figure. 4 Addis Ababa land use areas in Km^2 according to 2002-2012 master plan

3.1.3 Population

Population size is one of the most important input data for travel demand modeling. Stratified population and socio-economic data of the study area is needed to utilize it in the model. As it is stated in the statistical report of Addis Ababa (Addis Ababa Statistics, 2008), the general population of Addis Ababa according to 2007 housing and population survey was 2,739,551; 1,305,387 males and 1,434,164 females with an average house hole size of 4.1 persons. The recent CSA report of Employment Survey Project in Addis Ababa (Addis Ababa Employment, 2013) showed that the total population of Addis Ababa City Administration residing in conventional households in June 2013 estimated to be 3,156,057 of which 1,464,887 (46.4 percent) were males and 1,691,170 (53.6 percent) were females excluding the visitors, persons residing in collective quarters (hotel/hostels, boarding schools, prisons) as well as homeless persons, and the distribution of population by place of residence indicates that Addis Ababa City Administration constitutes 3.9 percent of the total population of Ethiopia (Addis Ababa Employment, 2013). Additionally, Kebele level population data were collected up on the request of the author from Central Statistics Agency for the year 2014 – 2017 and aggregated in sub-city level as it is shown in figure 6. Additionally, basic demographic indicators of Addis Ababa is also presented below.

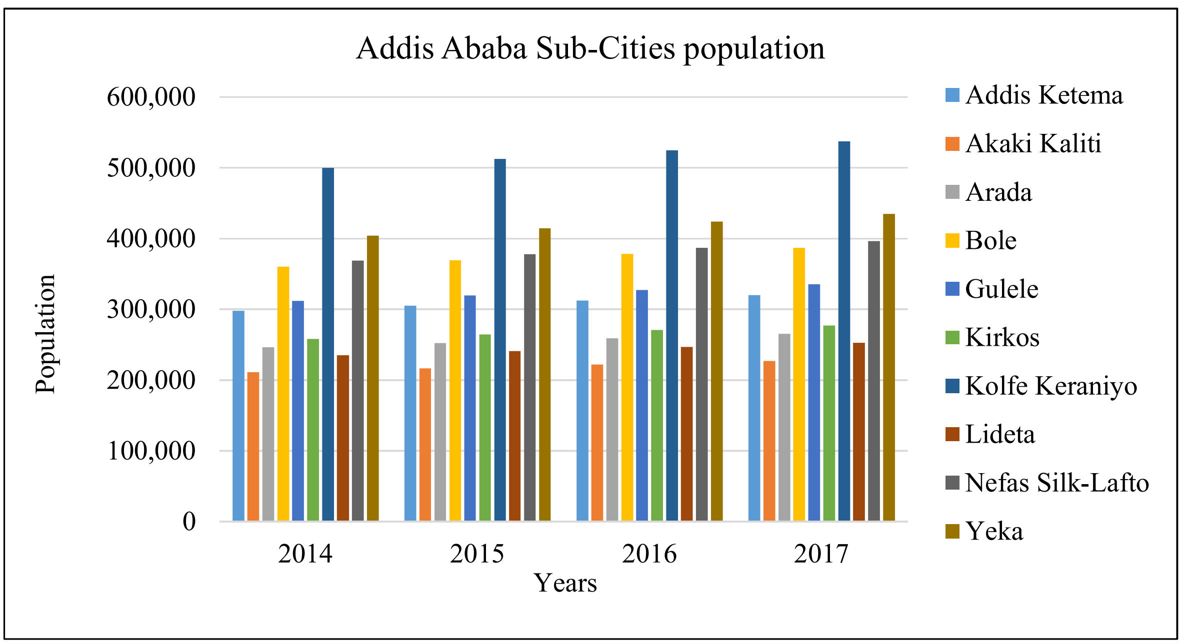


Figure. 5 Population prediction for 2014 – 2017

Table. 1 Demographic indicators of population projection of Addis Ababa 2008-2037
Source: (CSA Inter Censal Population Survey)

		2008-2012	2013-2017	2018-2022	2023-2027	2028-2032	2033-2037
Fertility	Input TFR	1.8	1.9	1.9	2	2	2.1
	Calculated TFR	1.8	1.9	1.9	2	2	2.1
	GRR 0.9	0.9	0.9	0.9	1	1	1
	NRR 0.8	0.8	0.8	0.9	0.9	0.9	1
	Mean age of child bearing	31.2	31.2	31.2	31.2	31.2	31.2
	Child-Woman ratio	0.3	0.3	0.3	0.3	0.3	0.3
Mortality	Male LE	59.8	62.3	64.8	67.1	68.9	70.4
	Female LE	66.4	68.7	71.1	73.5	75.4	77.2
	Total LE	63.3	65.7	68.2	70.5	72.4	74
	IMR	58.6	50.3	42.6	36.1	31.4	27.6
	U5MR	89	74.5	61	50.1	42.4	36.3
Vital rates	CBR per 1000	21.9	22.7	20.5	17.8	16.1	16.3
	CDR per 1000	7.5	7	6.4	5.9	5.8	6
	RNI percent	1.4	1.6	1.4	1.2	1	1
	GR percent	2.3	2.4	2.2	1.9	1.8	1.7
	Doubling time	30.6	29.1	31.6	36.1	39.8	40.2
Population	Percent 0-4	9.3	10.2	9.8	8.8	7.8	7.6
	Percent 5-14	13.7	14.4	16.9	17.6	16.7	15.1
	Percent 15-24	22.2	15.5	13	13.7	15.9	16.7
	Percent 15-19	66.1	63.6	59.5	57.4	54.5	51.8
	Percent 15-49	73.6	71.9	69.4	69.2	70.4	70.7
	Percent 65 and above	3.3	3.5	3.9	4.5	5.1	6.5
	Percent female 15-49	67.4	65.5	61.6	60	57	53.7
	Sex ratio	90.5	89.8	89.4	88.9	88.4	87.7
	Dependency ratio	0.4	0.4	0.4	0.5	0.4	0.4
	Median age	27	29	31	32	32	32
	Percent urban	100	100	100	100	100	100

3.1.4 Socio-Economic Characteristics

Ethiopia is categorized as the Least Developed Country with the per capital income of 550 USD, which shows high level of poverty, very susceptible to; external economic factors, climate change, and natural disasters. Addis Ababa too shares this same socio-economic status of the country. Despite sustainable economic growth for the last decade, poverty remains the great challenge to the city administration. With recorded double digit economic growth, the level and distribution of poverty is declining continuously. According to the first Household Income, Consumption and Expenditure (HICE) and Welfare Monitoring (WM) Surveys of the Central Statistical Agency (CSA), (HCES;WM, 1999/2000) about 44 percent of the total population of the country (45 percent in rural and 37 percent in urban) areas were found below poverty line. When the second survey conducted in 2004/2005 (HCES;WM, 2004/2005), the survey result showed that 39 percent of the total population (39.3 percent in rural and 35.1 percent in urban) were found under poverty line too. According to the resent 2010/2011 survey of (HCES;WM, 2010/2011) the percentage of population below poverty line further reduced to 29.6 percent. Similarly, percentage of population under poverty line has reduced in Addis Ababa from 36 percent to 33 percent to 28.1 percent respectively in the above mentioned years. Even with the challenges of poverty, the city administration considers transport infrastructure building as a means to serve the need of people's transportation demand and same time to enhance economic developments of Addis Ababa.

3.1.4.1 GDP and Per-capital Income

A study made by Dargay and Gately (1999) showed that there is a positive relationship between income and demand for transportation, and it is true of course for both passenger and freight transports, and the highest growth for transportation demand was shown in developing countries. Since the demand for transport service heavily influenced by multitude of socio-economic influencing factors, the economic performance of the city, usually measured by Gross Domestic Product (GDP) has significant domino effect in per capital income, car ownership, and mobility rate. Since Addis Ababa is the financial, manufacturing, and industrial hub of the country, it plays a leading role in the national economy as well. In parallel with Ethiopia's double digit economic growth, Addis Ababa's GDP raise from 15.6 Billion in 2005 to 34.34 Billion in 2009 with per capital income of 4,027 and 6,857 respectively, with an average of 8.6 percent annual economic growth (AACGBoFED, 2010). Of the contributing economic sectors, Service sector account 77 percent, Industry 22 percent and Agriculture has 1 percent of contribution.

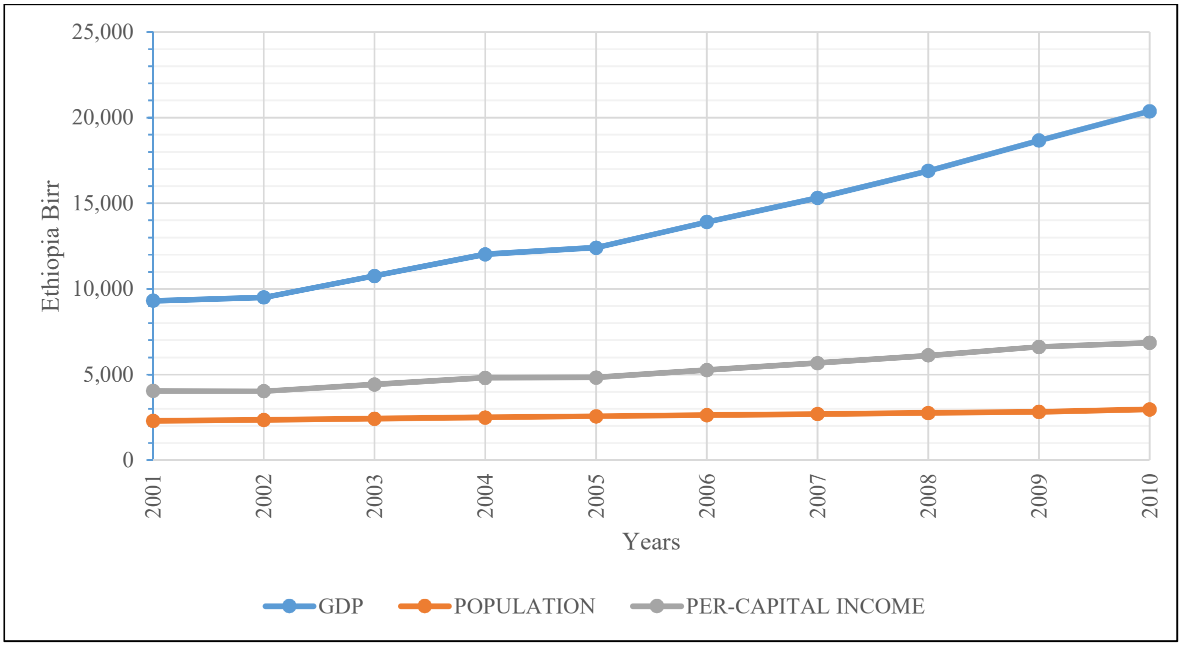


Figure. 6 Addis Ababa GDP (millions), population (thousands) and per capital income (Source: AACGBoFED)

3.1.4.2 Employment Rate

Employment / unemployment rate is an important yardsticks measure of the economy's strength. Higher unemployment rate generally indicates that an economy in recession with fewer job opportunities, in contrary, lower unemployment rate shows that an economy of in good performance and higher job opportunities, and high rate of mobility in transportation perspective also. According to the CSA Unemployment Survey (2009) out of the total population, an age group of ten years and above unemployment rate of Addis Ababa city is in 2003(32), 2004(29.1) ,2005(31.4), 2006(28.6) and 2009(27.9) in person.

Table. 2 Unemployment rate in Addis Ababa
(Source: CSA)

	Unemployment rate in %		
Year	Male	Female	Total
2003	21.2	43.7	32
2004	22.3	36.8	29.1
2005	22.8	40	31.4
2006	21.4	36.1	28.6
2009	18.4	38.3	27.9

3.1.4.3 Number of Vehicle in Addis Ababa

The number of motor vehicles available for household use has a major impact on the travel behavior of the members of the household. As a result, in travel demand modeling we try to incorporate modeling household vehicle availability or motorized vehicle ownership in the city as one of the input value. The availability of vehicles to households can influence trip generation, trip distribution, and mode choice. The advantage of incorporating vehicle availability, rather than simply estimating it from trends or assuming that vehicle availability levels remain constant across scenarios and forecast years, is to consider the effects of changes in demography, such as household size and income, on vehicle ownership. Furthermore, accessibility by various transportation modes and changes in land use patterns; both of which affects transportation and have shown to affect vehicle availability.

In recent years the size and types of socio-economic activities in the city has diversified and Addis Ababa is experiencing rapid motorized vehicle growth. As the growth of motorized vehicle were approximately following a linear trend with very low value of slope, whereas as of the current growth rate tend to following polynomial trends being commercial and private vehicles are the dominant contributing factors.

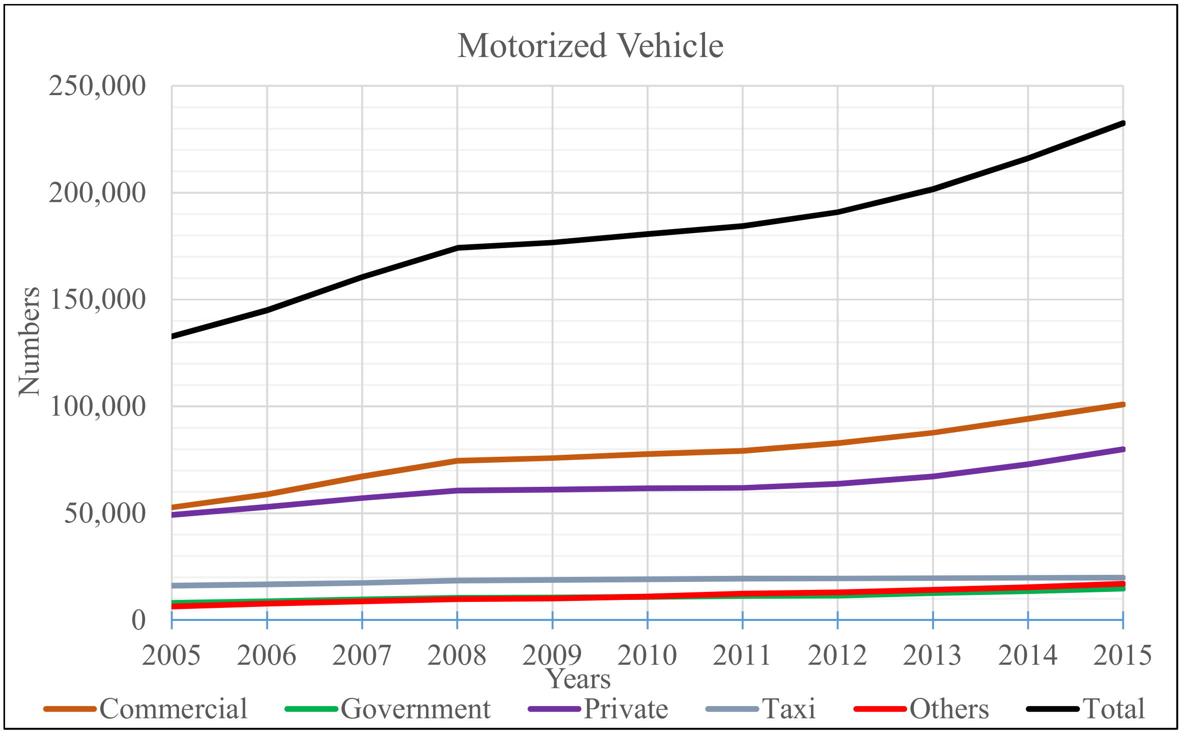


Figure. 7 Motorized vehicles in Addis Ababa (Source: MoT)

Table. 3 Car ownership in Addis Ababa
(Source: CSA)

Sub cities	2012
	Percentage Own
Akaki Kality	3.75
Nefase Silk Lafto	3.44
Kolfe Keranyo	3.17
Gulele	10.98
Lideta	7.5
Cherkos	15.32
Arada	1.89
Addis Ketema	5.63
Yeka	5.18
Bole	7.82
Average	6.47

3.1.5 Transport Networks

Transportation network refers to the computerized representation of the study area's transportation infrastructure. For the purpose of computer analysis, transportation system network is represented by links and nodes and the traffic zones are represented by centroids, which are connected to the network. The transport network model includes all roads/rail functionally classification according to local standards. The network also includes some key local roads where they added unique access between the Traffic Analysis Zones (TAZ) and the regional transport system.

Development of transportation networks coding usually done in GIS environment, and mostly it begins with the use of high resolution satellite Ortho-photos like that of Ikonos and Quick Bird will to stablish the basic transportation system network. Detailed development of network need to apply the principles of *topology*, *geocoding*, *linear referencing* and other principles of GIS. Further incorporation of detailed traffic data like that of, lane width, road way direction, type of lane, parking lane, bus or transit lane, speed and speed limit, lane capacity, information about signalized intersection, or at grade or grade separated, stop line capacity, intersection delay, transit stations nodes, speed, schedule of arrival, headway time could be modeled and stored in GIS database, so that it will be ready for further analysis.

The very common modeling tools utilized for network development are TransCAD, CUBE Voyager, EMME, VISUM, AIMSUN, DYNAMEQ, SATURN, and TRACKS. Specifically, considering the rail transportation system, it is a network of links and nodes, with the links of the network referring to the lines of track over which the movement of traffic occurs (Assad, 1980), and the nodes refer to stations or yards which are carriers to pick up or deliver traffic. Additional information about transit line includes, headway, route name/ number, and an average speed, can be derived from capacity determination process and which could be a fed back into the transit model.

Since 2015, the only means of transportation available in Addis Ababa was road transportation and its coverage and accessibility has been improved in the last decade. The total road network coverage of the city of Addis Ababa in 2009 was 2814 km, of which 1,280 km is asphalt road and the rest 1,534 km gravel road (AACGBoFED, 2010). The road network of Addis Ababa is shown in figure 8.

3.1.6 Transportation Analysis Zones (TAZ)

Travel demand modeling require areas that represent a series of small geographic areas called travel analysis zones (TAZs), or as some says traffic zone, are the smallest area that could be able to generate trips. It is the basic data unit in transportation modelling and TAZs is expected represent an area of homogeneous land use that could produces and attracts trips. Traffic zones characterized by their shape and position within the study area and are associated with all types of relevant data needed for modelling purpose.

The aggregates of TAZs' cover the entire study area create boundaries of the study area. Those inside the study area are called the "internal zone system" and it is also necessary to develop an external zone system that represents areas outside the study area. External zones usually do not have area to cover since they represent large regions and remote cities connected with the border of the study area therefore they usually represented by a regional road/rail/transport links.

Each of travel analysis zones are characterized by their population, employment, land use and others. And in these areas are where trips begin (trip producers) or end (trip attractors). Therefore, trip making is then first estimated at the household level and then aggregated to the zone level. Within travel analysis zone, trips are assumed to begin at the center of zone centroid and those trips that are very short, that begin and end in a single zone (intra-zonal trips), are usually not directly included in the forecasts.

The development of the zoning system is one of the first steps in the development of travel demand model and needs to be carefully designed. Once the zone system is created it is difficult to change later. There are many competing issues to be accounted for developing zone systems. When zones are too large, local transport demand tends to be omitted. When zones are too small, there is often too few data to adequately represent transport demand patterns in each zone and computation times become prohibitive. Number of zones also depends on the size of the study area and sometime based on software limitations. It is generally expected that models for smaller study areas will include a more refined zone system than large metropolitan cities models. Consequently, model's results and robustness are largely dependent on the quality and suitability of the internal zone system. If zones cross physical barriers (e.g. rail line, creek, major arterial road) and are not homogenous in land use, the modelling process will be compromised. It is difficult to connect zones to the road and public transport networks and therefore, trip generation, distribution models and assignment models become less reliable as a result.

In creating a zone system, transport modeler needs to consider potential future land use changes in the remote future, areas of future development need to be recognized and an appropriate zone system created for these developments that require a comparable level of detail as existing zones. Therefore, travel demand study area delineating of in to different TAZ areas has methodologies and criteria's need to be followed, but is should be noted that it may not be possible to follow every one of these recommended criteria's, whereas experiences showed that the recommendations provide good guidance for model development,

- As much as possible TAZs should contain homogeneous land uses in both base and future year and should consider future significant developments.
- The TAZ structure should be compatible with the base- and future-year highway and transit networks. The level of detail in the highway network should be consistent with the TAZ structure (and vice versa) to permit proper network loading.
- TAZ boundaries should be compatible with census, physical, political, and planning or administrative district/sector boundaries. This will bring compatibility with data sources.
- There should be a reasonable (and relatively small) number of intra-zonal trips in each TAZ, based on the mix and density of the land use.
- TAZ numbering should be sequential and better to associate with existing administration, which will be acceptable for practice, and those of external zone need to be numbered at the end. It is better to leave gaps in the numbering between two administrative regions so that additional TAZs can be added without disrupting the overall numbering system whenever changes like that of land use happens.
- External zones represent significant roadways that cross the model area boundary.

- Zone boundaries correspond to places with very low trip generation densities (reducing the probability of misallocating trips to zones near the zones boundaries)
- Try to minimize intra-zonal trips.
- Definition of zones with very low number of trips or very large area should be avoided.
- As much as possible density of trip production inside a zone should be homogeneous.
- Highway network compatibility with existing and planned transportation facilities and those of centroid connector loadings should be given a good consideration.
- Socioeconomic data (existing and future), homogeneous land uses, where feasible; Special generators; Trips per zone; and developments of regional impact
- Access to transportation infrastructure including those of Transits and inter-modal, if there is and or fright facilities should be considered.
- Zone size and intra-zonal trips and internal versus external zones trips need to be considered during TAZ formations.
- One should consider roadway network and physical geography when delineating TAZ boundaries.
- Boundary compatibility with
    - Physical geography; considering physical geography during delineating TAZ boundaries provide realistic access from the TAZ centroid to the nodes on the model network., as centroids are coded in the model network to identify the center of travel zone. Centroid connectors are needed to be coded in the model network to show the connection of the centroids with that of transportation facilities, usually it represents access via local/major roads. Having a centroid connector passing through a physical barrier conflicts with the assumption of free movement from the TAZ into the network, as the barrier does not allow for such movement. Therefore, understanding the physical geography provides the transport modeler with an ability to determine accessibility between TAZs and transportation infrastructure.
    - Census geography; Travel demand models typically use variety of demographic data as inputs. These data should be prepared at a TAZ level and input into the models. Population and number of household units are two widely used attributes that are also available at a variety of Census geographies, census

geography normally called *enumeration area*. Formulating TAZ boundaries along the Census geography enables transport modelers to readily access all census demographic data; hence, formulating TAZ boundaries along census geography provides seamless access to all information. The 2007G.C census carried out by Central Statistics Agency applied the enumeration areas similar to that of Kebeles of Addis Ababa City Administration.

- Political geography boundaries; the primary purpose of delineating TAZ boundaries consistent with political geography is for analysis of model outputs. Entities using travel demand models often need to analyze/evaluate travel patterns relevant to certain predefined political geographies, such as cities. Nesting TAZs within this political geography facilitates easy grouping of TAZs that fall within that geography, and assists in aggregating outputs from the travel demand models. Having a TAZ structure consistent with political boundaries also assists in isolating and extracting certain sets of TAZs according to their location under political boundaries, and analyzing travel patterns relevant to each administrative area or within different political geographies.

Having said that, it was checked that how representative Kebeles could be as primary TAZ's for this research. Other similar literatures showed that primarily when Kebeles are formed geographical, political, natural boundaries and road networks were the major criteria which is applicable in TAZ's formations. And it is good to note that this same reasons were used to form Kebeles and Kebeles were also used for Addis Ababa Urban Transport study (ERA, 2005) as primary TAZ's.

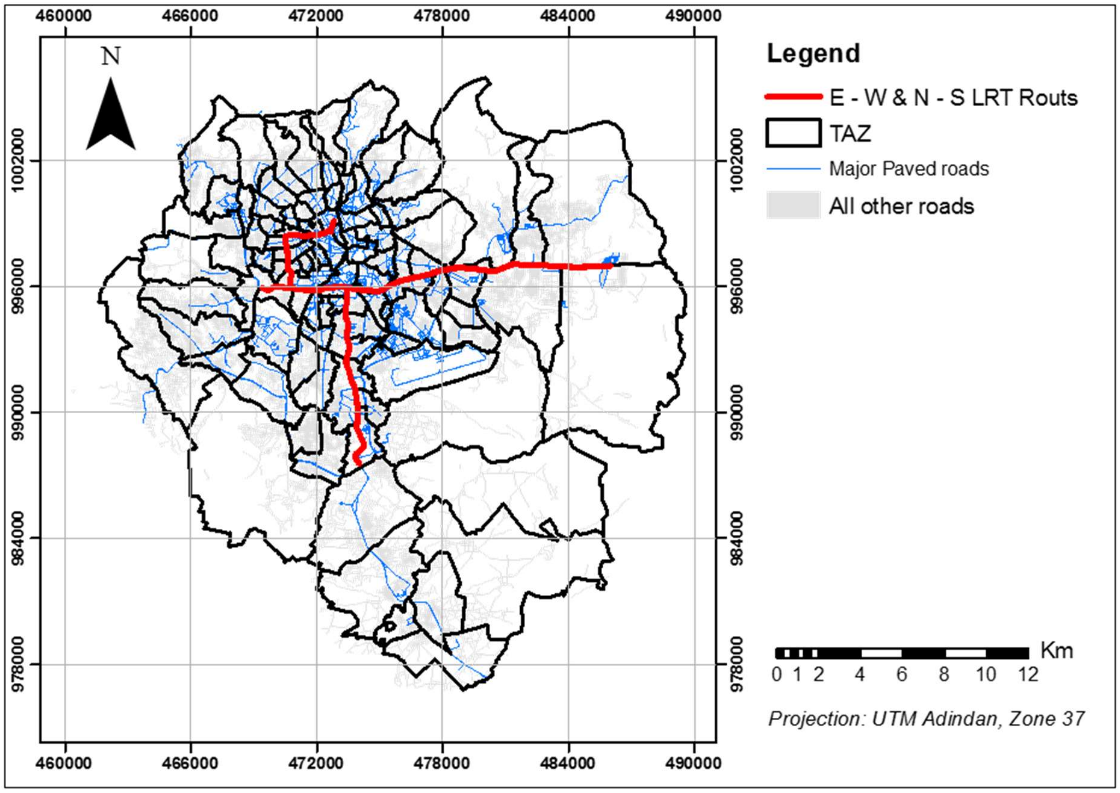


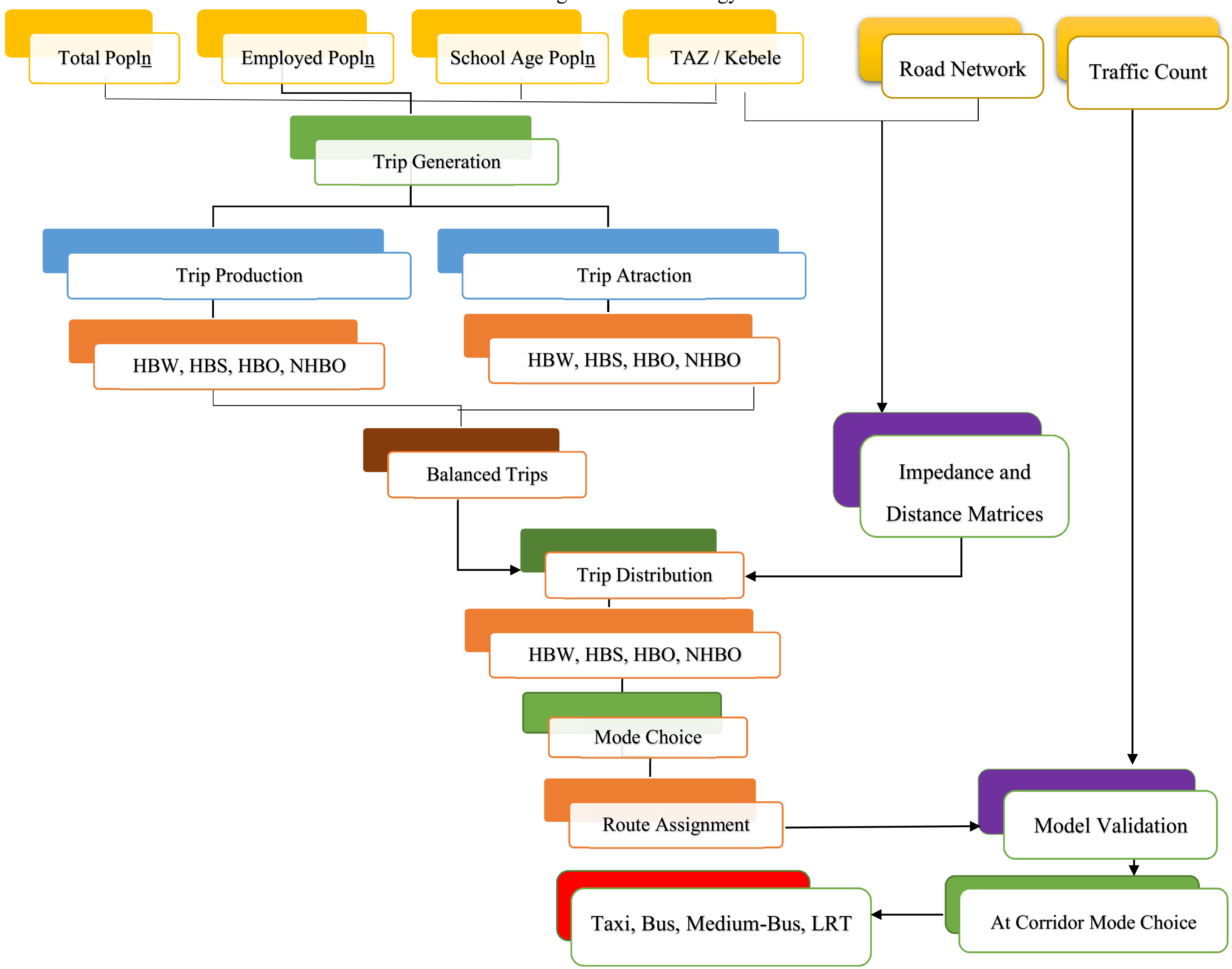
Figure. 8 Transportation networks and traffic analysis zones of Addis Ababa

3.2 Methodology

Travel demand analysis methodology basic steps are trip generation, distribution, modal split and route assignment. This modeling process is aggregate and trip based with limited analysis of travel behavior but it relays on statistical correlation between socioeconomic/ demographic and traffic pattern (VTM, 2009). The basic conceptual ground of analysis in the four step travel demand modeling is, the trips considered as the product of human behavior and that of trips production and attraction follows similar principles like that of gravitational attraction. The four step travel demand modeling has no unique travel behavior theory to support rather it uses a combination of spatial, economic, and demographic aggregates of data for its analysis. In order to analyze travel demand of current and future; current and future time scale data like that of number of households, population, employment condition, … etc. will be used.

In the process of developing 4-step modeling, trip generation model derive the model from trip rate model developed using linear regression model and the input is aggregated zonal level. Since in this research city wide trip production – attraction survey is not carried out, trip rates developed by multiple regression method adopted for trip attraction and production of TAZ's/Kebles used from long range transport plan study, Urban Transport Study (ERA, 2005). Similarly, the other modeling steps, trip distribution, modal split, and traffic assignment utilize, Gravity model, Logit model and All-or-nothing method of modeling respectively.

Figure. 9 Methodology flow chart



CHAPTER IV
RESULTS AND DISCUSSION

4.1. Socio Economic Analysis Results

4.1.1 Population Forecasts

Comprehensive population and housing survey has been done by CSA in 2007. After this general survey, inter censual survey has carried out in 2012. Based on the two surveys CSA has provided the author Kebele level population by sex group data for the year 2014 – 2017. Using these population data projections for the years 2018 – 2040 has developed. The projection results were verified using the inter censual survey results, which is presented in every five years' interval in Sub − City levels. The results of table 4 showed that the projected population in Sub – city level accuracy was not less than 98.81 percent. Similarly, population forecast in Kebele level was done and the aggregated to Sub – city level which gives similar result.

Table. 4 Population projection of Addis Ababa for the next 30 years

	Year	Addis Ketema	Akaki Kaliti	Arada	Bole	Gulele	Kirkos	Kolfe Keraniyo	Lideta	N. Silk Lafto	Yeka	Total	ICP,2012	Percentage between ICP and projected
CSA	2014	297,793	211,380	246,680	360,387	312,096	258,035	500,163	235,246	368,883	404,336	3,194,999		
	2015	305,058	216,538	252,705	369,189	319,712	264,337	512,369	240,989	377,892	414,212	3,273,001		
	2016	312,414	221,759	258,808	378,104	327,426	270,721	524,729	246,805	387,017	424,217	3,352,000		
	2017	320,053	227,182	265,141	387,355	335,434	277,346	537,561	252,842	396,486	434,599	3,433,999		
Projected	2018	327,364	232,372	271,205	396,214	343,099	283,689	549,844	258,622	405,553	444,540	3,512,500		
	2019	334,777	237,634	277,354	405,195	350,872	290,121	562,299	264,482	414,746	454,619	3,592,099		
	2020	342,191	242,897	283,502	414,177	358,645	296,552	574,755	270,342	423,940	464,698	3,671,699		
	2021	349,604	248,160	289,651	423,159	366,417	302,984	587,210	276,203	433,133	474,778	3,751,299		
	2022	357,018	253,422	295,799	432,141	374,190	309,416	599,666	282,063	442,327	484,857	3,830,899	**3,854,866**	**99.38**
	2023	364,432	258,685	301,948	441,123	381,963	315,847	612,121	287,924	451,520	494,936	3,910,499		
	2024	371,845	263,948	308,097	450,105	389,736	322,279	624,576	293,784	460,713	505,016	3,990,099		
	2025	379,259	269,210	314,245	459,087	397,509	328,711	637,032	299,644	469,907	515,095	4,069,699		
	2026	386,672	274,473	320,394	468,069	405,281	335,143	649,487	305,505	479,100	525,175	4,149,299		
	2027	394,086	279,736	326,542	477,051	413,054	341,574	661,943	311,365	488,294	535,254	4,228,899	**4,268,158**	**99.08**
	2028	401,499	284,998	332,691	486,032	420,827	348,006	674,398	317,226	497,487	545,333	4,308,498		
	2029	408,913	290,261	338,840	495,014	428,600	354,438	686,853	323,086	506,680	555,413	4,388,098		
	2030	416,327	295,524	344,988	503,996	436,373	360,869	699,309	328,946	515,874	565,492	4,467,698		
	2031	423,740	300,787	351,137	512,978	444,145	367,301	711,764	334,807	525,067	575,572	4,547,298		
	2032	431,154	306,049	357,285	521,960	451,918	373,733	724,220	340,667	534,261	585,651	4,626,898	**4,670,091**	**99.08**
	2033	438,567	311,312	363,434	530,942	459,691	380,164	736,675	346,528	543,454	595,730	4,706,498		
	2034	445,981	316,575	369,583	539,924	467,464	386,596	749,130	352,388	552,647	605,810	4,786,098		
	2035	453,395	321,837	375,731	548,906	475,237	393,028	761,586	358,248	561,841	615,889	4,865,698		
	2036	460,808	327,100	381,880	557,888	483,009	399,460	774,041	364,109	571,034	625,969	4,945,298		
	2037	468,222	332,363	388,028	566,870	490,782	405,891	786,497	369,969	580,228	636,048	5,024,898	**5,085,540**	**98.81**
	2038	475,635	337,625	394,177	575,851	498,555	412,323	798,952	375,830	589,421	646,127	5,104,497		
	2039	483,049	342,888	400,326	584,833	506,328	418,755	811,407	381,690	598,614	656,207	5,184,097		
	2040	490,463	348,151	406,474	593,815	514,101	425,186	823,863	387,550	607,808	666,286	5,263,697		

4.1.2 Population Density

Density refers to the number of people or jobs per unit of land *(Kilometer square).* Density of the city has its own pros and cons of factors for the city's socio-economic development contribution and regarding travel demand in specific and generally in transportation as well. The major advantages of density in the city area are; availability of labor force, generate more wealth, better infrastructure, better utilization of natural resources and greater cultural diversity are the major advantages. Whereas high crime rate, high in-equality of wealth, pressure on land and natural resources, more different societies and more different opinion on development and other policy matters, high chances of outbreak of epidemics are the major disadvantages.

In addition to density, clustering is very important issue in understanding city dwellers travel demand needs. Clustering refers to land use patterns in which related activities are located close by together. usually within convenient walking distance, which is location and mix of activities in an area. Therefore, clustering improves accessibility by reducing travel distances and improving transportation options.

Simply increasing population densities in a residential area may do less to improve accessibility than clustering destinations such as schools and shops in the center of the development. For example, in the peripheries of Addis Ababa where we have low densities, the developments of destinations such as schools, shops and other public services can lead to clustered mixed use development.

Clustering increases accessibility, increases opportunities to interact with neighborhood socio economic activities, which leads to the creation of nearby transportation nodes. Based on the population forecast we have calculated population densities in sub-city levels and shown in table 5 and population density in Keble level too is shown in figure 10.

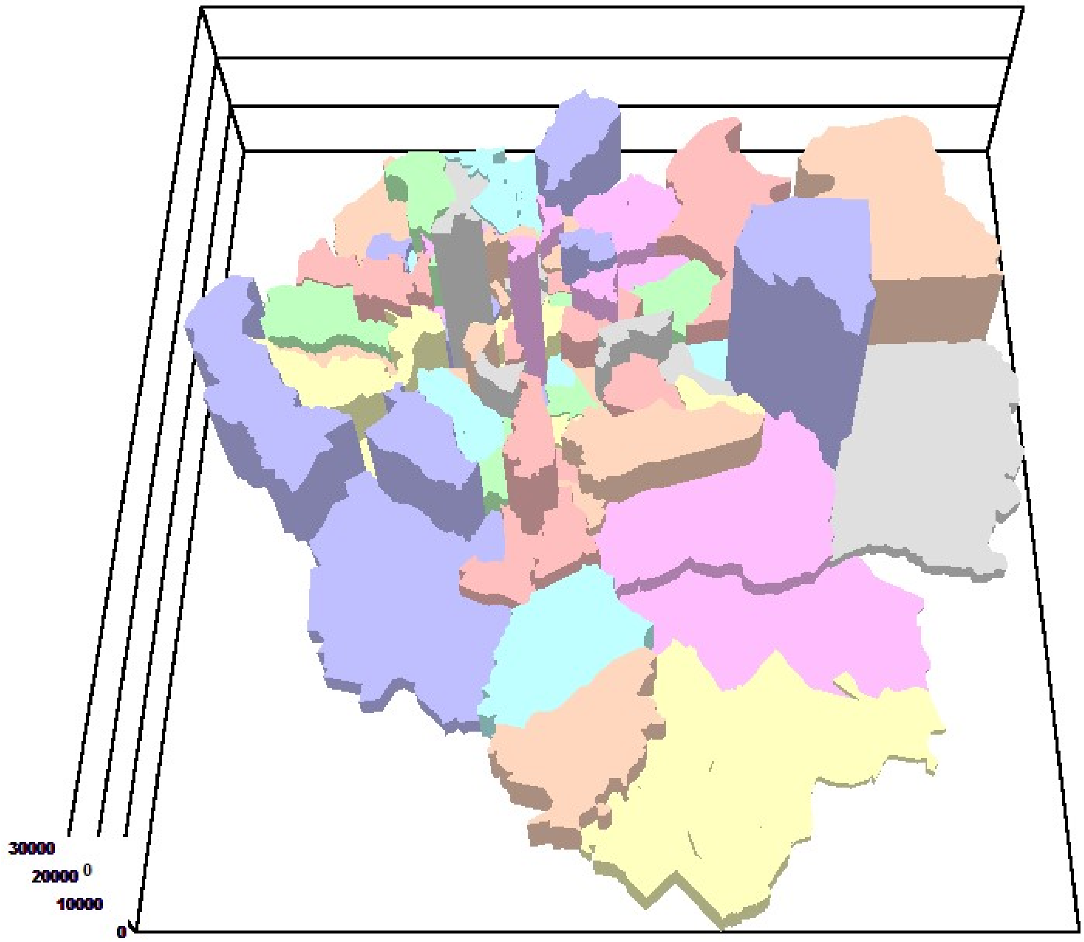


Figure. 10 Population densities of traffic analysis zones / Kebeles (Source: CSA)

Table. 5 Population densities of sub- cities (Source: CSA)

Sub city	km^2	Density people/Km^2
Akaki Kality	118.08	1834
Nefase Silk Lafto	68.301	5533
Kolfe Keranyo	61.251	8366
Gulele	30.184	10593
Lideta	9.175	26266
Cherkos	14.621	18080
Arada	9.914	25490
Addis Ketema	7.408	41180
Yeka	87.444	4737
Bole	120.61	3062

4.1.3 Mobile Population by Age Group

In order to determine the number of population who could possibly use the transport infrastructure, it is very important to classify the population of Addis Ababa in to different classes like, age groups, student or none student, employed or unemployed… etc. so that these population groups in conjunction with socio economic, land use and traffic networks will lead to find out the number of population who utilizes the transportation infrastructures.

It is very important to note that before proceeding to further development of aggregation and development of population based data, the basic data source is the last general census which was carried out in 2007, and additionally the inter censual population survey carried out in 2012 (CSA Inter Censal Population Survey, 2013) were the basic population data utilized with the basic demographic indicator data in table 1.

According to Addis Ababa Statistics (2008) and Addis Ababa Employment (2013) survey the age structure of Addis Ababa showed in table 6. As it is shown in the table 24.65 percent of the population under the age of fifteen, and 3.46 percent of the population above sixty-five. According to International Labor Organization, the age group between 15– 65 expected to be productive worker group, with has 71.89 percentage, and as it is shown in table 6 out of the total age group, 10.21 % of the population is below the age of 5 years which is doesn't utilize transportation infrastructure, and 89.79 percent of the population is potential user of transportation infrastructure.

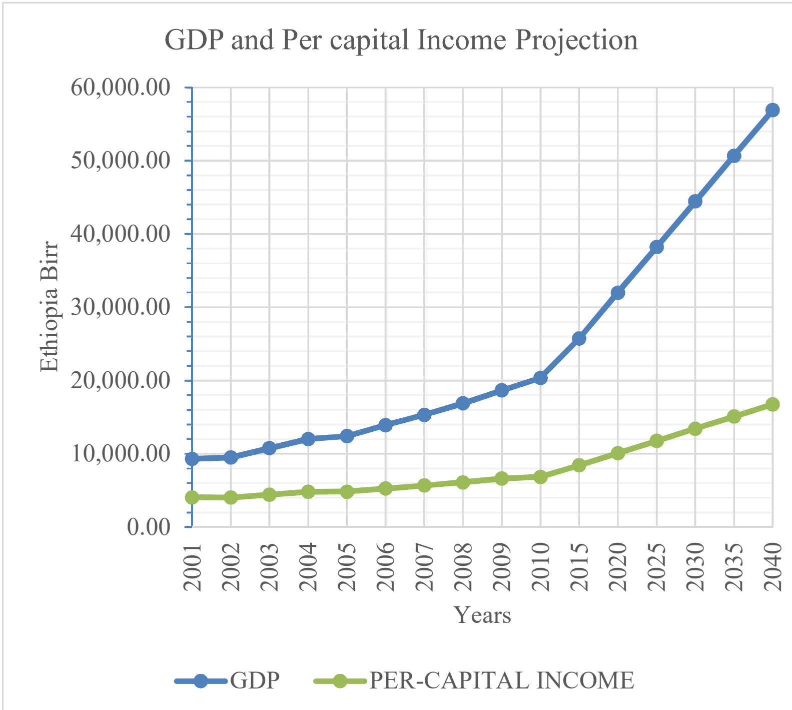
It is evident that according to the demographic characteristics population is dynamic and percentage population age group and others important demographic parameters which influence travel demand modeling input data were presented in the demographic indictors of Addis Ababa in table 1. Even though percentage of age group changes every year for sake representation only the year 2012 population age group presented in a table below and similarly for others year presented in appendix B.

Table. 6 Percentage of population by age group

All ages	Total	Male	Female	Percentage
0-4	283,135	142,892	140,243	9.29
4−9	200,643	100,253	100,390	6.58
10−14	218,057	104,205	113,852	7.16
15-19	266,223	113,621	152,602	8.74
20-24	409,558	160,677	248,881	13.44
25-29	422,594	191,491	231,103	13.87
30-34	376,677	182,505	194,172	12.36
35-39	234,048	126,426	107,622	7.68
40-44	188,200	97,522	90,678	6.18
45-49	118,171	64,521	53,650	3.88
50-54	99,519	49,430	50,089	3.27
55-59	77,399	37,015	40,384	2.54
60-64	51,650	25,997	25,653	1.69
65-69	42,253	20,849	21,404	1.39
70-74	28,634	14,373	14,261	0.94
75-79	19,325	8,950	10,375	0.63
80+	11,148	6,724	4,424	0.37
Total	3,047,234	1,447,451	1,599,783	

4.1.4 GDP and Per-capital Income Forecast

As it is shown in the previous sub-topic, GDP and per capital income has significant impact in the way trips are made. It is evident that the more the GDP is growing similarly per capital income is growing and the number of trip frequencies increases and trip making mechanisms and modes varies as well. Taking in to consideration the last ten years of economic performance of the city of Addis Ababa, GDP and income per capital income of Addis Ababa has projected for the coming years as shown below.



Year	Real GDP (in Millions)	Per capital Income
2001	9,307.80	4,046.90
2002	9,505.00	4,027.54
2003	10,762.00	4,428.80
2004	12,021.30	4,808.50
2005	12,405.30	4,827.00
2006	13,905.30	5,267.10
2007	15,309.70	5,670.20
2008	16,886.60	6,118.30
2009	18,659.69	6,616.90
2010	20,367.75	6,857.80
2015	25,751.23	8,427.60
2020	31,981.85	10,091.13
2025	38,212.48	11,754.65
2030	44,443.10	13,418.18
2035	50,673.72	15,081.70
2040	56,904.35	16,745.23

Figure. 11 GDP and per capital income projection

4.1.4 Employment and Education Forecast

Researches shows that, in travel demand modeling the two main types of trip purposes, Home based to work and Home based to school, trips account near to eighty percent of the total trip generated. Therefore, the number of population engaged in school enrolment and employed population determined for base year 2012 and forecast for the come years as well. The number of population in school and employed is well documented in CSA documentations of (Addis Ababa Employment, 2013), and based on this base year and number of students and employed population forecast presented in the table below.

Table. 7 Percentage of school enrolled and employed population

Year	Percentage of population 0-4 age	Percentage of school age population 5-19 age	Percentage of work age population 20-64 age	Percentage of population 65 and above age	Percentage of employed population	Percentage of un-employed population
2012	9.29	22.48	64.91	3.33	73.67	26.33
2020	10.21	21.33	65.00	3.46	75.82	24.18
2025	9.84	22.87	63.37	3.91	77.93	22.07
2030	8.75	25.03	61.71	4.51	80.75	19.25
2035	7.84	24.97	62.05	5.14	83.34	16.66
2040	7.62	23.41	62.45	6.51	88.48	11.52

4.2 Travel Demand Modeling Results

4.2.1 Trip Generation

Accordingly, in order to procced on modeling of trip generation, trip production and attraction rate are utilized. Trip purposes of the city categorized in to four, *Home based work trip (HBW)*, *Home based educational trips (HBE)*, *Home based other trips (HBO)*, and *None home based other trips (NHBO)*. Therefore, based on the independent variables, total number of trip for each trip category calculated. As it is expected the number of trips produced and trips attracted were not balanced between the zones; as the system to be in equilibrium trip balancing has performed keeping number of trip productions unchanged since trip rate productions are more reliable than attraction rates.

Table. 8 Trip production and attraction rates

Trip Types	Trip production	Trip attraction
Home based work trips	WTP = 1.48W	TWTA = 1.57E
Home based education trips	ETP = 1.684ST	TSTA = 1.61ST
Home based other trips	OTP = 0.199Pop	TOTA = 0.86E
None home based trips	NHBTP = 0.023Pop	NHBTA = 0.0695E
	WTP - work trip production	TWTA - Total work trip attractions
	W -number of workers	E - employment
	ETP - Educational trip production	TSTA - Total education trip attractions
	ST - number of student	ST - number of student
	OTP - Other purpose trip production	TOTA - Total other purpose trip attraction
	Pop - population	NHBTA - Total non-home based trip attraction

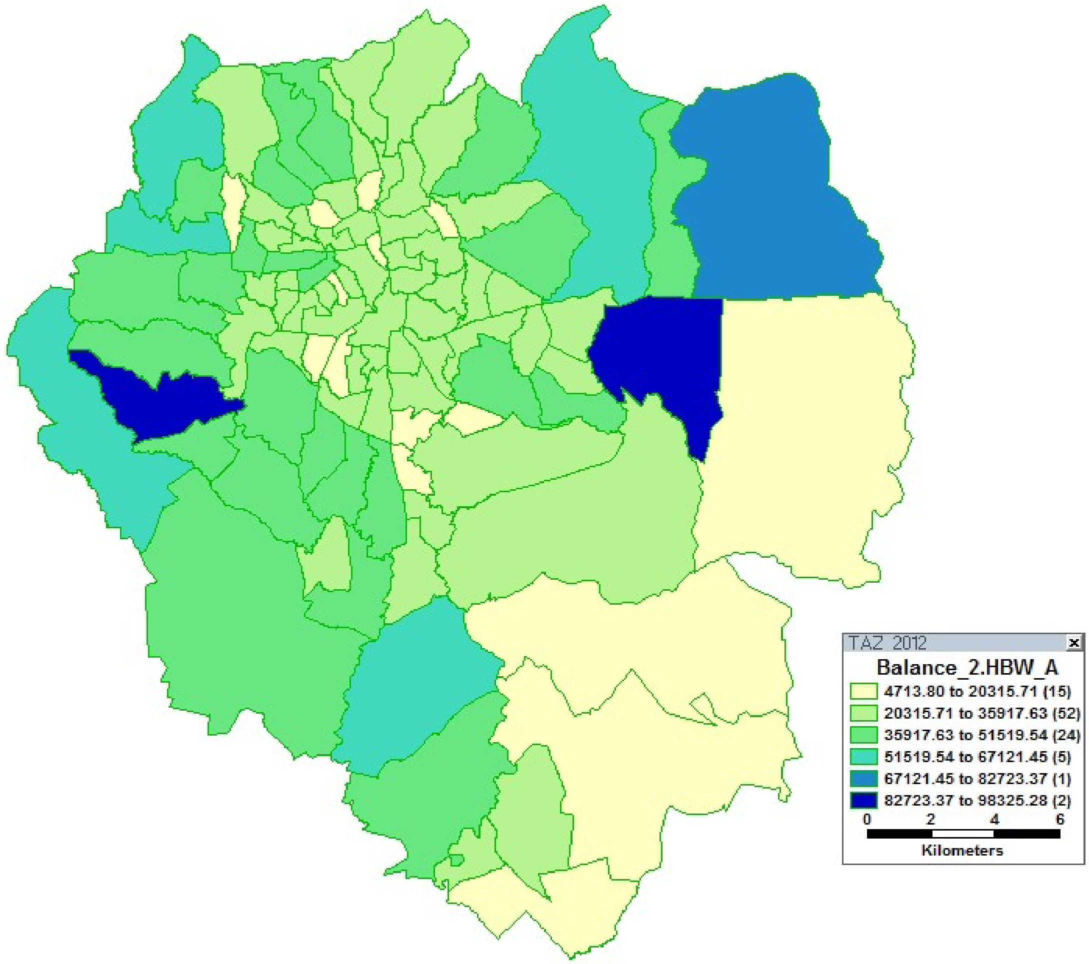


Figure. 12 Home Based Work Balanced Trip per TAZ

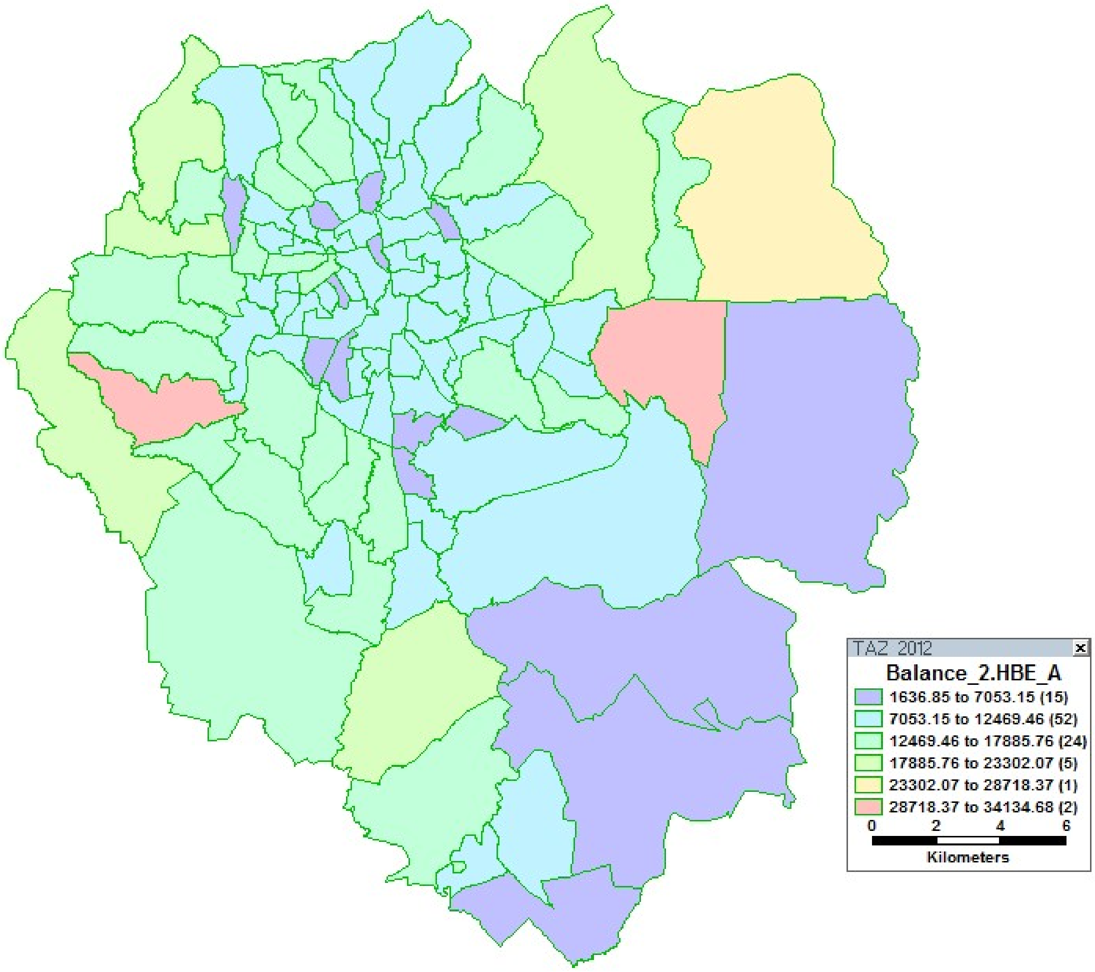


Figure. 13 Home Based Education Balanced Trip per TAZ

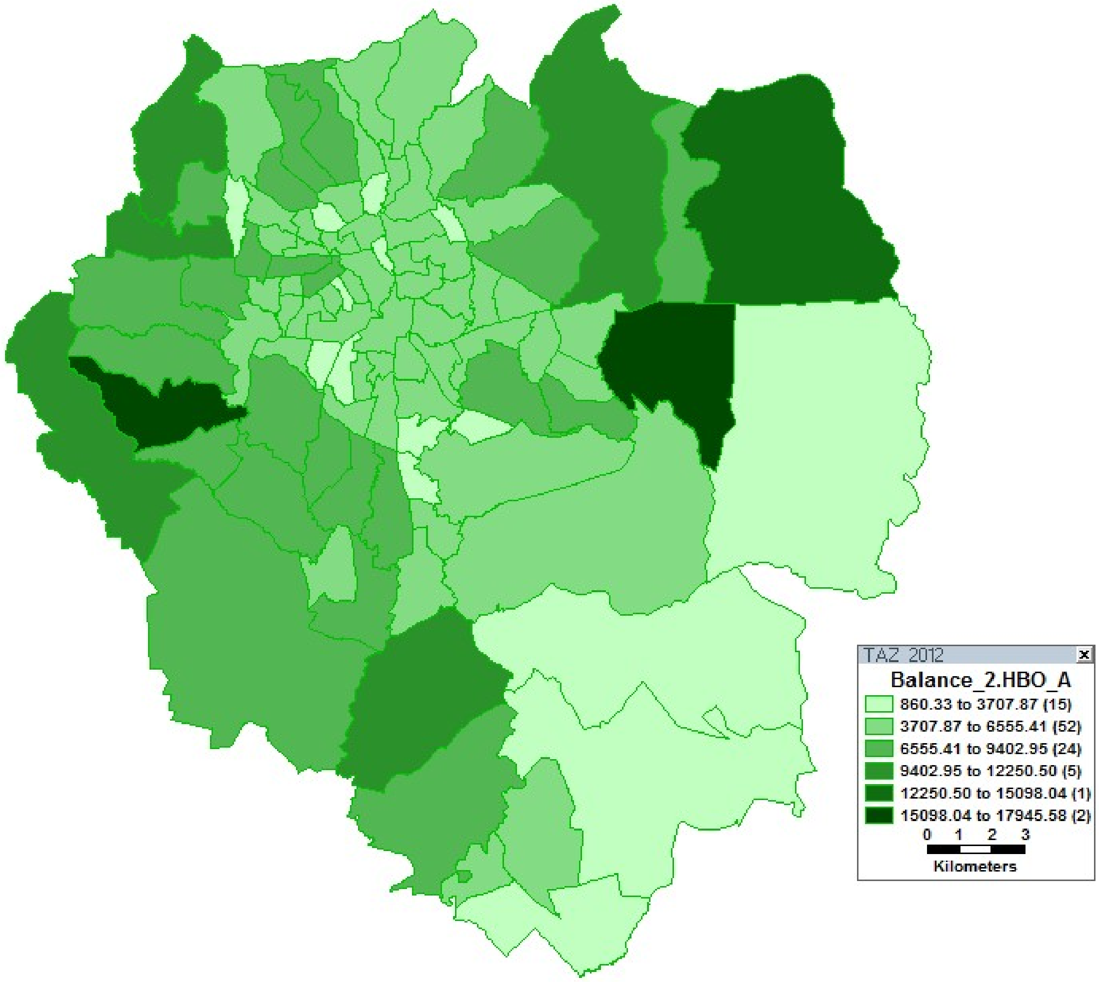


Figure. 14 Home Based Other Balanced Trip per TAZ

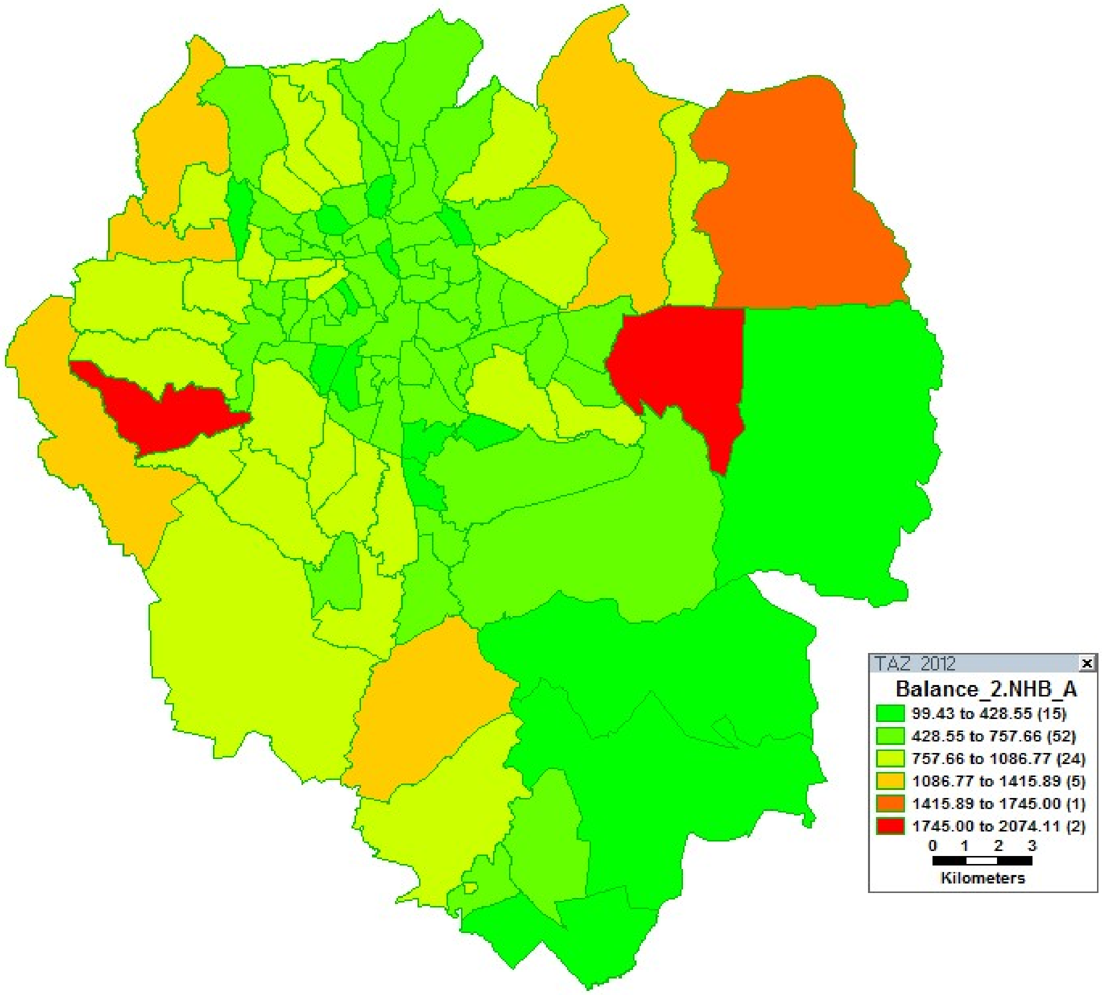


Figure. 15 Non-home Based Balanced Trip per TAZ

4.2.2 Trip Distribution

Because of the good reasons mentioned in the preceding chapters, Gravity model is employed in trip distribution sub-model. Gravity models estimate flows between all zones, given an input matrix of impedances between zone to zone, and balanced trips of productions and attractions. An impedance matrix is simply a matrix of the amount of difficulty to travel between any pair of zones. Frequently used measures of impedance are travel time, travel distance, or cost. In our case impedance matrix is calculated as shortest travel times between all zones in the study area, and as a result 99X99 matrix generated for each trips kind; *Home based work trip (HBW)*, *Home based educational trips (HBE)*, *Home based other trips (HBO)*, and *Non-home based other trips (NHBO).*

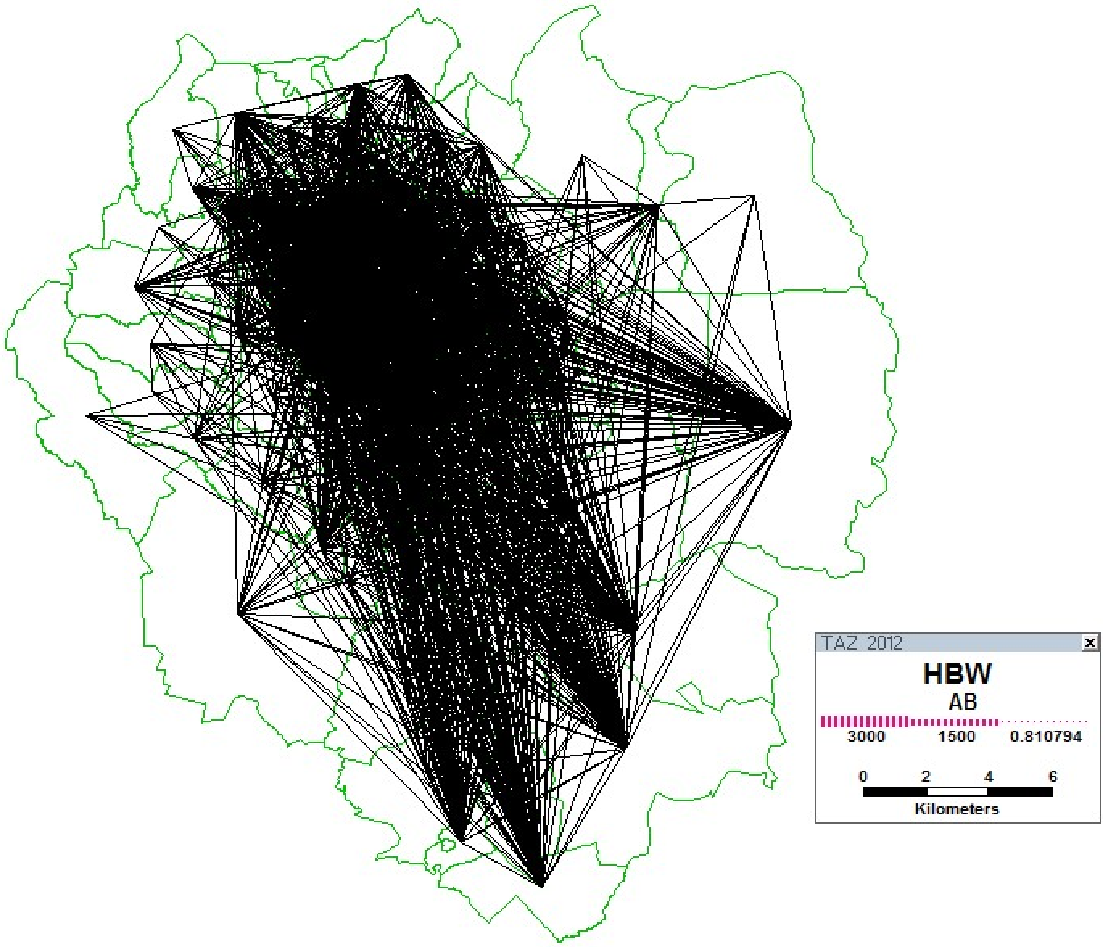


Figure. 16 HBW Distribution Diagram

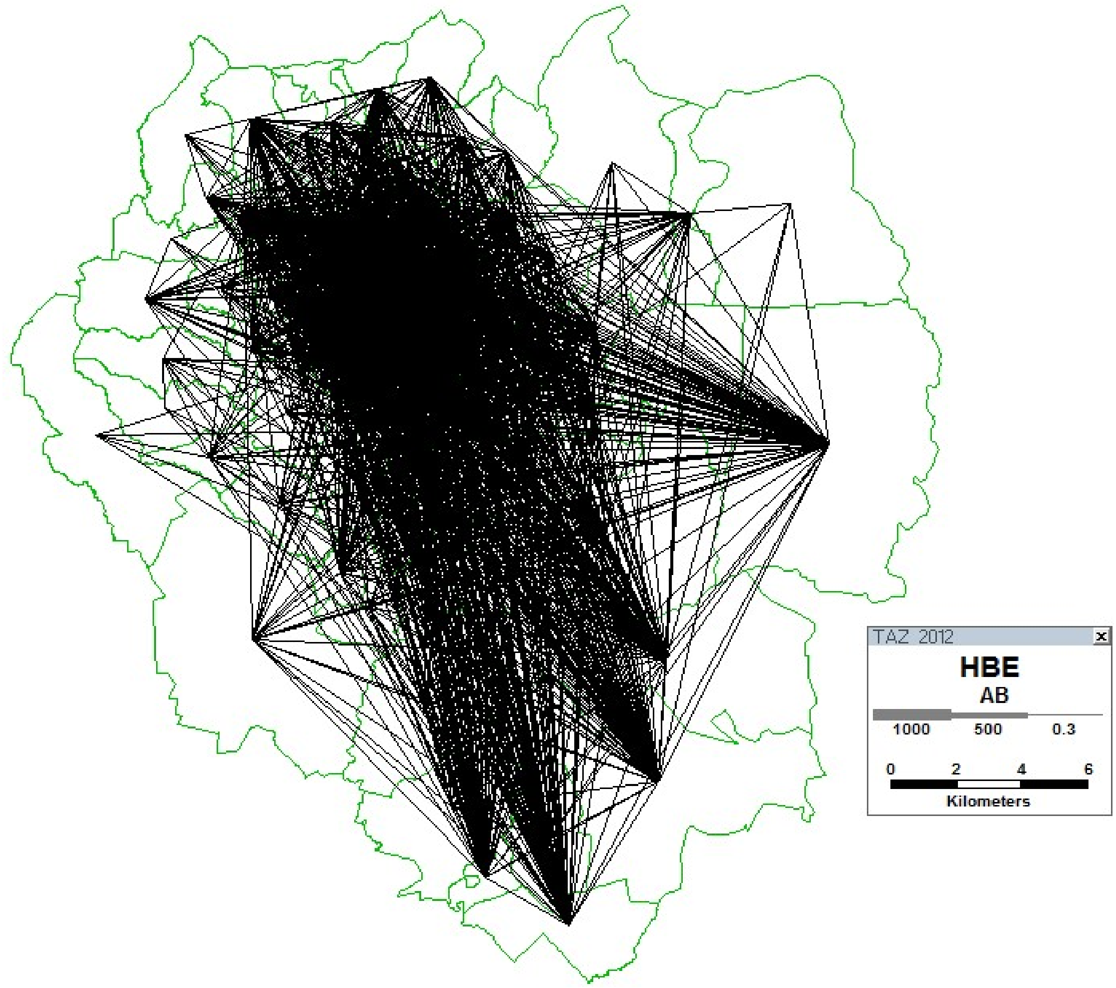


Figure. 17 HBE Distribution Diagram

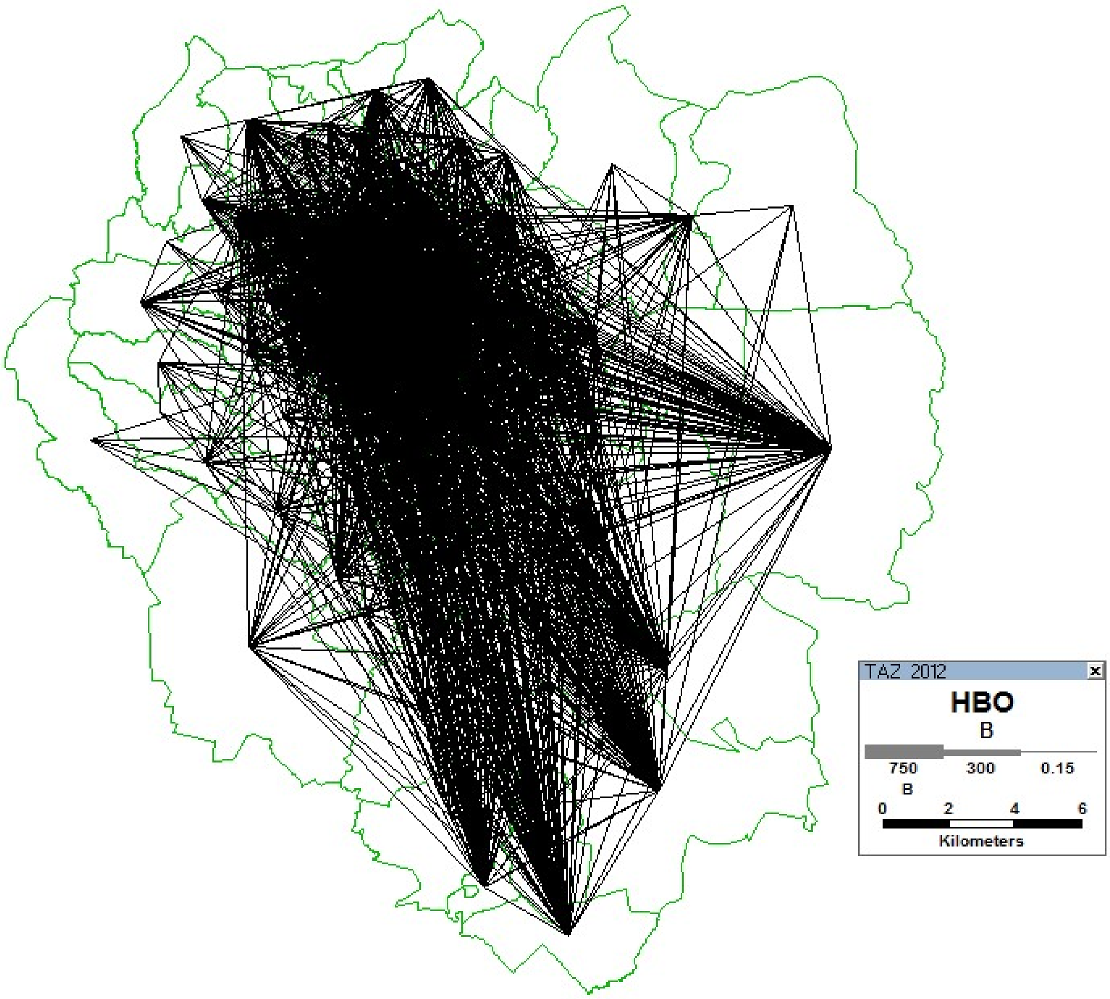


Figure. 18 HBO Distribution Diagram

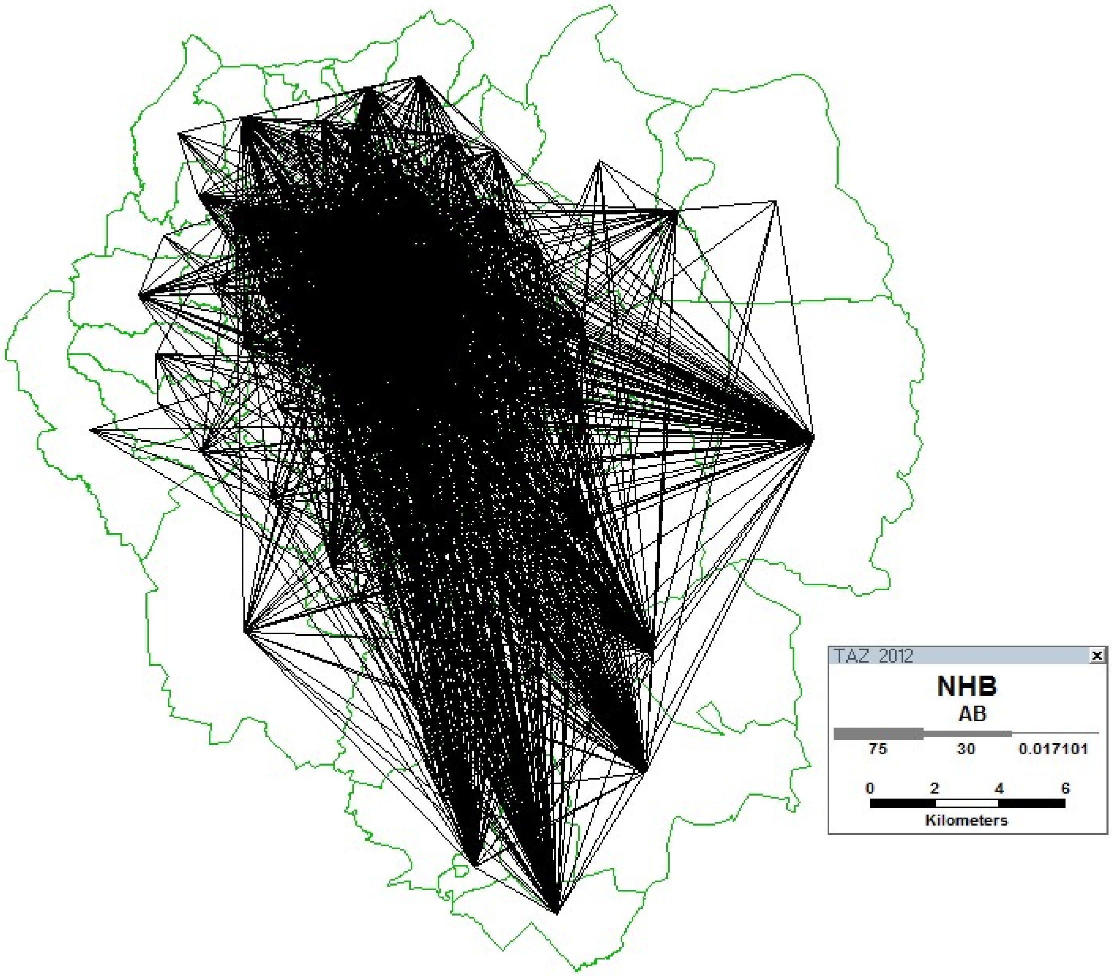


Figure. 19 NHB Distribution Diagram

4.2.3 Modal Split

The third step of modeling is modal split. An important objective in mode choice modeling is to predict the share of trips attracted to available means of transportation. The most commonly applied method to study mode choice is the logit model. It should be noted that our input data for the previous modeling steps were aggregate TAZ/ Kebele levels. Aggregate models predict the zonal shares of trips by mode. Aggregate models are typically estimated using mode shares by origin-destination pair and average zonal demographics data. Two data sets are needed for aggregate logit modeling. The first is a dataset for decision making of zones, which is explanatory characteristics of the origin or destination zone for the choice decision that is going to be made, in our case it travel cost and the second input data set needed for logit mode development is characteristics of travel time/ impedance.

For the development of logit model, available means of transports need to be assessed. According to Addis Ababa Transport Bureau (Addis Ababa Transport Bureau, 2015) survey report, Taxi (Mini bus), Walk, City Bus (Abessa), Medium Bus, Private car, Services, Bajaj, Lada taxi (Salon taxi), Bicycle, and Motor Bikes are the means of transports in Addis Ababa.

For the development of travel demand modeling only public transport means of, Taxi (Mini bus), City Bus (Abessa), and Medium Bus, are considered. Except the walking the others are excluded because the percentage contribution and availability is insignificant, whereas the percentage of walking is significant therefore in order to perform modeling walking trips need to be excluded from the total trips. According to Addis Ababa Transport Bureau (2015), 23.13 % of HBW, 47.85 % of HBS, 26.77% of HBO, and 31.43 % of NHB trips performed by walking and the exclusion of these percentage values give motorized traffic. Of the available motorized modes, auto mobile utilization depends on the availability, therefore being an automobile available and its use for the specific purpose of trip should be given special considerations. Similarly considering the possibilities of using other modes of transports like, Bajaj, Lada, and Motor Bike a total of 8 percent trip deducted. And next using an average cost of traveling, and their impedance matrices we reach on the total number of trips of each mode. The figure below shows the cost and speed used to cost matrices and impedance matrices calculations.

Table. 9 Mode split inputs

(Source: Ministry of Transport)

	Travel Cost Birr/ Km	Speed
Taxi	0.58	25kph
Medium - Bus	0.43	15kph
Bus	0.30	20kph

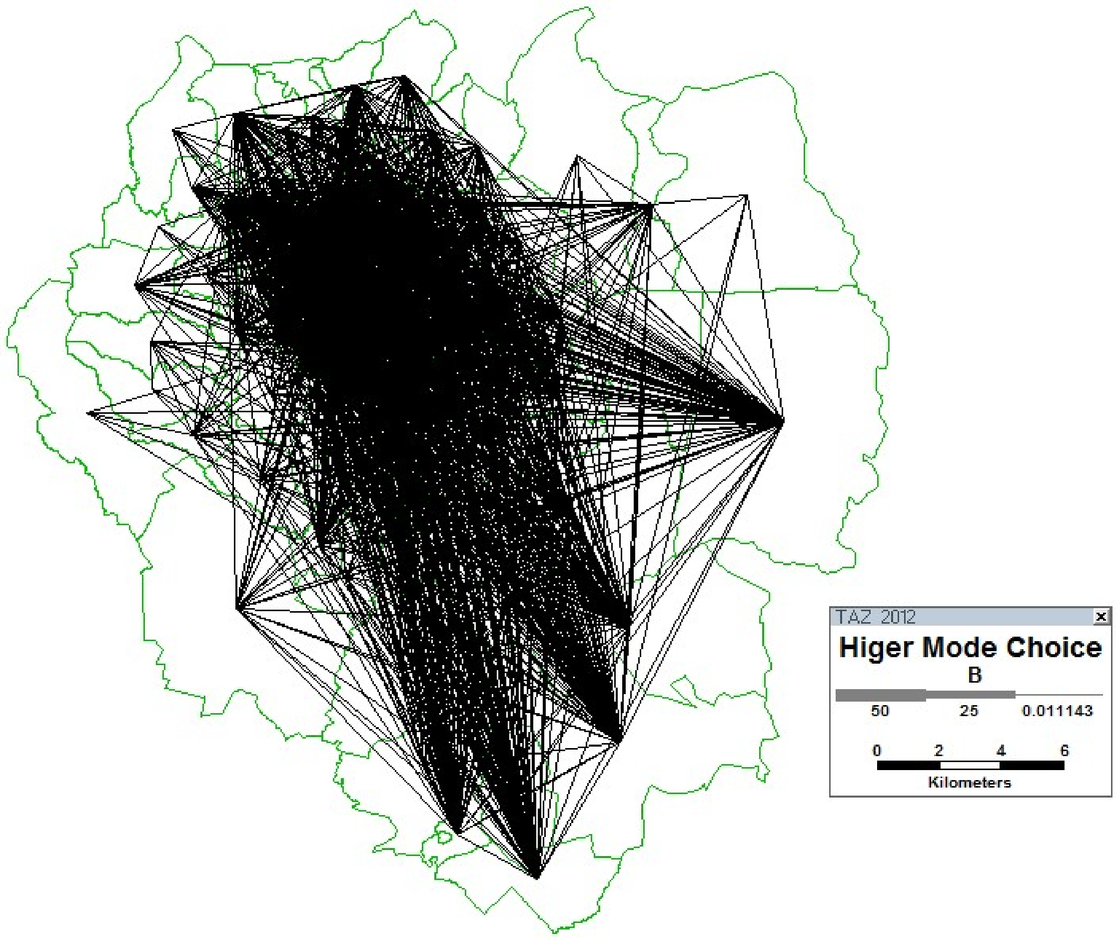


Figure. 20 Medium Bus Mode Choice Diagram

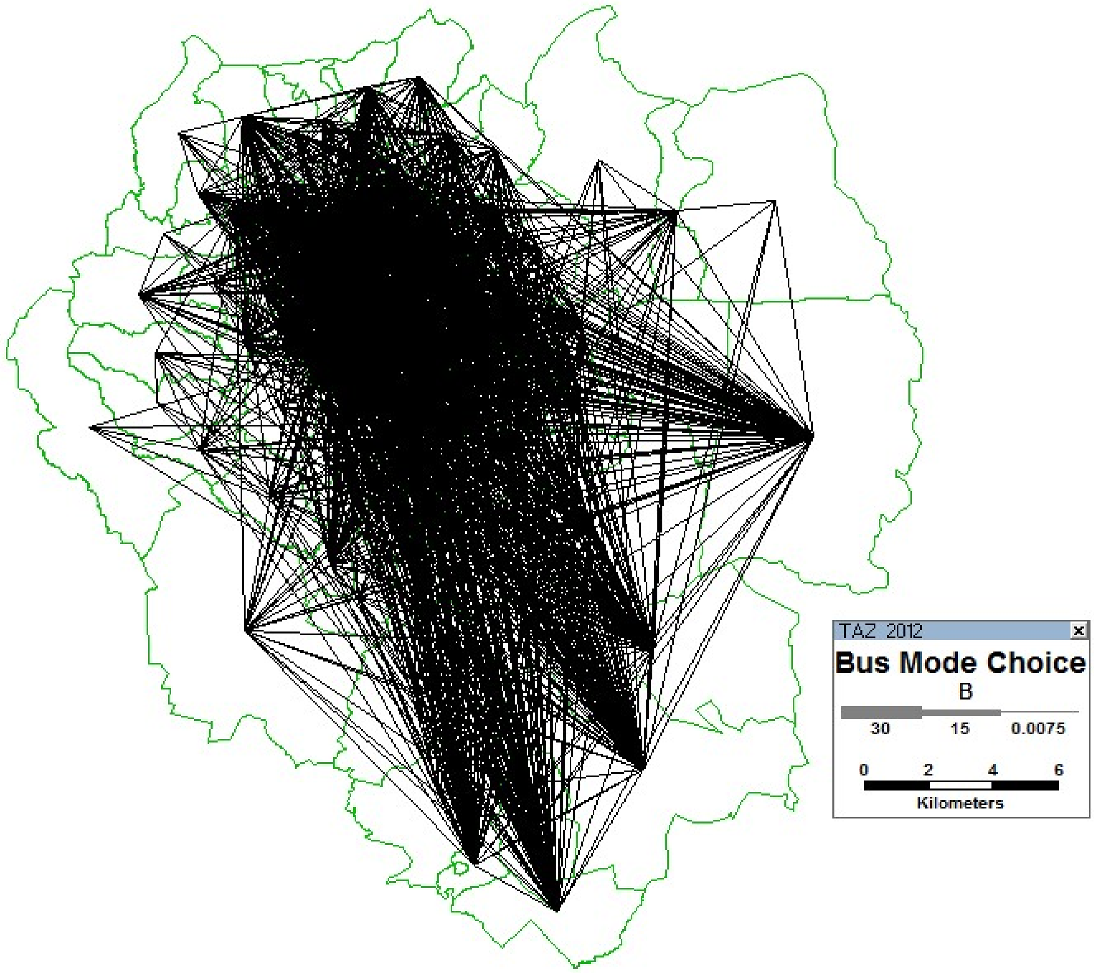


Figure. 21 Bus Mode Choice Diagram

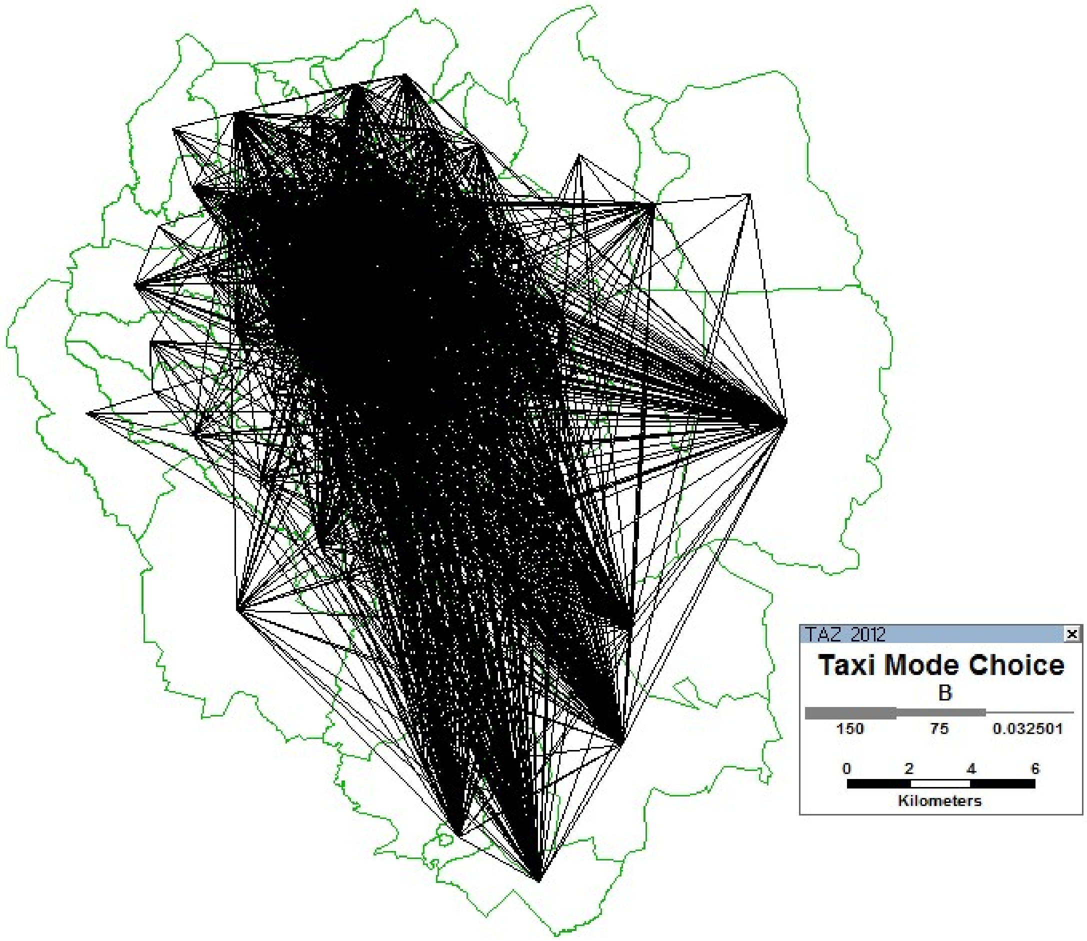


Figure. 22 Taxi Mode Choice Diagram

4.2.4 Traffic Assignment

The last step of travel demand modeling in traffic assignment to the road network under study. The required data for traffic assignment are O-D matrix which contains the vehicle volumes to be assigned for each O-D pair, and transportation networks with the appropriate attribute fields. From the methods described in the preceding chapter, All-or-Nothing Assignment method is chosen. All-or-Nothing Assignment does not require much mathematical procedure, it depend on the travel time of the network only. The results of traffic assignment shown in figure 23 - 25.

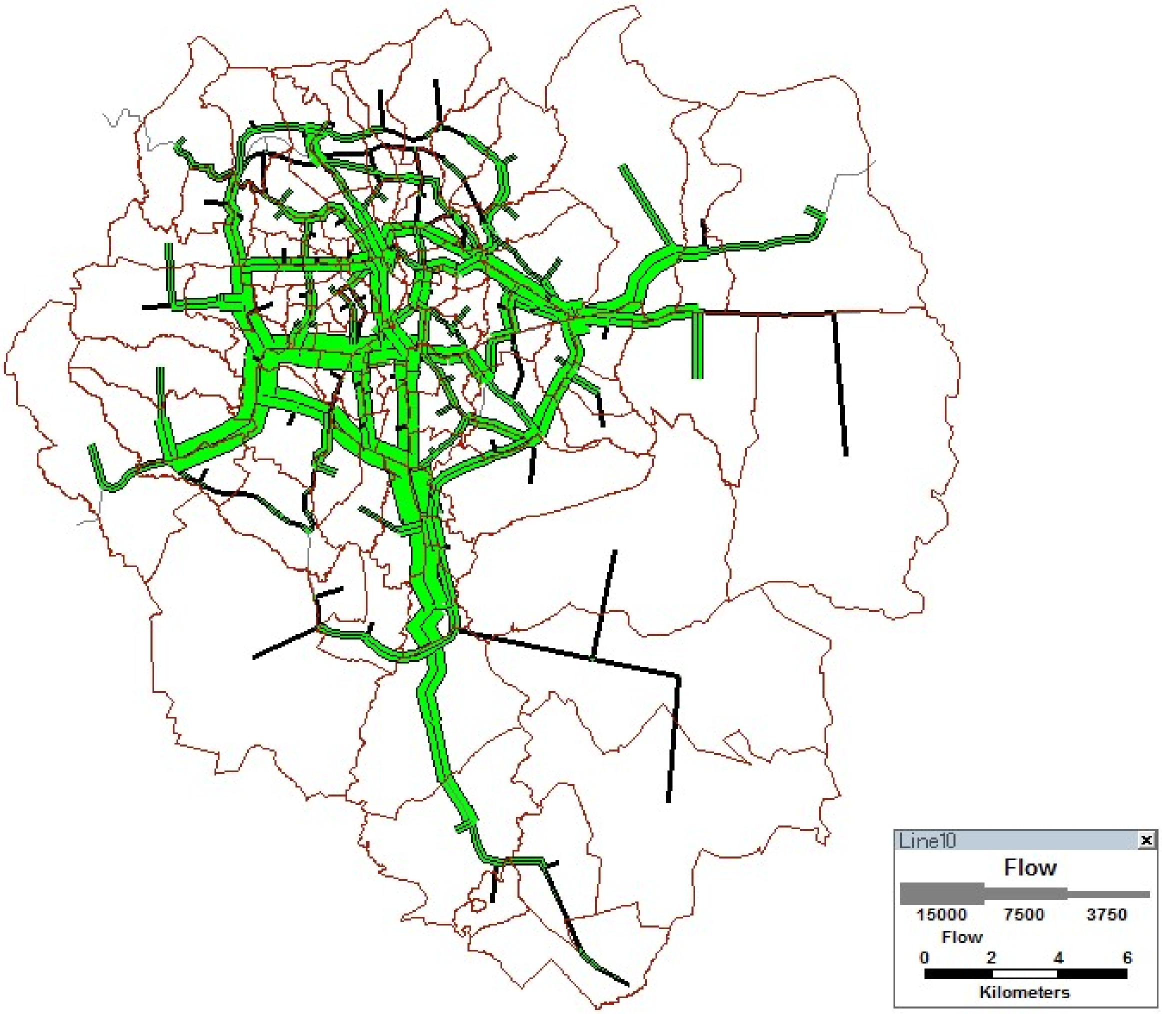


Figure. 23 Traffic Assignment of Taxi

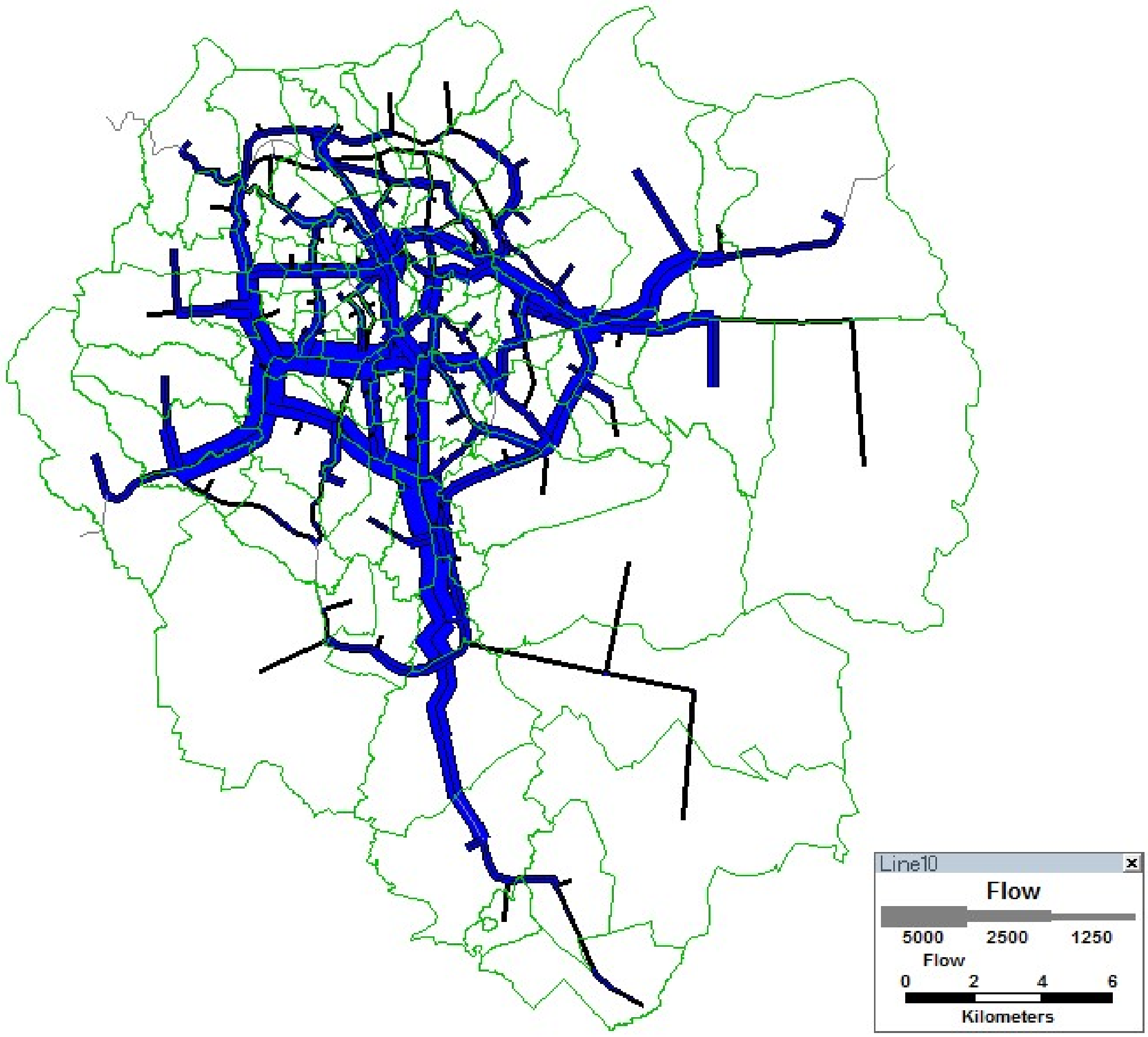


Figure. 24 Traffic Assignment of Medium Bus

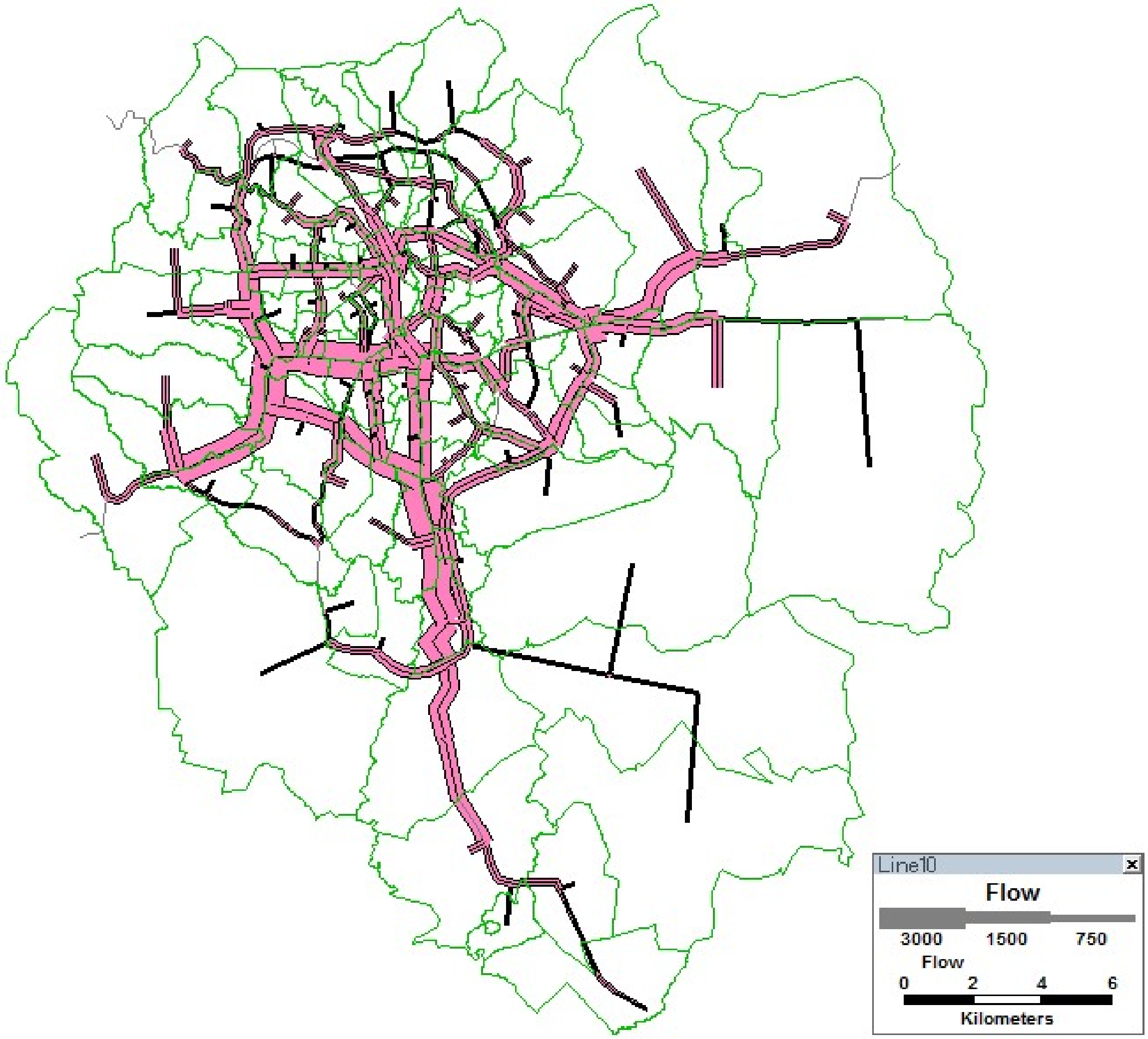


Figure. 25 Traffic Assignment of Bus

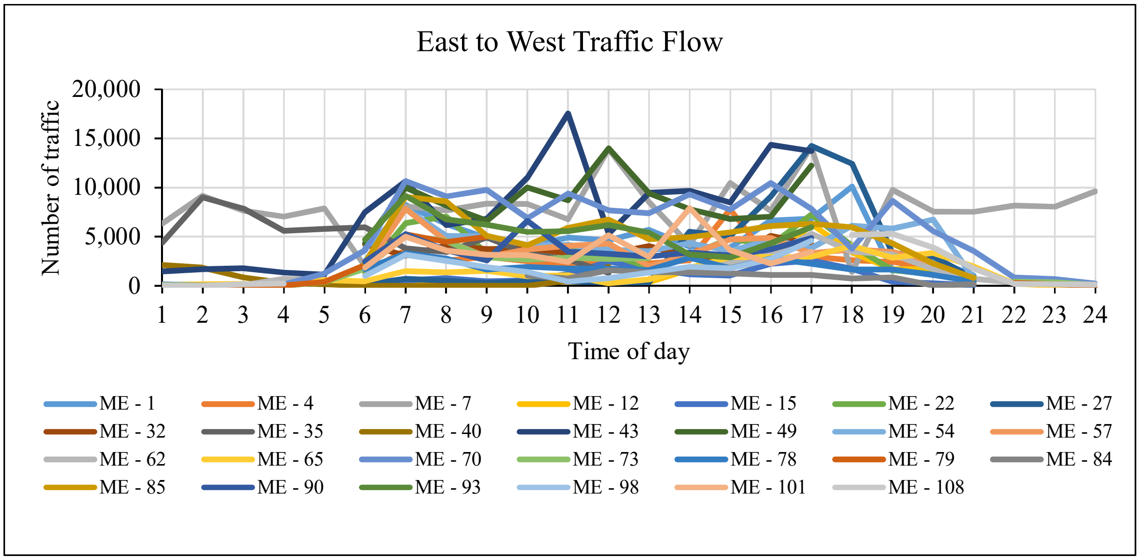
4.2.5 Model Validation

As the main research objectives were to develop and updated travel demand model of the study area that can be used from base year of 2012 up to 2040, there is a need to make sure that the travel demand model is valid for the base year as well as for the coming 20 years ahead. In order to assure the validity of our model, model validation test need to be done on model results.

Model validation is needed not only to show predictive capability of the model but also it shows model's accuracy as well. Therefore, it is common and good practice to make travel demand models validation by comparing model results with that observed data within reasonable tolerance between the two before being taken the results of the model as final model output and also before producing future year forecasts. The model validation procedure had performed by comparing cumulative assigned traffics on the existing roads with that of collected traffic counts on East – West road corridor.

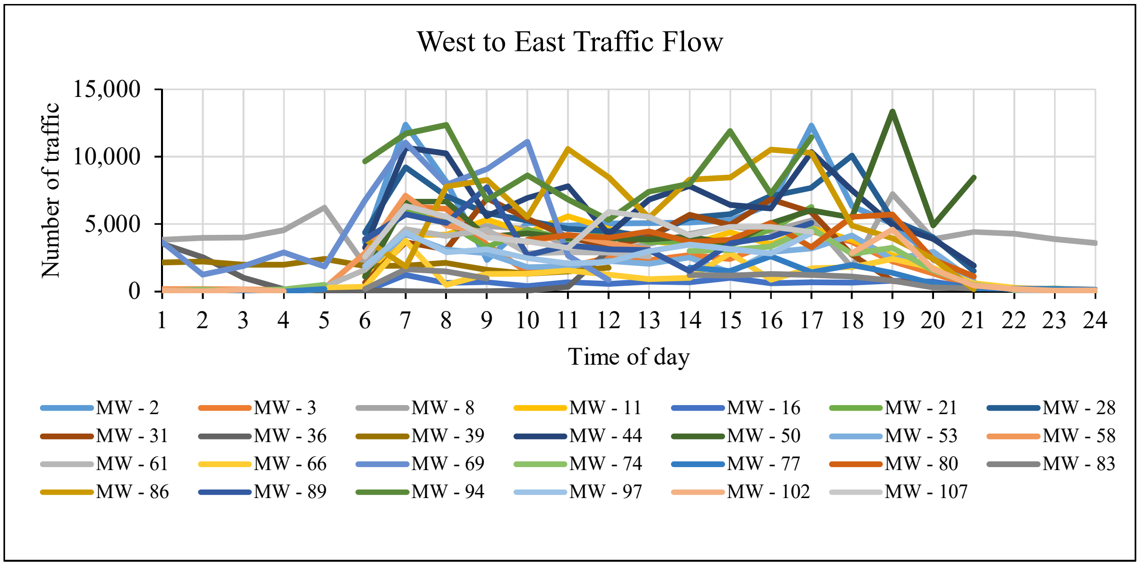
The traffic count of East _ West corridor was performed on 114 nodes, out of this 27 nodes are on main corridor, with traffic movement from east to west direction (ME), 27 nodes too are in main corridor taking traffic from west to east (MW) direction, 30 nodes take traffic out of the main corridor (EO), and the remaining 30 nodes bring traffic to the main corridor (EI).

The traffic count was done in the base year of 2012 for seven days, five days of twelve hours count and two days of twenty-four-hour count by CORE Consulting Engineers P. L. C. For validation purpose whichever day of the count which gives maximum number of public passenger traffic were taken. Since the direct traffic count give number of vehicle count, by visual observation on public transport vehicles across the corridor vehicle occupancy of ratio of 0.7, 0.7, and 0.5 with the total carrying capacity of 12, 35, and 80 persons respectively for Taxi, Medium Bus, and Bus was used.



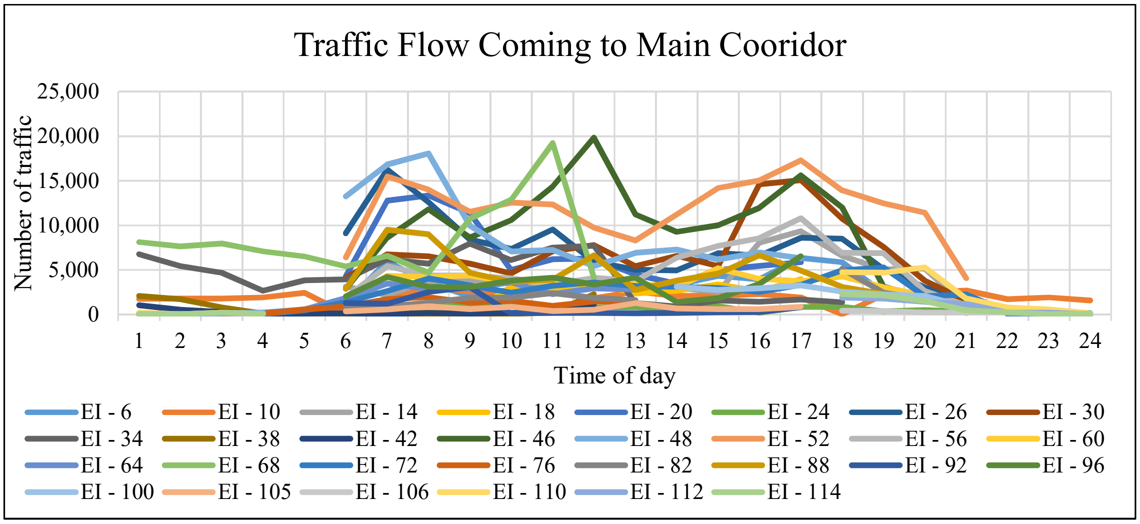
ME - 1	ME - 4	ME - 7	ME - 12	ME - 15	ME - 22	ME - 27	ME - 32	ME - 35
87.851	77.362	75.095	76.597	73.672	75.058	91.746	78.935	83.055
ME - 40	ME - 43	ME - 49	ME - 54	ME - 57	ME - 62	ME - 65	ME - 70	ME - 73
78.215	73.453	84.050	73.600	80.715	84.646	85.511	78.459	78.173
ME - 78	ME - 79	ME - 84	ME - 85	ME - 90	ME - 93	ME - 98	ME - 101	ME - 108
80.785	79.877	74.526	68.614	84.410	75.477	91.150	90.810	86.831
				Average				
				80.321				

Figure. 26 East to west traffic flow



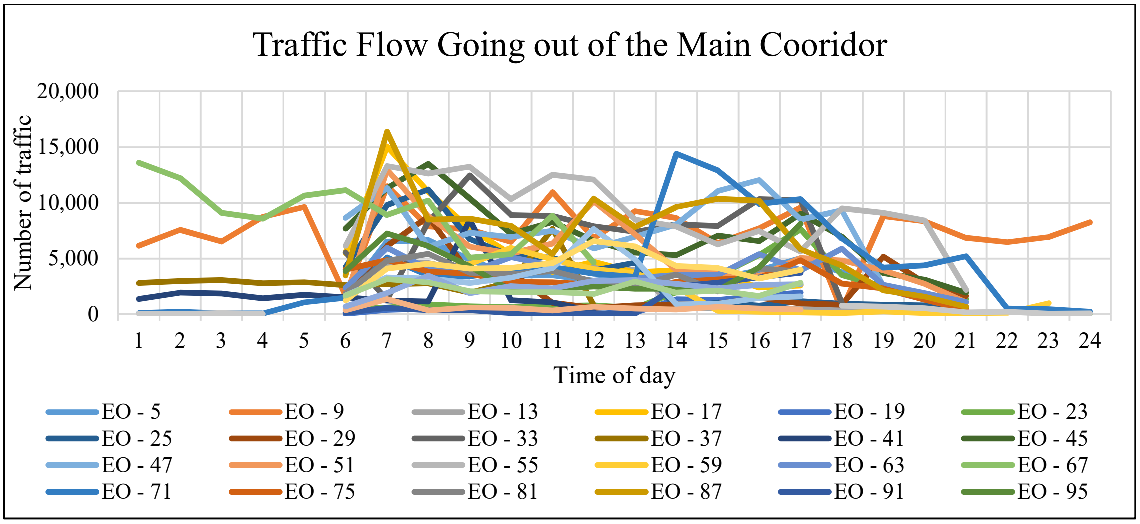
MW - 2	MW - 3	MW - 8	MW - 11	MW - 16	MW - 21	MW - 28	MW - 31	MW - 36
83.305	73.598	78.392	89.402	86.545	77.392	82.802	71.266	78.632
MW - 39	MW - 44	MW - 50	MW - 53	MW - 58	MW - 61	MW - 66	MW - 69	MW - 74
70.791	84.550	96.775	76.713	73.361	77.457	80.518	89.265	71.724
MW - 77	MW - 80	MW - 83	MW - 86	MW - 89	MW - 94	MW - 97	MW - 102	MW - 107
79.857	87.251	85.340	81.565	87.467	84.069	90.228	70.319	82.023
				Average				
				81.134				

Figure. 27 West to east traffic flow



EI - 6	EI - 10	EI - 14	EI - 18	EI - 20	EI - 24	EI - 26	EI - 30	EI - 34	EI - 38
84.924	93.614	78.247	87.112	86.878	87.057	87.647	89.777	89.386	84.198
EI - 42	EI - 46	EI - 48	EI - 52	EI - 56	EI - 60	EI - 64	EI - 68	EI - 72	EI - 76
81.250	73.150	91.611	73.488	91.105	84.463	83.087	92.604	94.177	89.703
EI - 82	EI - 88	EI - 92	EI - 96	EI - 100	EI - 105	EI - 106	EI - 110	EI - 112	EI - 114
84.464	88.356	89.961	93.011	86.940	85.288	85.125	86.530	89.028	89.401
				Average					
				86.719					

Figure. 28 Traffic flow coming to the main corridor



EO - 5	EO - 9	EO - 13	EO - 17	EO - 19	EO - 23	EO - 25	EO - 29	EO - 33	EO - 37
78.818	73.337	85.495	95.389	87.246	88.228	86.785	94.737	84.026	94.203
EO - 41	EO - 45	EO - 47	EO - 51	EO - 55	EO - 59	EO - 63	EO - 67	EO - 71	EO - 75
87.356	97.347	92.088	87.880	84.006	88.257	81.022	74.121	86.366	74.163
EO - 81	EO - 87	EO - 91	EO - 95	EO - 99	EO - 103	EO - 104	EO - 109	EO - 111	EO - 113
87.819	81.182	88.537	85.047	84.075	76.365	79.141	94.806	75.313	88.032
				Average					
				85.373					

Figure. 29 Traffic flow going out of the main corridor

4.2.6 Modal Split for East – West Light Rail

As it is shown in the above modeling steps, a complete four step modeling has been performed, and now modal split for the light rail remains. Whenever a means of transportation is chosen first it should be available as a choice. Bearing this in mind, the choice of light rail could only be reasonable to consider for the traffic which reached in any node of the East – West road corridor.

The traffic assignment performed for the entire city includes this road corridor, which is parallel to East – West light rail. As it is shown in the above three figures of traffic assignments, the maximum traffic flow occurred in the road parallel to the East – West and North – South LRT line, that is why in the first place LRT is introduced in to these two corridors. By isolating the road corridor running from east to west, it is possible to identify the percentage of contribution of each mode of, Taxi, Medium Bus, and Bus in the road corridor. Here it is good to notice that this percentage of contribution is the final result of the model, traffic assignment, and it was a result of impedance, and other input variables.

Considering at corridor mode choice parameters of speed and travel time, the generalized travel cost could simply produce by the multiplication of the two. With trend analysis of generalized cost with that of percentage contribution, 35 percent of traffic prefer to use LRT on the corridor. The generalized cost analysis with that of percentage contribution in the corridor is performed by disregarding other factors that could possibly affect mode choice, like comfort and headway time. Therefore, taking the total number of traffic in the corridor and balancing of contribution factors the final percentage of contribution of each mode in East – West corridor are 16.4, 47.7, 10, and 25.9 percent of mode choices respectively for Medium Bus, Taxi, Bus, and LRT.

Table. 10 Mode split inputs

Mode of transport	Travel Cost per km	Speed KPH	General cost	Mode contribution without LRT from corridor assignment	Ratio of GC/mode contribution	Unbalanced mode contribution with LRT introduced in the corridor	Balanced mode contributions in the corridor
Medium Bus	0.430	15	6.450	0.221	29.212	0.221	0.164
Taxi	0.580	25	14.500	0.644	22.516	0.644	0.477
Bus	0.300	20	6.000	0.135	44.379	0.135	0.100
LRT	0.340	18	6.120		17.471	0.350	0.259

Consequently, number of traffic which utilize the four modes of transport has calculated based on the assigned traffic value and balanced mode contribution ratios as shown in the table below. As it is shown in the table the maximum traffic is 5,364 and located between Mexico to Laghar section of LRT, the second largest traffic is in Megenagna with 5,126 traffic and the third largest traffic is between Torhayloch to Lideta with 4,881 number of traffic.

Taking 5,364, the maximum number of traffic in the corridor to compare with the design traffic values of, 2,679 persons per hour for initial stage, 5,502 persons per hour for short term stage, and 7,696 persons in long term stage, the base year traffic already exceed not only the initial stage but also the short term expected traffic as well.

Table. 11 Model out-put number of traffics at East – West LRT nodes

Node Description	From	To	Medium Bus	Taxi	Bus	Rail	Rank
ME - 1 / MW - 2	Torhayloch	Coca	2,431	7,089	1,488	3,856	11
ME - 4 / MW - 3	Coca	Lideta	3,077	8,975	1,884	4,882	4
ME - 7 / MW - 8	Torhayloch	H.Court	3,077	8,975	1,884	4,882	4
ME - 12 / MW - 11	H.Court	Lideta	3,077	8,975	1,884	4,882	4
ME - 15 / MW - 16	Lideta	Mexico	3,077	8,975	1,884	4,882	4
ME - 22 / MW - 21	Mexico	Leghar	3,381	9,862	2,070	5,364	1
ME - 27 / MW - 28	Mexico	EEPCO	3,381	9,862	2,070	5,364	1
ME - 32 / MW - 31	EEPCO	Leghar	2,774	8,092	1,699	4,401	9
ME - 35 / MW - 36	Mexico	Leghar	2,774	8,092	1,699	4,401	9
ME - 40 / MW - 39	Leghar	Stadium	1,894	5,524	1,160	3,005	12
ME - 43 / MW - 44	Leghar	STADIUM	1,894	5,524	1,160	3,005	12
ME - 49 / MW - 50	STADIUM	Mexico	2,921	8,518	1,788	4,633	8
ME - 54 / MW - 53	Mexico	Bambis	1,588	4,631	972	2,519	14
ME - 57 / MW - 58	Torhayloch	Bambis	1,588	4,631	972	2,519	14
ME - 62 / MW - 61	Bambis	Urael	1,588	4,631	972	2,519	14
ME - 65 / MW - 66	Mexico	Urael	233	680	143	370	27
ME - 70 / MW - 69	Urael	Megenagna	1,070	3,120	655	1,697	17
ME - 73 / MW - 74	Urael	Wuha lemat	1,070	3,120	655	1,697	17
ME - 78 / MW - 77	Wuha lemat	22	1,070	3,120	655	1,697	19
ME - 79 / MW - 80	Urael	Getahun Besha	1,070	3,120	655	1,697	19
ME - 84 / MW - 83	Getahun Besha	Megenagna	1,070	3,120	655	1,697	19
ME - 85 / MW - 86	Mexico	22	1,070	3,120	655	1,697	19
ME - 90 / MW - 89	22	Megenagna	1,070	3,120	655	1,697	19
ME - 93 / MW - 94	22	Lem Hotel	1,070	3,120	655	1,697	19
ME - 98 / MW - 97	Lem Hotel	Megenagna	1,070	3,120	655	1,697	19
ME - 101 / MW - 102	22	Megenagna	1,070	3,120	655	1,697	19
ME - 108 / MW - 107	Megenagna	CMC	3,231	9,425	1,979	5,126	3
		Total / G. Total	52,684	153,661	32,259	83,583	**322,186**
		Maximum	3,381	9,862	2,070	5,364	

4.3 Discussion

As noted in the literature review, there were four important papers related to the subject under study. The focus of Mekdim (2007) was mode choice determination for Bole sub city without considering rail as one of the choice and Binyam (2007) work on to develop simplified model for travel demand model without the help of advanced modeling tool like TransCAD and EMME/2, instead by using Excel spread sheet and Visual Basic – Application language by utilizing the data collected for the development of long term travel demand model of Addis

Ababa. The third study is the long term travel demand model (ERA, 2005); were inclusive model which cover from land use planning and mobility index to the proposal of mass transit transports like Bus Rapid Transport and Light Rail Transport which practically includes every sector of transport planning with an intention of serving as transportation master plan of Addis Ababa till the year 2040.

As this paper bases the long term master plan study basic findings and results, for model development and updating purposes results and findings of this paper could not compared with transportation master plan study.

The fourth document of Schematic Design report of (2012), is the fundamental design document used for East – West light rail implementation which bases primary data collected on the corridor and other secondary data sources. Since the first and second researches doesn't consider rail transport as an available means of transport, the results and finding of this paper cannot be compared or comment on it. Therefore, based on the findings of this research many of the design document design parameters like that population forecast, total number of corridor traffic, number of light rail users…etc. commented and critically evaluated.

According to the design document, the total population forecast of Addis Ababa for initial stage (2018), short term (2025), and long term (2040) was; 4,950,000, 5,880,000 and 7,580,000 respectively, whereas the total population forecast of this research is 3,512,500, 4,069,699, and 5,263,697 for the respective years (see Table.4). The variations between the two population forecast is near to 30 %, which is significant and this eventually leads to significant result variations to those of consequent model results that depend on population. Since the population forecast of this research was compared with CSA's interim forecast, it showed an accuracy of more than 98 percepts, therefore the research result is more reliable.

Similarly, comparing results of East – West corridor public transport users of the two studies; by taking the base year 2012 traffic, the final total mode choice result gives 322,186 traffics in the corridor for morning or evening peak, in other words a total of 644,372 trips are expected in a day. Whereas the design documents calculated 734,393 total number of traffic in a day for the base year 2012 showing 14 percent increase. Considering only the number of rail users for the base year 2012, a total of 167,166 (83,583×2) passengers are expected, whereas in the design document it is 121,500, 242,000, and 355,800 number of passenger is expected in 24-

hour cycle with rail transportation percentage contribution of 27%, 31%, and 33% for initial, short term and long term service respectively. As it is shown in this research, the model base year (2012) number of traffic is already higher that the initial stage (2018) by 37.5 percent whereas percentage of contribution of the model base year is 25.9% (table 10).

In addition, it is clear to see discrepancy in the results of 2012 corridor traffic of 734,393 and 2018 percentage corridor traffic user of rail transport of 27 percent. Assuming the impossible, number of traffic and percentage of light rail transport growth between 2012 to 2018 is zero, total number of rail user per day will be 198,286 (0.27×734,393). This result is 18.6 percent greater than 2012 model output and 63.2 percent greater than the design document itself.

Another important finding of this study is, number of traffic on rail mode users across the corridor. As it is shown in Table 11, for the base year 2012, the highest number of rail traffic users located in Lagar, Mexico, EEPCO area with 5,364 passengers and the second busiest rail segment is between Coca and Mexico with 4,882 passengers per day. The third and fourth largest traffics are Torhyloch and Stadium with 3,856 and 3,005 rail users respectively. Whereas in the design document the busiest station locations ranking from one to four are Bambi/EW14, Orael/EW13, Megenagn/EW9, and Gurd Shola/EW8 with respective passenger volume of 2,679, 2,654, 2,575, and 2,513. As the results showed the locations as well as maximum number of passenger differ in the two studies. As the modeling results are based on socio – economic and transportation networks input variables and the results were well validated with traffic count, modeling results are more accurate and reliable. In addition to that of the model, traffic flow diagrams of figure 25 and 26 which were generated from 2012 traffic count data indicated the maximum traffic locations similar with that of the model.

CHAPTER V
CONCLUSION AND RECOMMENDATIONS

As it is shown in the previous sections, the main objectives of this research was achieved; travel demand modeling of East – West LRT line using four – step travel demand modeling principle by utilizing TransCAD modeling tool and to compare results with that of the number of traffic proposed for LRT design.

As it has been shown in the modeling results, the base year number of intended LRT user traffic is bigger than the design's initial as well as short term ranges traffics. The design document of LRT line doesn't clearly state the methodology used to come up with the design figure for mode choice other than stating discrete mode choice formula with variables like modal share ratio, comfort, level of service, and living standards to be used as input to the calculation. Because of this reasons result discussions were limited to comparisons of result and findings only without commenting on the methodologies. Therefore, in this research it was possible to update model inputs of Addis Ababa travel demand model, and as a result of that, it was possible to determine, number of traffic in road corridor, number of traffic for different means of transport and possible station locations for LRT. With a percentage contribution of 25.9 % Addis Ababa East – West Light Rail Transport becomes the second mostly used mode of public transportation in the corridor next to Taxi. Looking at the modeling results number of LRT user is higher than expected/designed. In order to reduce the current influx of LRT passenger a quick review of operational plan is needed using model output results.

And finally, even though all the necessary efforts have been put on this research, there are number of limitations, therefore the recommendation given for further researcher is to avoid these limitations stated below.

The first limitation is modeling the transport network. As it is known to all, modeling transport infrastructure network for a big city like Addis Ababa by itself is a very big study which demands lot of resources. In this study, major road networks of the city, those of asphalts and at least two lanes were modeled in the network. With incorporating all transport networks and by categorizing with classes, and types, we could be able to incorporate parameter like those of level of service, design speed, and actual link speed and other network parameters that significantly affect modeling results. The second limitation of the research arise from the assumption of equal mode choice availability for a given transport means over a given network link. This limitation similarly associated with transportation network development. Since it was very difficult to model more than 300 route of Taxi, Bus or Medium Bus routes through Addis Ababa the above mentioned assumption was applied. The third limitation of this research was, conversion the twenty-four-hour trip rate (general base of travel demand models) over hourly flow rate, usually known as P – A to O –D conversion. Since it was very difficult and out of the scope of this research to collect city level O – D data for the entire Addis Ababa, and considering the mobility index of Addis Ababa (1.05), it is assumed that half of the total daily expected trip to be generated in the morning or evening rush hours. The fourth and final limitations of this research was vehicle occupancy determination of for public transport vehicles, which is collected on Lideta, Mexico, Lagar and Bambis area. With the help joint utilization of automatic traffic count and CCTV camera more accurate vehicle occupancy rate could be calculated for network links. Therefore, it is recommended for future researcher, to utilized detailed transportation network, traffic count, O – D matrixes, vehicle occupancy rate, data which hope fully collected and compiled by Addis Ababa Transport Bureau. Therefore, the recommended

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APPENDICES

Appendix A Calculated Population Projection of Addis Ababa in Kebele level

		2015	2020	2025	2030	2035	2040
AKAKI KALITY	KEBELE 01/03	30,422	34,124	37,820	41,517	45,213	48,909
	KEBELE 02/04	16,692	18,723	20,752	22,780	24,809	26,837
	KEBELE 05/06	21,003	23,562	26,116	28,670	31,224	33,778
	KEBELE 07/08/09	50,549	56,706	62,852	68,998	75,144	81,291
	KEBELE 10/11	54,742	61,401	68,049	74,697	81,345	87,993
	KEBELE 12/13	32,354	36,294	40,228	44,161	48,095	52,028
	KILINITO, FECHE KOYE (17/18/19)	6,117	6,861	7,603	8,346	9,088	9,831
	GELANGORA	4,660	5,225	5,790	6,355	6,919	7,484
NEFAS SILK LAFTO	KEBELE 03/04/05	41,638	46,714	51,782	56,849	61,917	66,984
	KEBELE 06/07/08	48,225	54,100	59,965	65,830	71,696	77,561
	KEBELE 09/14	40,061	44,944	49,818	54,692	59,565	64,439
	KEBELE 10/18	49,342	55,354	61,355	67,356	73,357	79,359
	KEBELE 12/13	33,487	37,570	41,647	45,723	49,800	53,877
	KEBELE 16/17	43,104	48,352	53,592	58,831	64,070	69,310
	KEBELE01, HANA, LEBU, DERTU	37,782	42,383	46,975	51,567	56,160	60,752
	KEBELE 02	38,502	43,194	47,878	52,562	57,247	61,931
	KEBELE 11	19,126	21,455	23,781	26,106	28,431	30,756
	KEBELE 15	26,625	29,873	33,114	36,356	39,598	42,840
KOLFE KERANIYO	KEBELE 02/03	39,265	44,047	48,821	53,595	58,369	63,143
	KEBELE 01/05	90,904	101,987	113,051	124,114	135,178	146,241
	KEBELE 08/09	48,625	54,537	60,438	66,340	72,242	78,144
	KEBELE 10/11	61,504	68,982	76,447	83,912	91,377	98,842
	KEBELE 13/14	45,348	50,868	56,379	61,889	67,400	72,910
	KEBELE 15/16	52,566	58,969	65,361	71,753	78,145	84,537
	KEBELE 06	49,892	55,977	62,051	68,125	74,200	80,274
	KEBELE 07	42,546	47,722	52,888	58,055	63,221	68,388
	KEBELE 12	15,568	17,462	19,353	21,244	23,135	25,026
	KEBELE 04	66,150	74,203	82,242	90,281	98,320	106,359
GULELE	KEBELE 01/02	25,003	28,046	31,083	34,120	37,158	40,195
	KEBELE 03/04/05	33,602	37,697	41,785	45,872	49,960	54,047

	KEBELE 07/17	29,258	32,818	36,371	39,925	43,478	47,032
	KEBELE 08/16	44,284	49,679	55,065	60,451	65,837	71,223
	KEBELE 09/15	38,180	42,835	47,481	52,126	56,772	61,418
	KEBELE 10/11/12	39,073	43,834	48,587	53,339	58,092	62,844
	KEBELE 13/14	28,347	31,800	35,247	38,694	42,141	45,588
	KEBELE 19/20/21	34,926	39,180	43,426	47,673	51,919	56,165
	KEBELE 06	15,849	17,782	19,711	21,640	23,570	25,499
	KEBELE 10/18	31,189	34,974	38,753	42,532	46,311	50,090
LIDETA	KEBELE 01/18	25,602	28,723	31,838	34,953	38,068	41,183
	KEBELE 02/03	29,362	32,938	36,508	40,078	43,648	47,218
	KEBELE 04/06	32,027	35,925	39,817	43,709	47,600	51,492
	KEBELE 05/08	33,652	37,752	41,845	45,937	50,030	54,123
	KEBELE 09/10	34,846	39,088	43,322	47,556	51,790	56,024
	KEBELE 07/14	31,526	35,368	39,202	43,036	46,871	50,705
	KEBELE 15/16/17	17,151	19,240	21,326	23,412	25,498	27,584
	KEBELE 11	15,968	17,913	19,854	21,796	23,737	25,679
	KEBELE 12	20,855	23,396	25,932	28,469	31,006	33,542
KIRKOS	KEBELE 01/19	21,789	24,445	27,096	29,747	32,399	35,050
	KEBELE 02/03	29,870	33,512	37,148	40,783	44,419	48,055
	KEBELE 05/06/07	34,016	38,164	42,305	46,445	50,585	54,726
	KEBELE 08/09	25,013	28,060	31,103	34,145	37,187	40,230
	KEBELE 11/12	27,327	30,657	33,982	37,307	40,632	43,957
	KEBELE 13/14	27,114	30,417	33,715	37,012	40,310	43,607
	KEBELE 15/16	20,464	22,954	25,439	27,925	30,410	32,896
	KEBELE 17/18	25,700	28,834	31,963	35,092	38,221	41,350
	KEBELE 20/21	24,565	27,560	30,550	33,540	36,530	39,520
	KEBELE 04	15,281	17,141	18,997	20,854	22,711	24,567
	KEBELE 10	13,199	14,807	16,412	18,017	19,623	21,228
ARADA	KEBELE 01/02	25,609	28,728	31,842	34,955	38,069	41,182
	KEBELE 03/09	29,542	33,143	36,737	40,331	43,925	47,519
	KEBELE 04/05	26,293	29,494	32,690	35,885	39,081	42,276
	KEBELE 07/08	30,237	33,925	37,606	41,287	44,968	48,650
	KEBELE 11/12	23,731	26,624	29,512	32,399	35,287	38,174
	KEBELE 13/14	33,647	37,750	41,847	45,943	50,039	54,135
	KEBELE 15/16	29,424	33,010	36,589	40,168	43,747	47,326
	KEBELE 06	16,332	18,323	20,310	22,298	24,285	26,272
	KEBELE 10	16,155	18,124	20,089	22,055	24,020	25,986

	KEBELE 17	21,734	24,382	27,025	29,668	32,311	34,954
ADDIS KETEMA	KEBELE 01/02/03	39,726	44,559	49,384	54,208	59,033	63,858
	KEBELE 04/05	32,427	36,376	40,318	44,260	48,202	52,144
	KEBELE 06/07	34,708	38,930	43,144	47,359	51,574	55,788
	KEBELE 08/09/18	39,503	44,306	49,101	53,895	58,690	63,485
	KEBELE 10/11/12	39,013	43,763	48,506	53,248	57,990	62,733
	KEBELE 13/15	27,716	31,092	34,463	37,833	41,203	44,573
	KEBELE 16/17	34,101	38,255	42,402	46,550	50,697	54,844
	KEBELE 19/20	23,654	26,535	29,410	32,285	35,161	38,036
	KEBELE 14/21	34,211	38,375	42,531	46,688	50,845	55,002
YEKA	KEBELE 01/02	32,458	36,415	40,365	44,315	48,266	52,216
	KEBELE 03/04	38,648	43,359	48,061	52,763	57,465	62,167
	KEBELE 06/07	22,518	25,264	28,006	30,748	33,489	36,231
	KEBELE 08/15	36,349	40,779	45,201	49,623	54,045	58,467
	KEBELE 16/17/18	65,751	73,760	81,756	89,751	97,746	105,741
	KEBELE 19	38,061	42,699	47,330	51,961	56,592	61,222
	KEBELE 20/21	77,803	87,276	96,733	106,189	115,646	125,103
	KEBELE 13/14	28,513	31,990	35,462	38,933	42,405	45,876
	KEBELE 11/12	25,445	28,549	31,648	34,747	37,845	40,944
	KEBELE 09/10	32,297	36,238	40,171	44,105	48,038	51,972
	KEBELE 05	16,370	18,369	20,363	22,358	24,353	26,348
BOLE	KEBELE 03/05	37,944	42,569	47,185	51,801	56,418	61,034
	KEBELE 04/06/07	34,688	38,917	43,139	47,361	51,584	55,806
	KEBELE 08/09	24,167	27,111	30,049	32,988	35,926	38,865
	KEBELE 12/13	29,111	32,661	36,204	39,748	43,292	46,836
	KEBELE 14/15	97,254	109,098	120,922	132,746	144,570	156,394
	KEBELE 16/18/21/22	16,161	18,126	20,088	22,050	24,012	25,974
	KEBELE 17/19/20	25,827	28,969	32,106	35,243	38,379	41,516
	KEBELE 01	33,699	37,806	41,907	46,007	50,107	54,208
	KEBELE 02	9,745	10,934	12,121	13,307	14,494	15,680
	KEBELE 10	38,551	43,252	47,944	52,636	57,329	62,021
	KEBELE 11	22,042	24,734	27,421	30,108	32,796	35,483

Appendix B. Population Projection of Addis Ababa with Age Groups by CSA

Population by sex and age group of Addis Ababa July 1,2007			
	Total	Male	Female
All ages	2,735,500	1,307,800	1,427,700
0-4	198,300	100,800	97,500
5−9	210,300	102,000	108,300
10−14	250,700	109,200	141,500
15-19	386,500	153,500	233,000
20-24	405,900	184,800	221,100
25-29	371,900	180,000	191,900
30-34	233,300	126,300	107,000
35-39	189,400	98,300	91,100
40-44	120,300	65,900	54,400
45-49	102,400	51,100	51,300
50-54	80,800	39,000	41,800
55-59	55,300	28,300	27,000
60-64	47,500	23,900	23,600
65-69	34,800	17,900	16,900
70-74	26,500	12,700	13,800
75-79	13,600	6,800	6,800
80+	8,000	7,300	700

Projected population size of Addis Ababa by five-year age (medium variant) July1,2008			
	Total	Male	Female
All ages	2,791,989	1,332,622	1,459,367
0-4	209,499	106,246	103,253
5−9	206,602	101,507	105,095
10−14	235,877	105,434	130,443

15-19	368,315	145,264	223,051
20-24	412,147	182,321	229,826
25-29	390,389	186,617	203,772
30-34	257,272	136,616	120,656
35-39	197,891	103,639	94,252
40-44	131,194	71,209	59,985
45-49	104,333	53,146	51,187
50-54	85,257	41,058	44,199
55-59	58,611	29,573	29,038
60-64	48,144	24,230	23,914
65-69	36,085	18,467	17,618
70-74	27,100	13,113	13,987
75-79	15,024	7,257	7,767
80+	8,248	6,925	1,323

Projected population size of Addis Ababa by five-year age group (medium variant) July 1,2012			
	Total	Male	Female
All ages	3,047,234	1,447,451	1,599,783
0-4	283,135	142,892	140,243
4−9	200,643	100,253	100,390
10−14	218,057	104,205	113,852
15-19	266,223	113,621	152,602
20-24	409,558	160,677	248,881
25-29	422,594	191,491	231,103
30-34	376,677	182,505	194,172
35-39	234,048	126,426	107,622
40-44	188,200	97,522	90,678
45-49	118,171	64,521	53,650
50-54	99,519	49,430	50,089
55-59	77,399	37,015	40,384

60-64	51,650	25,997	25,653
65-69	42,253	20,849	21,404
70-74	28,634	14,373	14,261
75-79	19,325	8,950	10,375
80+	11,148	6,724	4,424

Projected population size of Addis Ababa by five-year age (medium variant) July 1, 2017			
Age group	Total	Male	Female
Total	3,434,458	1,625,142	1,809,316
0-4	350,829	177,289	173,540
4−9	285,568	142,065	143,503
10−14	210,301	103,182	107,119
15-19	236,800	109,637	127,163
20-24	295,407	123,154	172,253
25-29	430,486	169,769	260,717
30-34	429,059	195,105	233,954
35-39	376,182	182,129	194,053
40-44	232,861	125,502	107,359
45-49	184,791	95,479	89,312
50-54	115,211	62,593	52,618
55-59	95,621	47,083	48,538
60-64	72,609	34,193	38,416
65-69	46,373	22,901	23,472
70-74	35,181	16,945	18,236
75-79	21,203	10,306	10,897
80+	15,976	7,811	8,165

Projected population size of Addis Ababa by five years' age group (medium variant) July 1,2022			
	Total	Male	Female
All ages	3,854,866	1,819,241	2,035,625
0-4	379,452	191,993	187,459
5–9	354,509	176,931	177,578
10–14	295,972	145,159	150,813
15-19	231,151	109,355	121,796
20-24	269,605	120,470	149,135
25-29	321,101	134,392	186,709
30-34	439,223	174,952	264,271
35-39	429,354	195,312	234,042
40-44	373,316	180,503	192,813
45-49	229,095	123,118	105,977
50-54	180,159	92,667	87,492
55-59	111,067	59,842	51,225
60-64	90,067	43,733	46,334
65-69	65,646	30,357	35,289
70-74	39,106	18,870	20,236
75-79	26,480	12,365	14,115
80+	19,562	9,221	10,341

Projected population of Addis Ababa by five-year age group (medium variant) July 1,2027			
	Total	Male	Female
All ages	4,268,158	2,008,509	2,259,649
0-4	373,454	189,160	184,294
5–9	384,999	192,519	192,480
10–14	365,614	180,188	185,426
15-19	317,638	151,350	166,288

20-24	266,089	120,773	145,316
25-29	297,501	132,478	165,023
30-34	332,733	140,866	191,867
35-39	440,841	176,149	264,692
40-44	426,824	194,025	232,799
45-49	367,327	177,151	190,176
50-54	223,772	119,715	104,057
55-59	173,792	88,701	85,091
60-64	105,060	55,870	49,190
65-69	81,876	39,078	42,798
70-74	55,978	25,290	30,688
75-79	29,961	14,013	15,948
80+	24,699	11,184	13,515

Projected population size of Addis Ababa by five-year age group (medium variant), July 1, 2032			
	Total	Male	Female
All age	4,670,091	2,190,651	2,479,440
0-4	365,915	185,500	180,415
5−9	380,827	190,663	190,164
10−14	397,051	196,142	200,909
15-19	388,424	186,666	201,758
20-24	354,090	163,084	191,006
25-29	296,012	133,639	162,373
30-34	310,634	139,605	171,029
35-39	336,740	143,158	193,582
40-44	439,397	175,784	263,613
45-49	420,850	190,865	229,985
50-54	359,017	172,336	186,681
55-59	216,336	114,842	101,494
60-64	164,807	83,050	81,757

65-69	96,066	50,222	45,844
70-74	70,416	32,825	37,591
75-79	43,624	19,036	24,588
80+	29,885	13,236	16,649

Projected population size of Addis Ababa by five-year age group (medium variant), July 1,2037			
	Total	Male	Female
All ages	5,085,540	2,376,095	2,709,445
0-4	387,729	196,647	191,082
5−9	374,903	187,661	187,242
10−14	394,116	194,637	199,479
15-19	421,608	202,849	218,759
20-24	427,114	198,574	228,540
25-29	385,403	176,044	209,359
30-34	310,432	141,262	169,170
35-39	315,728	142,282	173,446
40-44	337,598	143,768	193,830
45-49	434,251	173,440	260,811
50-54	412,109	186,003	226,106
55-59	347,515	165,459	182,056
60-64	205,715	107,842	97,873
65-69	151,313	74,897	76,416
70-74	83,228	42,501	40,727
75-79	55,409	24,936	30,473
80+	41,370	17,293	24,077