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M.A. PROJECT ON

GIS BASED SPATIAL INVESTIGATION AND MODELING OF ROAD NETWORK STRUCTURE IN ADDIS ABABA CITY

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GIS BASED SPATIAL INVESTIGATION AND MODELING OF ROAD NETWORK STRUCTURE OF ADDIS ABABA, ETHIOPIA

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A Project Submitted to the Department of Geography and Environmental Studies in Partial Fulfillment of the Requirements for the Degree of Master of Arts in Geography and Environmental Studies with Specialization in GIS, Remote Sensing and Digital Cartography.

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This is to certify that the project prepared by Tseday Tesfahu, entitled*: GIS Based Spatial Investigation and Modeling of Road Network Structure in Addis Ababa City* and submitted in fulfillment of the requirements for the Degree of Master of Arts in Geography and Environmental Studies with Specialization in GIS, Remote sensing and Digital Cartography.

Examining committee

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ABSTRACT:

GIS BASED SPATIAL INVESTIGATION AND MODELING OF ROAD NETWORK STRUCTURE OF ADDIS ABABA , ETHIOPIA

TSEDAY TESFAHUN

ADDIS ABABA UNIVERSITY, 2014

This project designed aiming for equitable road network structure for both people of urban and peripheral areas. In order to investigate road network structure, the research employed GIS techniques and some statistical analysis by Trans-CAD for cross sectional efficiency of the system. Types of data i.e. data obtained through methods such as, socio economic data, land use map, current road network and master plan road network. The result of this project indicated that road density, higher trip production and attraction is exhibited in the central areas (characterized by high population and important socio-economic activities of the city including freight terminals, service centers and schools). As settlements in Addis Ababa are mainly established along the road network, the road length per unit person in the central areas is found to be low. Proximity to the roads within the central areas is less than 500m, allowing more people to access these roads. However, in the periphery, people have to travel more than 1km to access the existing road infrastructure, indicating the inadequacy of the system. The Mobility Index indicated that have high values in the South-East and Western parts of the city. The overall conclusion obtained from the indicators show that there is less road infrastructure in the peripheral regions of the city and the central area clearly has a capacity limitation.

KEY WORDS; *Central Business District, Mobility Index, Proximity, Trip production and Trip Attraction.*

Acknowledgment

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“All things were made through him and without him nothing was made that was made”; John; 3

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List of Acronyms

AACRA	Addis Ababa City Road Authority
AutoCAD	Computer Aided Design
CBD	Central Business District
CRBS	China Road Bridge Corporation
EMA	Ethiopian Mapping Authority
EUTP	Ethiopian Urban Transport Policy
ERA	Ethiopian Road Authority
ERC	Ethiopian Railway Corporation
ESRI	Environmental Systems Research Institute
FSUTM	Four Steps Urban Transport Model
GIS	Geographic Information System
NBI	Network Based Indicators
ODM	Origin Destination Matrix
PCE	Passenger Car Equivalent
SI	Sufficiency Index
SMI	Spatial Mismatch Index
SPSS	Statistical Package for the Social Science
TAZ	Traffic Analysis Zone
UNEP	United Nation Environmental Program
UTPS	Urban Transport Planning System
UTS	Urban Transport Study
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WHO	World Health Organizations

CHAPTER ONE

1. INTRODUCTION

1.1 Background to the Study

Transport service is one of the important urban services, which influences and impacts on regional pattern of development, economic viability ,environmental impact and on maintaining socially acceptable levels of quality of life (Murray et al.,1998). Hanson in 1984 states that transport is an absolutely necessary means to an end and allow people to carry out the diverse range of activities that make up daily life. It is a means to access business activities, education, employment and recreational opportunities (Murray et al., 1998).

There are many reasons for why people take trips in urban areas, but trips to work and schools, accounting for (40-50 % and 20-35%) of urban trips respectively, are the major components of travel in developing countries (Mohan, 1994 cited in Ingram, 1998). In general, transportation systems form the base by which economic development can occur and the means by which society interact (Murray et al., 1998).

The urban road network plays a key role in the urban spatial structure (Weiping, and Chi, 2003). It is the main city social-economic activities and transportation carrier. Today, more researchers are paying attention to road network and one of the most important problems is how to assess the accessibility of road network. Hansen in 1959 proposed the accessibility concept for the first time and defines it as the transport network in various nodes interaction opportunity. Hereafter, accessibility is widely applied in research and road network plan, construction, and evaluation. In transportation geography, the road network accessibility evaluation has emerged as an important problem. But, accessibility does not have a uniform concept till now.

The current performance of road network can be investigated based on the structure of the road network (Xie & Levinson, 2007), the access and mobility it provides (Gtierrez, etal., 1998 & Lio and Zue, 2004), measuring the capacity of network (Chen et al., 1999) and by assessing special mismatch between demand and supply (Grishenko, 2011).

Even though, no transport network can serve all travel demand perfectly, the amount by which it fails to do so can be useful to study existing network and identify areas with inadequacy of infrastructure (Davidson, 1998). Network effectiveness indicators, which compare the real road network to geographically perfect network, can be used to identify these areas (Davidson, 1998).

Addis Ababa has a radial form of road network which is shaped by five major roads radiating from the central business district CBD (Yared, 2010). Although, the idea of building ring road was emerged during Derg régime, the construction of ring road was started in 1998 to implement the city master plan and enhance peripheral development (Yared, 2010). For this project, China Road and Bridge Corporation (CRBC) was the partner of Addis Ababa City Roads Authority (AACRA). The Ring Road has greatly helped to decongest and alleviate city car traffic (Yetnayet, 2012).

In Addis Ababa, light rail system is also planned; in September 2010, Ethiopian Railway Corp reached a funding agreement with Export and Import Bank of China scheduled for completion in 2015. Plans include a 30 km network with two lines; an east-west line from Ayat to the Torhailoch ring road and from Menelik Square to Mercato Bus Station, Meskel Square and Akaki (ERC, 2012).

While this railway network had been in progress since its construction started in 2013, it is difficult to assess its status. So, this project mainly emphasis to assess road network structure through four stage urban transport modeling.

1.2 Statement of the Problem

The transport sector is the backbone to the economic growth of a nation and road network remains the basic and critical component of transport system in the country.

Ethiopia has some of the most dangerous roads in the world and has pursued an ambitious road expansion policy in the past ten years (WHO, 2010). The Ethiopian national road safety coordination office sites a road crash fatality rate of 114 deaths from 10,000 deaths per year but the real figure may be higher due to under reporting (WHO, 2010).

In Addis Ababa, because of the rapid economic growth and transformation (Fentahun, 2011), there is a high mobility of goods and peoples who leads to high transportation demand. The evolution of the transportation network is closely related to the change and growth of central places (Ducruet, 2011). Recently constructed ring road has added an orbital road around the periphery of the CBD. There are other road links which in their continuity, can be considered as partial orbital corridors. Even though, a well defined hierarchal system is missing, still the road network could be classified into a hierarchal system comprising of arterial, sub arterial, collector and residential across roads (AACRA, 2013).

The road network of Addis Ababa suffers from many inadequacies including quality of roads, low accessibility level, narrowness, limited network extent and no pedestrian walkway, shortage of road network with respect to the size of the city, lack of street parking facility and over utilization of off street parking facility, over utilization of road spaced by parked vehicles poorly designed road junctions, substandard terminals for passengers and freight transport and inconvenient bus and taxi ways, lack of segregated bikeways (Fantahun, 2012). Main causes for these problems are link with poor infrastructure specially, on road and public transport network, poor interactive link between land use and transport planning, poor coordination between the cities urban development and road transport plans, and facilities. Most of peripheral areas of the city are victims of the above problems. There are newly developed real estates, and areas that provide agricultural products to the city. As per the urban transport study (2006) plan some of these areas are reserved for future industrial development.

There are few researches conducted with regards to the whole transportation system. The available researches consider, public transportation services, traffic accident effects, and so on. Such as Abate (2007) discussed on analyzing public transport performance using efficiency measures, Yared (2010) investigated the impact of vehicular traffic congestion of Addis Ababa, Fantahun (2012) discussed integrating public transport network and built up environment. Yetnayet (2012) tried to evaluate the whole status of transport network structure of Addis Ababa. But, their methodologies have a gap of focusing on the current road network coverage compared with demands side and not effectively use GIS instruments for analysis part.

Therefore, in this study, the researcher tried to use GIS software integrating with Trans-CAD, so as to investigate the road network of the city. Based on the analysis, remedial measures are proposed to improve the road network coverage and efficiency. In addition, assessing current road network with respect to the current demand helps decision making by understanding and identifying of how much the network satisfies the demand and identifies which areas need more attention for the future development plan.

1.3 Objective of the Study

The general objective of this project is to understand and investigate the existing road network structure status and trends using spatially modeling of travel demands and recommended feasible improvements in network structure, taking Addis Ababa city as a case study.

Specific objectives

1. To assess the status and trends of road network structure of Addis Ababa through four stage urban transport modeling.
2. To examine road density and road hierarchy as well as its capacity;
3. To develop areas of transportation mismatch;
4. To develop road network-based model on transport demand in the study area.

1.4 Research Questions

Based on the specific objectives identified, the following questions are forwarded.

1. In the existing road network structure, which areas are observed to be missing infrastructure?
2. Are existing roads having a capacity limitation?
3. Which parts of the city are exposed as areas of high transportation mismatch and why?
4. What special techniques are needed to develop road network-based model on transport demand in the study area?

1.5 Significance of the Study

This project would be significant in identifying the indicators that are used to investigate the current road network structure of the capital city. Also, it can be used as a reference for further studies. The city road authority may use it as a reference while they are preparing their route map. GIS students who want to study about transportation by integrating Arc GIS with AutoCAD have a clue to combine those of two elegant tools.

1.6 Scope of the Study

The study area is the capital city of Ethiopia, Addis Ababa. The total area of Addis Ababa is 540 km^2 with the total road network length of 701 km including all arterial, sub arterial, collector and local roads. The study area contains different types of land uses i.e. road network, business districts, industrial area and residential and the like.

This project mainly emphasizes on the road network coverage of both central and peripheral areas of Addis Ababa.

GIS is a spatial technique which is particularly used in this project. The parameter used by this project to assess road network structure are four stages of urban transport modeling, and other factor like proximity, mobility index and spatial mismatch are used by taking TAZs as raw data for analysis part but also other techniques like Trans-CAD are used to analysis based on socio-economic and demographic data.

1.7 Limitation of the Study

The drawback of this study is mainly availability of data, which is mostly at a zonal level while disaggregating these zones into smaller unit's assumptions had to be made, this may cause some uncertainty in the actual demographic and socio-economic data. The other limitation is the traffic assignment model used. Since this model doesn't consider the flow as a function of capacity some roads may be assigned traffic more than their capacity. The data collection has also encountered a problem, even there is no route map for Addis Ababa city road authority.

1.8 Definitions of key Terms

In situating road network structure in Global context, it may be useful to view the meaning and definition of the following terms.

Central Business District- Is a focal point of a city. It is the commercial (geographic heart of the city) and office center of the city and usually typified by a concentration of retail and office building **(**Olayiwola, 2014**).**

Euclidean Distance - Is the distance between two points in Euclidean space. It was originally devised by the Greek Mathematician Euclid around 300 B.C.E to study the relationship between angles and distance (Robinson, 2014).

Mobility - Is the movement of individuals or groups from place to place, job to job, or one social or economic level to another. The function of the road network is to facilitate movement from one area to another. As such, it has an important role to play in the urban environment to facilitate mobility. It further determines the accessibility of an urban area together with public transport options (Hagenzierker, 2000).

O-D Matrix - It finds and measures the least cost paths along the network from multiple origins and to multiple destinations (Williamson, 1978).

Proximity - Is nearness in distance, time, order, occurrence, or relation (closeness) creates a link between peoples and elements (Wilson, 2011).

Road Hierarchy- Is a classification of road according to their function and capacities. While source differ on the exact nomenclature, the basic hierarchy comprises freeways, arterials, collectors and local roads (Silcocks, 2004).

Road Network – Is a system of interconnected paved carriages ways which are designed to carry buses, cars and other vehicles. The road network generally forms the most basic level of transport infrastructure within urban areas, and will link with all other areas, both within and beyond the boundaries of the urban areas. It includes, motor way, high way, and main and national roads, secondary or regional roads and all other road in a country (Ahmed and Carlos, 2013).

Spatial Mismatch -Is the sociological, economic and political phenomena associated with economic restructurings in which employment opportunities for low income people are located far away from the areas where they live. I.e. the form of high concentration of poverty in central cities, with low wage, low skill employment opportunities concentrated in suburbs (Stoll, 2005).

Transportation Mismatch - Is the lack of access to a private automobile on neighborhood employment to population ratios and unemployment rates. It is responsible for high unemployment rates in the inner city (Paul and Miller, 2003).

Traffic Analysis Zone- Is the geographical unit most commonly used in conventional transportation model, the size of a zone varies, but for typical metropolitan planning software, a zone of under 3000 people is common (Taylor,1998).

1.9 Organization of the Project

The overall project is organized under five chapters as follows: Introduction, Literature review, Materials and Methods, Results and Discussion and Conclusion and Recommendations.

Chapter 1 - Gives brief introduction of the research, identifies research problems, defines research objectives and questions related to the objectives, and also significance of the project, scope of the study, limitations, and definition of key terms are discussed.

Chapter 2 - Briefly review literatures on transport network modeling, criterion that are used to investigate transport network structure and travel demand modeling.

Chapter 3- Describes the study area; data collection methods, data & software types used by this project, and also have a methodology part.

Chapter 4 – Give explanation about a result and discussion part of transport modeling and investigation of the current network. Furthermore, results of the spatial mismatch assessment are provided. Finally, in Chapter 5 conclusions and recommendations are made based on the results of the project

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Modeling Road Network

Transport demand modeling helped us to understand the travel demand, which itself provides an understanding of the relationship between urban structure and the transportation (Timnemeans et al., 2003).

Even though transport is dynamic in nature, modeling large real networks usually is done on the basis of static models as is done in this study from these GIS is able to handle huge data and analyze the variety of network related problems by itself and can also be integrated with other methods for road network analysis by providing a spatial data base and mapping platforms (Kubyo,et al., 2005). For instance, it can be integrated with graph theory to measure network efficiency (Rodrigue, 2009). Graph theory depends on the concept of representing networks as a graph or matrix. The underlying basics of this science assumes that road networks can be represented by straight graph with nodes and links where the nodes represent junctions while links indicate homogeneous road sections between nodes (Zuidgeest & Maarseveen, 2011, cited in Yetnayet,2012).

These network analysis methods are founded on the principle that the efficiency of a network depends partially on the geographical lay-out or structure of the nodes and links forming the network. The matrix representing the network can be manipulated mathematically with a series of network measures (Kubyo et al., 2005).

Since, the late 1950s, several networks based indicators/measures/ had been developed to analyze road network based on structural efficiency, connectivity, cyclic property, etc. of the network. For example, (Garrison and Marble, 1962, 1964 and 1965) developed the first of such indicators, including:

- Alpha index (a measure of connectivity which evaluates the number of cycles in a graph in comparison with the maximum number of cycles),
- Beta index (which measures the level of connectivity in a graph and is expressed by the

  relationship between the number of links over the number of nodes), and
- Gamma index (measure of connectivity that considers the relationship between the number of observed links and the number of possible links).

Recently, (Xie & Levinson, 2007) developed new indicators which consider flow on the road network for measuring the structure of road network. Even though these indicators consider flow, they do not consider spatial distribution of demand. The other difficulty is, indicators can differ significantly depending on many factors such as city type, regional transportation vision, or travel behavior even between modes (Derrible & Kennedy, 2011). Finding appropriate indicators that can be used to assess transport network structure of Addis Ababa is one of the interests of this study. In urban transport, the network structure and flow mutually affect each other (Xie & Levinson, 2007).

Therefore, while optimizing the network, a combination of spatial (with respect to demand) and network indicators is required. Network indicators analyze the network structure whereas the travel demand (trip) consists of the desire to make a trip.

Trips are made to join activities via particular modes of travel, which uses specific routes through the road network. Once this demand is realized, it becomes spatial interaction which flows through transport network.

In this study, the current road network structure of Addis Ababa investigated by using network indicators to analyze the existing pattern of travel demand and the structure of the network supply. Methodologies which assist in rationalizing the network by identifying and prioritizing the required infrastructure is developed and implemented in for Addis Ababa road Network. The recommended (proposed) road network that follows compared with the existing one based on pre-determined transport planning objectives.

2.2 Network Evaluation Indicators

2.2.1 Mobility

Mobility is the ability to move people and goods. Increasing the efficiency and effectiveness of road network will increase mobility. In developing countries with low infrastructure both of travel and safety are major factor affecting mobility and the quality of being moved (Zuidgest, 2005). In order to measure the efficiency of the road network, a mobility index defined. Mobility index is defined as the ratio of travel distance by the physical route (speed determined by the type of road) between an origin and destination and the travel distance by the air line distance at desire speed (ERA, 2001).

Mobility is affected by the network structure and condition. Network structure determines how direct the route between two points is and type of the road determines how fast the vehicles can travel. The network considered well connected if the mobility index falls between 1 and 1.41 (the ratio of the sum of the two sides of triangle and the diagonal)

(Ethiopian Roads Authority, 2001).

2.2.2 Equity

Equity refers to the distribution of resources (in this case road network) and if the distribution is considered appropriate (Litman, 2011). In developing countries with different nationalities like Ethiopia, equity between different ethnic groups must be considered. Based on the development plan for Addis Ababa, in this research I consider Spatial and socio-economical equities.

2.2.3 Accessibility

Accessibility is one of the important characteristics of urban transport and it shows the relationship between transport and land use (Liu & Zhu, 2004). In the past years researchers have used accessibility for integrated transport land use planning for urban areas (Liu & Zhu, 2004) ,as a key element in efficiency analysis of transport network and infrastructure planning (Gutierrez, et al., 1998), and to generate the travel demand on public transport (O'Sullivan, et al, 2000).Curl, et al.,2011 had revised literatures on the theoretical definition and measures of accessibility and to what extent it can be used to reduce inequality in the society. It can also be used to access changes by providing new road infrastructures (Liu & Zhu, 2004). (Linneker & Spence, 1996) used accessibility to analyses the impact of motor way development in regional development.

2.2.4 Transport Infrastructure Availability

One of the important factors affecting the performance of the road network is the availability of adequate transport infrastructure. Transport infrastructures include road length, road width, public transport hubs and even road furniture and these factors affect the accessibility of transport system (Scheurer, 2011). Roads should be of sufficient width, suitability graded and located, and adequately constructed to accommodate the traffic, afford adequate light and air, facilitate public transport, provide access for fire protection, and refuse protection vehicle and road maintenance equipment. These roads should be coordinated so as to compose a convenient system properly related to the proposal shown on the development plan. The arrangement of road should be such as to avoid undue hardship to adjoin property ownership /occupiers/ and no property shall be rendered inaccessible from an existing public road or from a proposed road in a subdivision (Scheurer, 2011).

2.2.5 Spatial Mismatch

It has been used by different authors to detect the availability of jobs for the low income group within their reach depending on the cost of travel (Joseph, 2011; SMcLafferty, 2001) and to analyze transport mode chose and ethnic groups (Patacchini & Zenou, 2005). Considering the jobs as supply and employees as demand, this concept is used to analyze the spatial difference that exists between demand and supply. This indicator compares trip distribution among traffic analysis zones considering the resistance (impedance) travelers experience by using the existing real network and that experienced in the direct route (Euclidean distance between two zones).The trips along TAZs are trips that use the links in these zones.

Trips equation

$\Delta Tij = \Delta TijED / \Delta TijND$ Spatial mismatch index 1

$\Delta Tij = \Delta TijED - \Delta TijND$ Spatial mismatch index 2

2.3 Transport Demand Modeling

Travel demand modeling is one of the important part of the decision making process in transport (Brutton & Hensher, 2000). It assists engineers and planners to improve road networks, better utilize current network capacity, understand special impacts (Zuidgeest & Maarseveen, 2011 cited in Yetnayet, 2012).

Demand is driven from the need for travel of people. Travel demand models should reflect the reasons for travel are to make part in activities and specially activities that are not present at the current position (Button & Hensher, 2000).

There are number of travel demand models used in urban transport studies. The researcher adopted some parts of Four Stage Urban Travel Demand Model.

The approach considers zoning and network system, and the collection and coding of planning Calibration of validation data (Ortúzar & Willumsen, 2011). The base year data include population of each zone and level of economic activities. It establishes quantifiable relationships between travel patterns and population, spatial distribution of economic opportunity (employment) and socio economic Characteristics of the population in the study area.

In this project, the researcher used several components of the Four-Step Transport Model (FSTM) for the analysis of travel demand on the road network.

As standard traffic modeling exercise on large networks suggests, the study area partitioned into TAZ to quantify the demand using the first sub model of the FSTM, namely, Trip Generation model used to estimate the correlation between socio- economic properties of the TAZ and levels of trip productions and attractions from them. The second sub-model of the FSTM, namely, Trip Distribution is, then, implemented by estimating the zone-to-zone cost matrix for the network by using trip distance as the only factor contributing to the generalized cost of travelling between the TAZ centroids. The resulting Origin-Destination matrix forms the trips that are made between the TAZ centroids. Since, at this stage, it should be considered all modes of transport, to make the trip, therefore, the modes not be split and the OD Matrix had considered all the available modes. At this stage, the third sub-model of FSTM, Modal Split modeled and implemented to estimate the trips that are made using the different modes of travel. The last of the Sub-Models of the FSTM is Traffic Assignment stage where we assign the trips by modes to the available network supply.

The research had used the All-Or-Nothing (AON) Traffic Assignment for this purpose. The AON Assignment is the simplest of available assignment models which, however, offers the best estimate of assigned traffic on the network in a case where the trips are heavily dominated by walking modes, as is the case in the study area under consideration.

Finally, trips passing through each zone are computed by corresponding OD routes passing through them. The following section discusses these transport modeling steps in greater detail.

2.4 Traffic Analysis Zones

Urban transport modeling depends on traffic analysis zones (TAZs) as its basic unit of analysis (You, Nedović-Budić, & Kim, 1998).The centered of TAZs is used to represent trip origins and destinations. Every employment centers, shopping centers, households and other activities of the planning region are aggregated into zones and are further simplified in to single node assuming they are concentrated at the centric.

Before performing a transport model, the researcher must decide the level of detail to be adopted in the study depending of the accuracy needed and resources available. A greater accuracy can be achieved by using more detail zoning system because this would eventually represent every individual. However, using highly detailed zones may not be economically feasible since handling large volume of data may be difficult whenever forecasting is involved (Ortúzar & Willumsen, 2003).

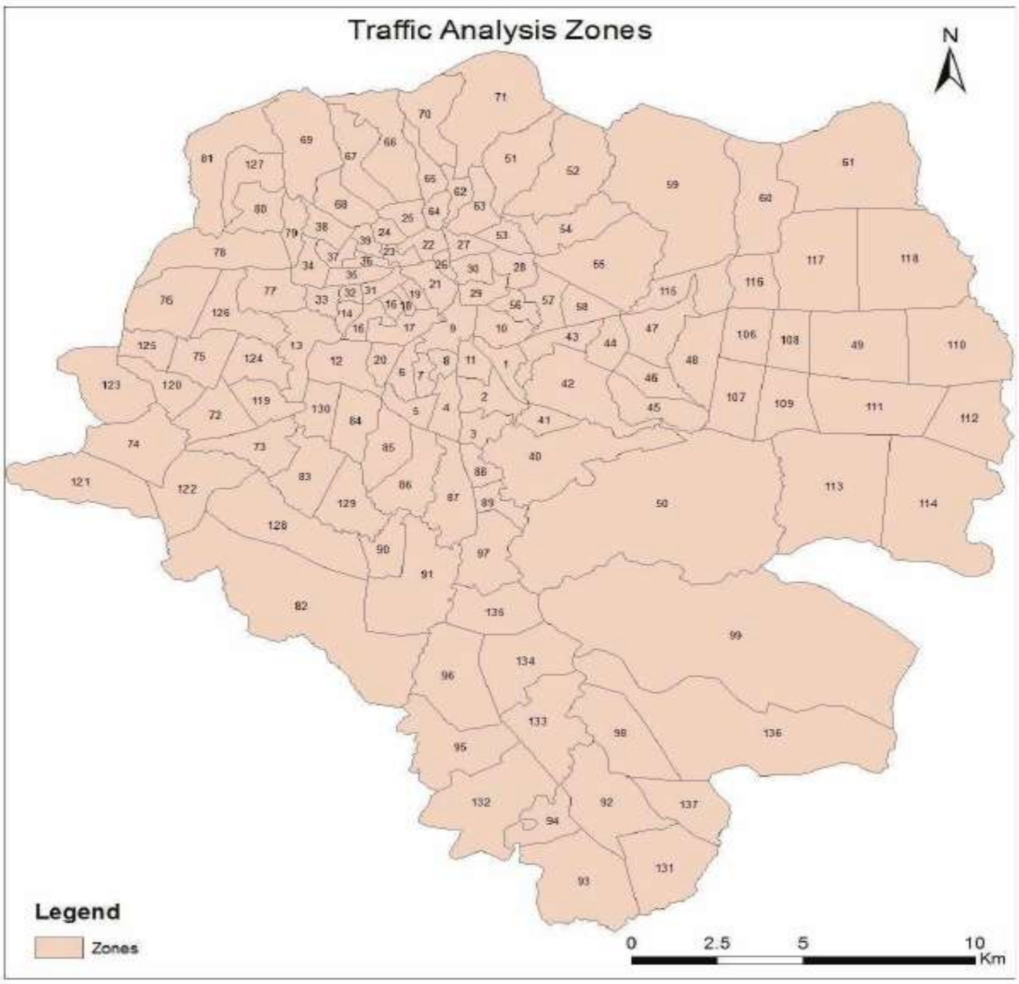


Figure 1: **Traffic analysis zones**

Source: *UTS, 2006*

Gravity Model

This model is mostly used when base year OD is not provided or important changes take place in the land use and road network. The model is mainly based on Newton's Gravity Low and assumes trip making behavior is influenced by external factors like total trip ends and distance travelled (Ortúzar & Willumsen, 2003). After many experiments and research it was concluded that the effect of distance on trip making could be modeled better by decreasing function with the following equation.

$T = \alpha O\ D\ (\ )$

Where: O and D are the number of total trip ends in zone i and j respectively.

α is balancing factor $f(c\ )$ is the deterrence function or impedance function. This function decreases as travel cost or distance (time) increases.

2.5 Traffic Assignment

This step is performed in the subsequent part of transport modeling exercise where demand is loaded to the transport network. There are number of traffic assignment models developed in the past years. The simplest route choice model is all-or-nothing assignment. In this assignment, all the trips from any origin to any destination are assigned to single minimum cost path between them (Ortúzar & Willumsen, 2011).

This method assumes that all trip makers are aware of the shortest route before making the trip and cost of travel stays the same. This method has some limitations because it ignores the fact that cost on link is a function of volume and that when there is congestion multiple paths may be used.

Mekbib in 2007 has noted that, simplified models like all-or-nothing (AON) assignment can be useful for developing countries like Ethiopia where versatile packages for traffic modeling and spatial data analysis are lacking for long term planning. AON assignment is also useful in areas where major mode of transportation is walking.

2.6 Road Density

Road density can be measured as the ratio of the total road network in an area to the land area or to the total population in that area. Given similar network topology, in different zones, higher road density (road per area) implies a higher availability of alternative routes (Jenelius, 2009). Also, this implies higher directedness and connectivity levels within the network. The road density assesses the network structure only considering the supply side whereas the road density per unit of population measures the availability of network distance per person.

Africa has low road density, 6.84 km per 100 km^2, as compared to Latin America's 12 km per 100 km^2 and Asia's 18 km per of 100 km^2 (Economic Commission for Africa, 2007). Object-Oriented Network Model a transport network can be represented by two object classes, defined above as Link and Node. The transport network, inherits the properties of its two subclasses. Because of the topological attributes of a network, a connection relationship has to be established between the link and node classes. It defines and nature and extent of the geometric connectivity.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Geographical profile of the study area

Addis Ababa is the capital city of Ethiopia. The city has historical, diplomatic and political significance for Africa that is why it's referred to as "the political capital" of Africa.

Addis Ababa lies at an average altitude of 7,546 feet (2,500 meters) and is a grassland biome, located at the latitude of 9°1′48″N and longitude of 38°44′24″E (United Nations Environmental Programme,2003) . The city lies at the foot of Mount Entoto. From its lowest point, around Bole_International airport, at 2,326 meters (7,631 ft) above sea level in the southern periphery, the city rises to over 3,000 meters (9,800 ft) in the Entoto Mountains to the north. Its topography ranges from rolling plate all too hilly area with relatively steeper gradients and numerous river stream valleys, Addis Ababa city Administration extends over 540 KM^2 with 10 sub-cities (UNEP, 2003).

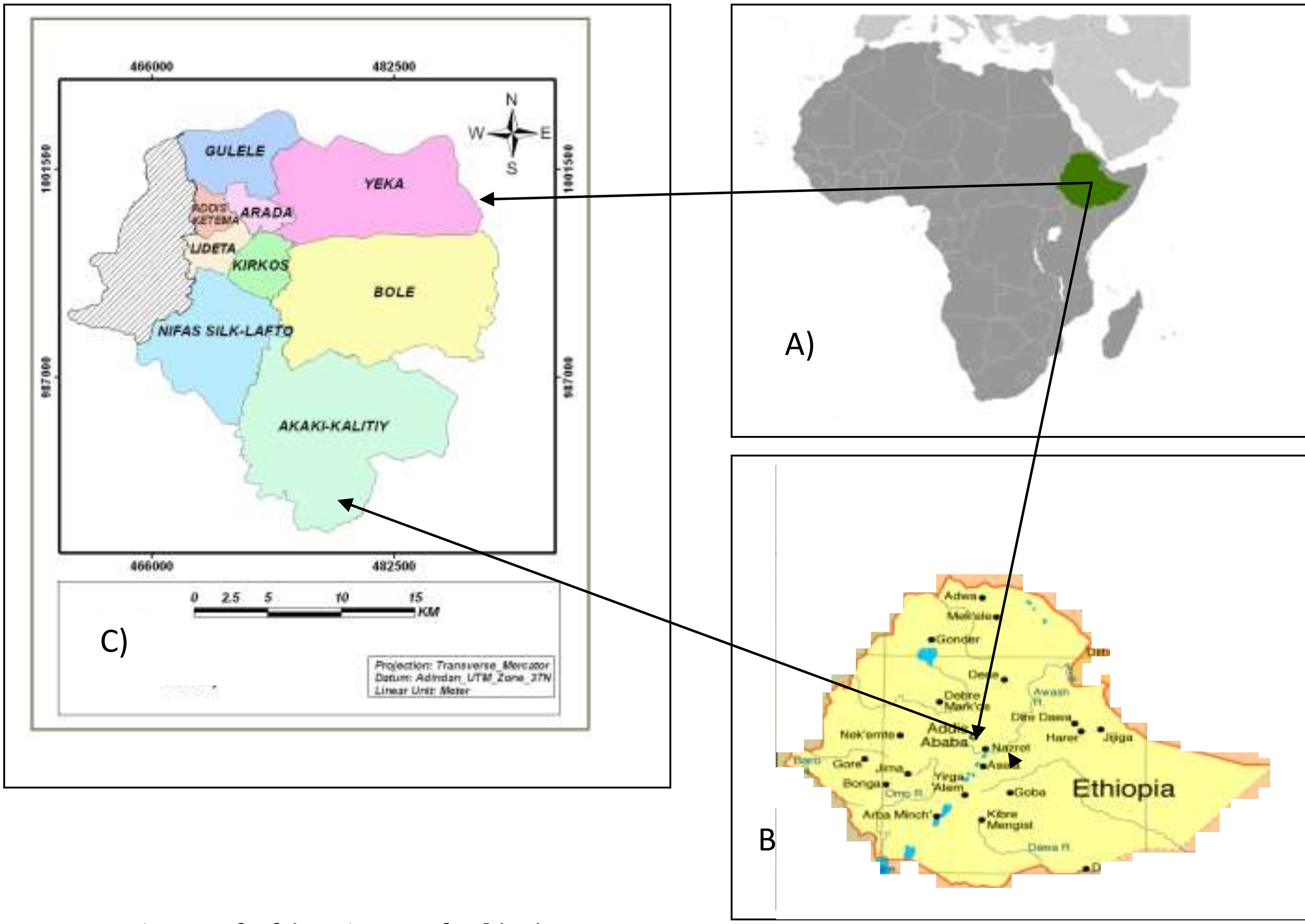


Figure 2: **A) Map of Africa B) Map of Ethiopia**

C) Map of Addis Ababa

Source: *CSA, (2010), Google Earth online, (2014)* Based on the master plan from Urban Transport Study, 2006 the administrative units are further divided in to 131 Traffic Analysis Zones. The city has experienced spatial spread mostly on outer boundaries three sub cities i.e. *Akaki- kality, Bole* and *Nifas Silk.* However, the spread is mainly guided by the city landscape and its road network development.

Population and socio-economic characteristics of the study area

In a mobile society, social, economic status and demographic characteristics are influential in the magnitude and pattern of their movement. So, exploring about peoples demographic characteristics and socio-economic status helped to know the purpose of why peoples travel.

3.1.2 Population

Addis Ababa has a total population of 3,227,268 of which 48% males and 52% females (CSA, 2010).

In the same year there were 662,728 households living in 628,984 housing units, which results in an average of 4.1 persons to a household.

Generally the densely populated areas are found in the central residential areas around Addis Ketema sub city, from where the density goes on decreasing towards the periphery.

The four core sub-cities have relatively equal distribution of population. Even though, these areas only account for 8% of the total of the city but accommodate about 32% of total population.

Table 1: **Addis Ababa Population by Sub-City, 2010**

N0	Sub city	Area (km^2)	Population (2010)	Density (in persons/km^2)
1	Addis Ketema	7.41	271,644	36,659.1
2	Akaky Kaliti	118.08	195,273	1,653.7
3	Arada	9.91	225,999	23,000
4	Bole	122.08	328,900	2,694.1
5	Gullele	30.18	284,865	9,438.9
6	Kirkos	14.62	235,441	16,104
7	Kolfe Keranio	61.25	546,219	7,448.5
8	Lideta	9.18	214,769	23,000
9	Nifas Silk-Lafto	68.30	335,740	4,915.7
10	Yeka	85.98	368,418	4,285
Central area total		41.12	947,853	428,659
Peripheral area total		485.87	2,059,415	30,433
Addis Ababa total		526.99	3,007,268	459,092

Source: *CSA, (2010)*

Most of the population is dominated by youth, with average age of 25- 29 years old.

The illiteracy rate is high, 19% of the adult population has no formal education. Based on the household income, consumption and expenditure survey UTS (2006) there were about 786,000 employed people.

3.1.3 Economy and Income

The economic activities in Addis Ababa are diverse. According to official statistics from the federal government, some 119,197 people in the city are engaged in trade and commerce; 113,977 in manufacturing and industry; 80,391 private producer of different variety; 71,186 in civil administration;50,538 in transport and communication; 42,514 in education, health and social services;32,685 in hotel and catering services; and 16,602 in agriculture.

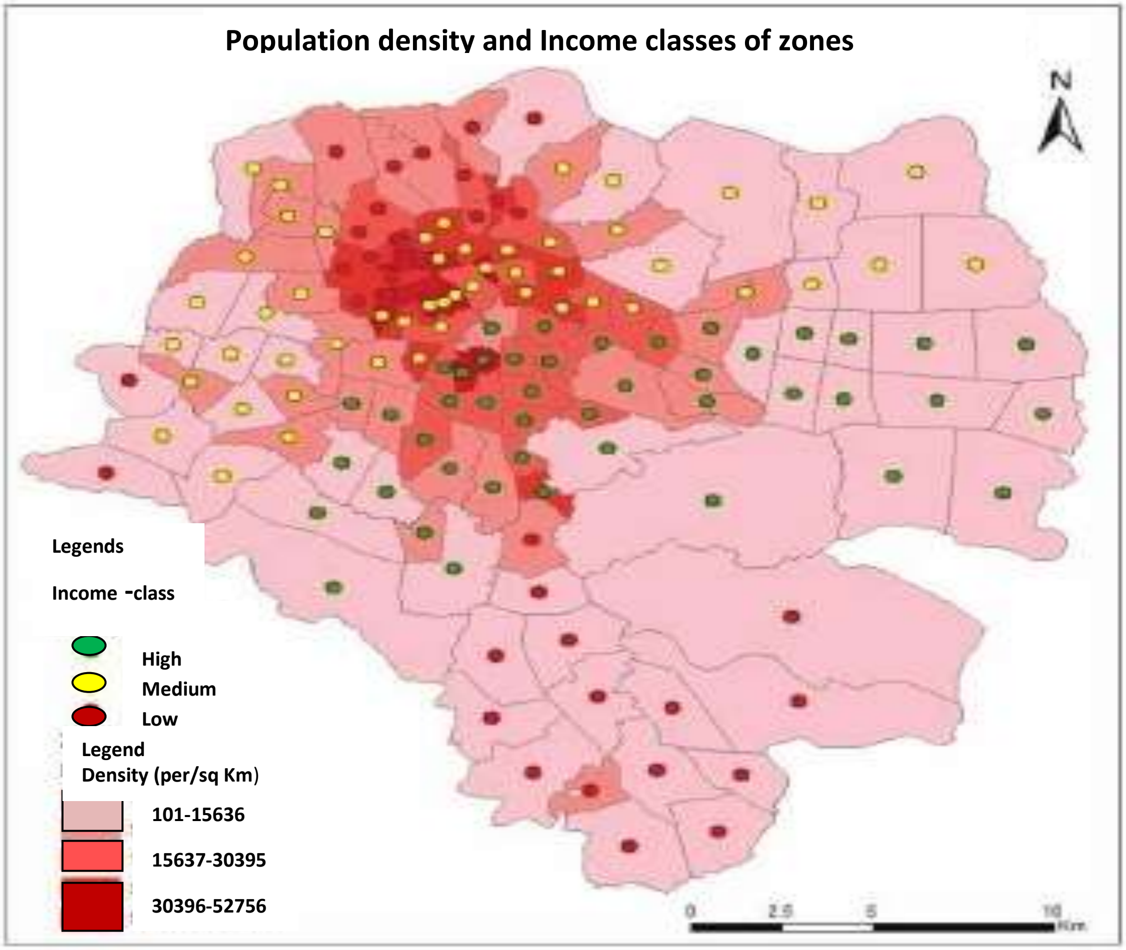


Figure 3: **Population density and income class of Zones**

Source: *(CSA, 2012)*

In addition to the residents of rural parts of Addis Ababa, the city dwellers also participate in animal husbandry and market Gardening. The irrigated land is 677 ha, on which about 129,880 quintals of vegetables are cultivated.

Based on the CSA in 2007, there were 652,000 households with average household size of the level of income is low and average household monthly income is about 725 Ethiopian Birr.

Nearly 50% of the population is below poverty line with income less than 400 birr per household per month and 23% are in absolute poverty with less than 260 Ethiopian Birr per month (Miheretu, 2005). The income levels are divided in to three classes, high income levels (>2500birr), medium (between500 and 2500birr) and low income groups (<500birr) per month (Miheretu, 2005). It can be observed that the central area has higher population and the income level at these areas is medium to low. These areas correspond to the old city. Mainly central sub-cities, *Arada, Cherkos, Lideta* and *Addis Ketema* are characterized by slum settlement.

In recent years, even though the government has been working on reducing the slum areas from central part, some pockets still remain. Low income class can also be observed in the southern part of the city with low population where these areas are mostly agricultural areas. High income levels are observed in the two sub-cities of *Bole* and *Nefas Silk Lafto*. These sub-cities have large development of new real estate and flourishing suburbs with low population density.

3.1.4 Land Use

Identifying about cities land use and its intensity is important to understand Mobility within the city. The following land use distribution of the city is prepared as part of the city master Plan (2002-2010).

Table 2: **Major component of the land use (2002-2010)**

Major Components of the land use Plan	**Area(ha)**	**Percentage**
Mixed use (Housing) Built up	16,274	31.3
Mixed use (Housing) Expansion Area	6,974	13.4
Existing Industry(industrial area)	1,244	2.4
Proposed Industry(industrial area)	1,777	3.4
Central business district	1,276	2.4
Existing Social Service Area	495	1
Proposed Social Services Area	600	1.2
Road Network coverage	1,975	3.8
Transportation	989	1.9
Forest Open Space/	12,176	23.4
Agricultural Area	7,175	13.8
Reserved Area	1,045	2
Total	**52,000**	**100**

Source: *AACRA(2012)*

From table 2, the researcher found that, out of the total land, the road network takes only 3.7%, which indicating poor level of network development. Whereas, an efficient system and demand needs 20 to 25%. The road network also suffers from inadequacies like absence of balanced hierarchy, capacity limitation and low connectivity (ERA, 2006). And, most of the development of the city is with defined residential, commercial and industrial areas.

The main commercial and industrial complexes can be identified being concentrated in three key areas, in addition to main road corridor strip development. *Merkato* is the main commercial center of the city lying mostly with in *Addis Ketema* sub-city.

The major land freight terminals are situated within this area. Most of governmental services lie in *Arada* and *Lideta* sub-cities, known as *Mexico, Piazza* and *Arat* kilo. Industrial areas are mainly located along the North-South road corridor mainly in *Akaki Kality*.

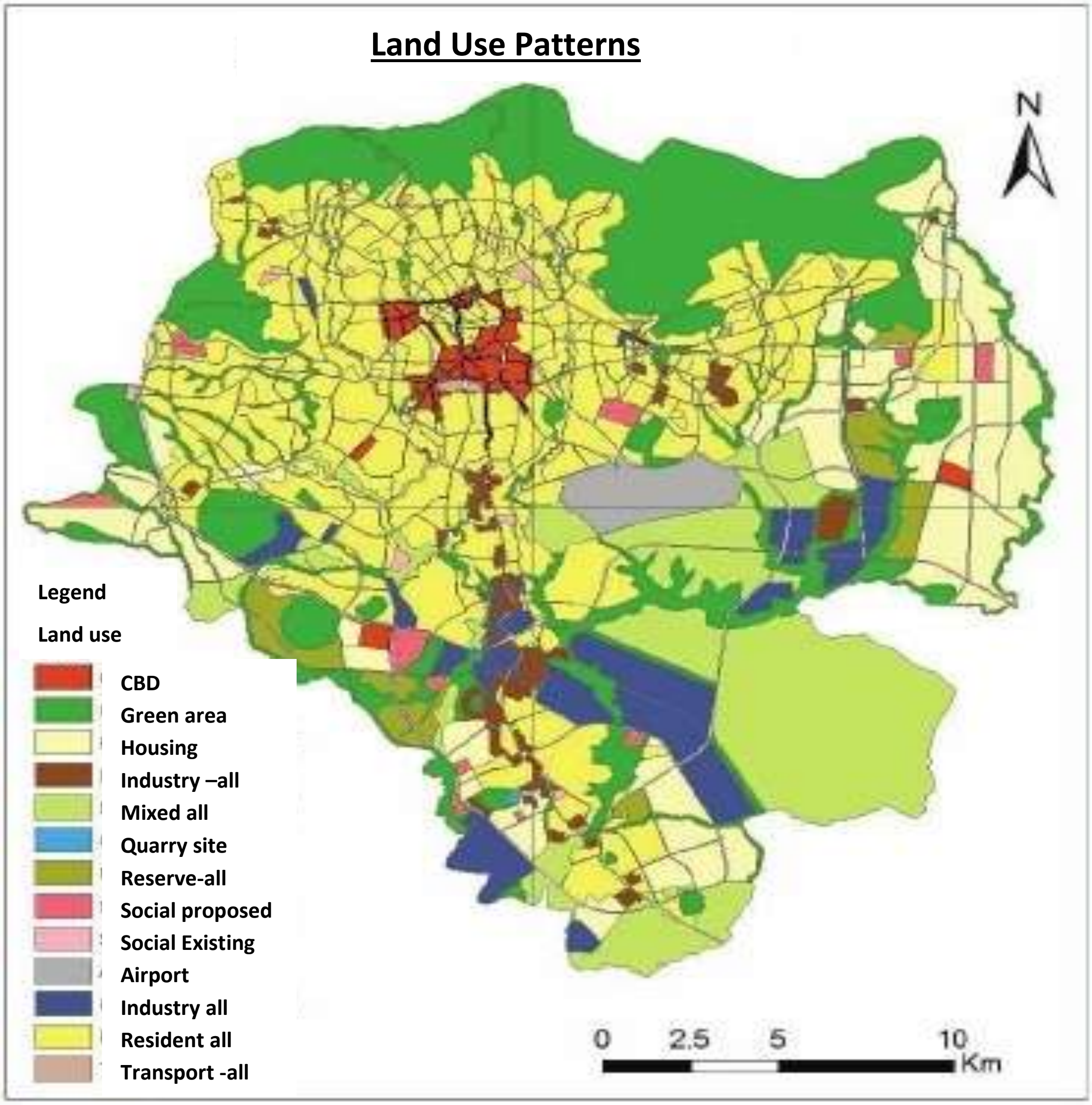


Figure 4: **Land use map of Addis Ababa**

Source: *AACRA (2012)*

3.1.5 Transport and Road Network

The main components of Addis Ababa transport system are the road network, city buses, minibuses, taxis, small number of private vehicles and large pedestrian. The road network provides the means for travel through the city. But, in the near future light railways expect to be another means of transport service assumed to extend for 30 km.

Distribution of passenger traffic by Modes of Transport (%)

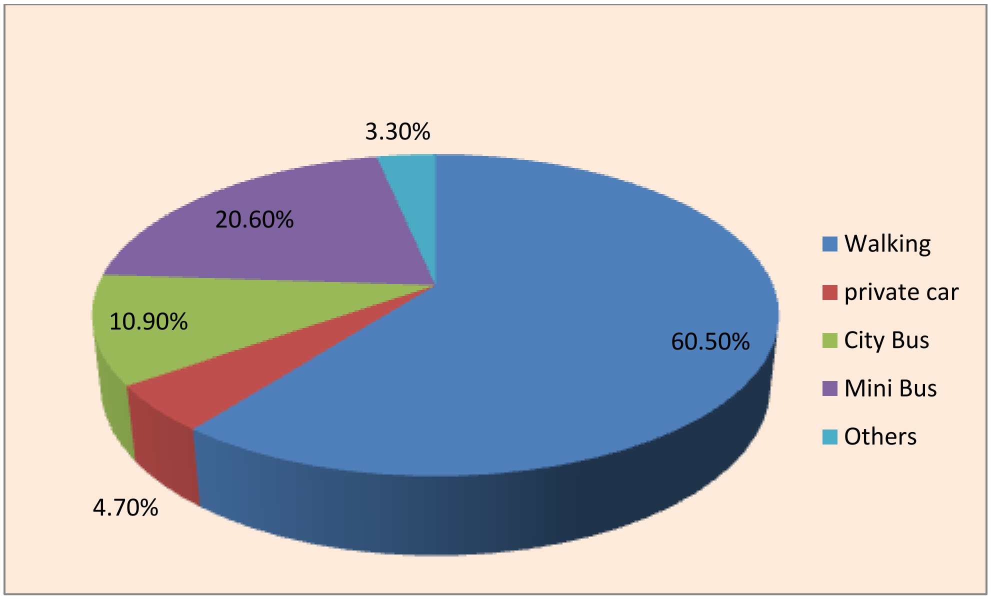


Figure 5: **Pie chart of modes of transportation and percentage**

Source: *AACRA, (2013)*

Based on Urban Transport Study (2006), the road availability is insignificant. The network is expected to carry additional 20000 daily passengers, to relieve transport congestion in the Ethiopian capital.

Central Business District areas are characterized by intense generation of traffic by all modes; but, capacities are limited due to high traffic volumes on street and on street parking. The road network has pattern which is shaped by five major roads radiating out of the Central Business District (CBD) to the outskirts. Proper identified four hierarchies are still mismatch. Which are, Arterials, Sub-arterials, collectors and local or residential roads. As up to July 10, 2013, AACRA had a total paved road network length of about 701 Km covering above four categories of roads. The distribution of road network length provided by AACRA is given below.

Arterial /Main Roads

These are main roads which include main residential roads, and would normally be used as bus routes or as heavily used traffic routes through residential areas: a minimum of 15.24m/50ft reservation is required. It covers 333kmof the total road length. These roads have varying widths ranging from 30m to 60m. These roads are expected to provide fast movement of traffic due to possibility of physical segregation of local and bus (public) vehicles traffic from the general traffic stream. The ring road is included in this category (AACRA, 2013).

Sub Arterial Roads

These roads are links of lower hierarchy with proposed widths of 20m and 25m.The sub arterial roads will operate as single or dual carriageway roads with constrained lane width of 3m, having direct implications on the speed and capacity. These roads seem to be of lower width than expected for the nature of traffic operations expected from roads of this category. It covers 119km of the total roads (AACRA, 2013).

Collector Roads

These roads are further lower categories in network hierarchy and are proposed to function as connectors as per the Master Plan. The proposed minimum width of collector and Local roads are proposed as 15m and 10m respectively. It covers 114km of the total roads (AACRA, 2013).

Local Roads

These are access links to residential or business areas. It covers 135km of the total road length of the city. In Addis Ababa city, 60% of the total passenger traffic is pedestrian, Anbessa city buses and mini buses and currently Bishoftu buses are predominant types of public transportation in the city which cover almost70% of public transportation system (AACRA, 2013).

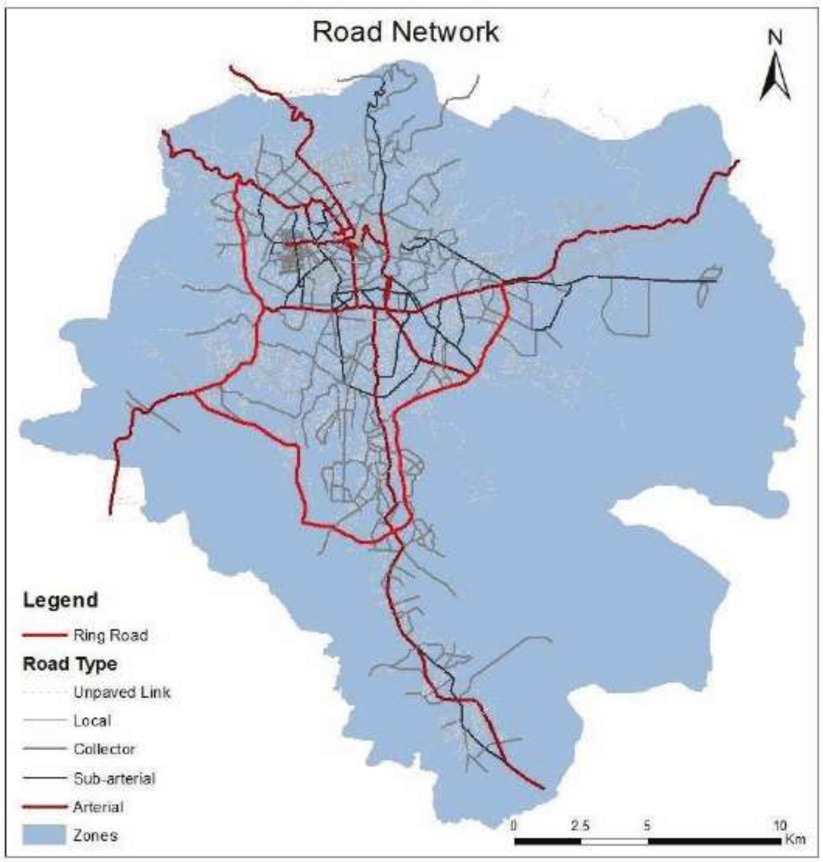


Figure 6: **Hierarchical road patterns of Addis Ababa**

Source: *AACRA, 2013*

Table 3: **Road hierarchy of Addis Ababa, 2013**

No	Road hierarchy	unit	Total length	Length in no.of pavement 7m	No of bridges status	Status of road pavment
1	Arterial	Km	333	1291	116	Very good
2	Sub arterial	Km	119	267	55	Very good
3	collector	Km	114	114	66	Good
4	local	Km	135	135	40	Good
Total		Km	701	1807	277	
Cobblestone		Km	147	147	-	-
Gravel road		km		1777	-	-
Total road length in km				3731	-	

Source: *AACRA (2013)*

3.1.6 Types of data collected and source

The types of data used in this project composed mainly secondary data. The data identified is given in table No. 4.

Table 4: **Secondary data collected and sources**

Data types	**Source**	**Format**
Socio-economic data	AACRA/Urban	Excel
Demographic data	AACRA/Urban transport	Excel
Land use map	AACRA	Auto cad
Traffic analysis zone of sub	AACRA	Shape file
Current road network	ERA/AACRA	Shape file
Master plan road network	EMA/AACRA	Auto-cad

Source: *by Author*

3.1.7 This project used the following Soft wares

The basic or main software that used by this project are the following

- ARC GIS 9.3or ARC GIS 10.1
- Auto-CAD
- Trans-CAD

3.2 Methodology

A key component in the emerging methods and techniques for better understanding transportation systems and process geographic information systems (GIS). GIS have proving to be valuable transportation management and modeling platforms. Its query, spatial analysis and network analysis capabilities make it attractive tool for this research uses were defined and validated. The attribute collected from different source as excel sheets were converted to DBASE file format and joined with the appropriate shape file in ArcGIS. Since the maps were obtained from different sources, the co-ordinates were defined and the coordinate systems of others were transformed into the working coordinate system.

So, visually the lines which make up the route were selected from general road network and topology rules were checked and validated. Finally, the routes were constructed in ArcGIS using the route create wizards.

Most map data were collected in AutoCAD format and for analysis in ArcGIS these data were converted into ESRI shape file. The method used is export data in Arc GIS 9.1. After data collection from secondary data maintenance and preparation and data analysis using statically (Trans-CAD) and GIS techniques .The state of art software like Arc GIS and Trans-CAD had been used by this project.

After gathering all the necessary data the first requirement is to prepare the data for analysis. Since the data collected are from different sources and period, converting them to same form and analysis period is essential to obtain accurate results in later stages. This is done by unifying data, changing data formats, building the road network, updating the demographic and socio-economic data, joining with map and adding missing attributes to the road network.

In this research, since the researcher does using ArcGIS software for analysis, the available data in AutoCAD format are converted into ESRI shape files. Before exporting these files to ArcGIS the data was cleaned and topological rules are defined in AutoCAD Map 2010. There is a three meter shift between the paved roads and the total road network. This was also corrected in AutoCAD by taking the paved road as reference. Finally, all shape files are transformed to Ethiopia coordinate system which is WGS1984 zone 37 N.

3.2.1 Project design and work flow

Figure 7 shows the procedural steps in carrying out the research. The necessary data were collected during the field work and prepared to make suitable for analysis. Finally, analyses at different levels were carried out. Existing situation analysis was done to assess the performance of the existing system which led to modeling of the public transport system to identify deficient network elements. Based on analysis result conclusion and recommendation for future were drawn.

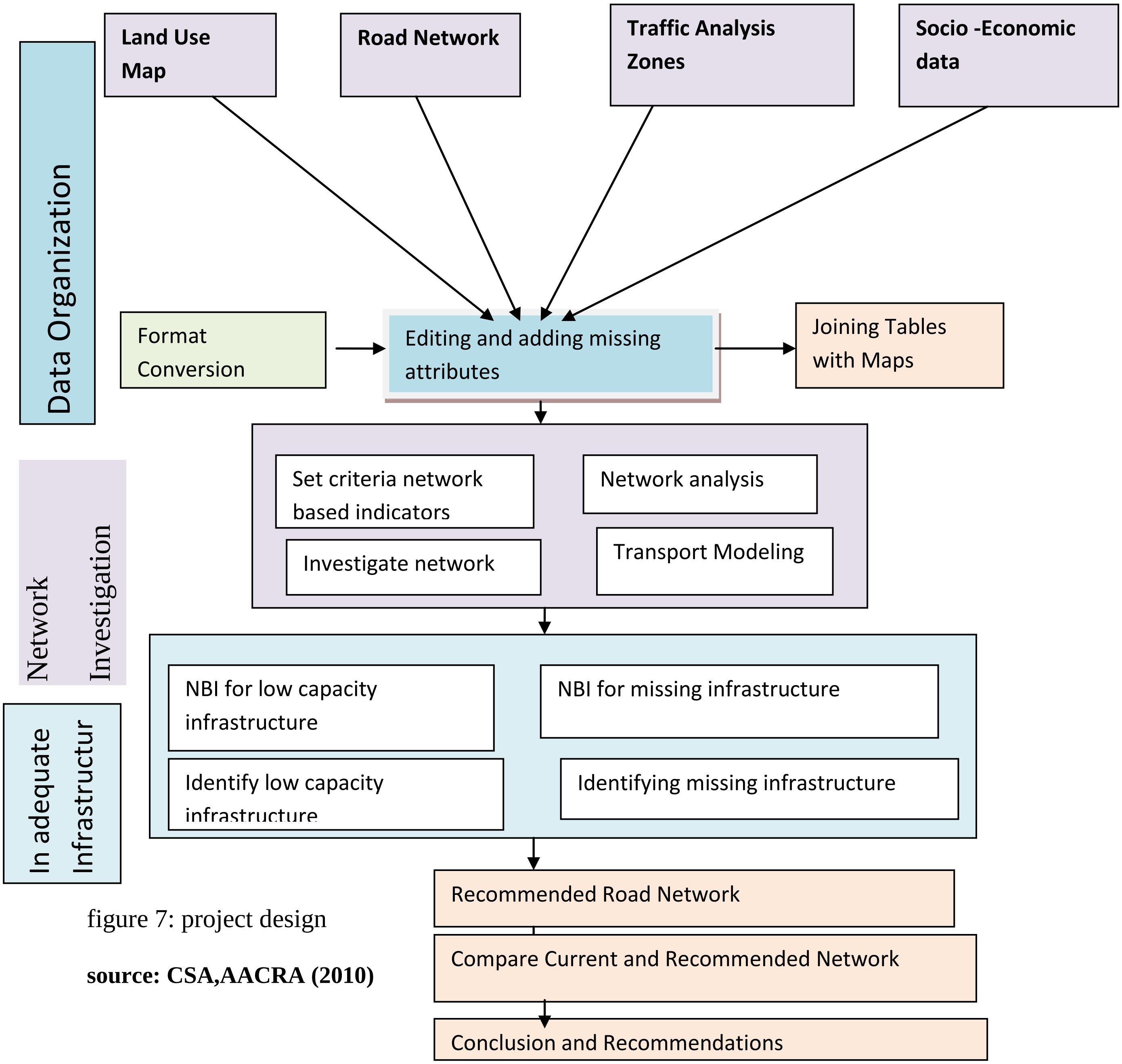


figure 7: project design

source: CSA,AACRA (2010)

3.2.2 How to build the Network Dataset

Using the data collected during field work the real network is built in ARCGIS using the following procedure. The road network data was in two formats; center lines of paved road in AutoCAD format while unpaved roads are available in a shape file format. Hence, the shape file is exported to AutoCAD Map10 and given a layer name 'unpaved road' and is later combined with the paved roads. In order to ascertain that the two data sets actually match, the total road network is added as a reference layer. After checking that the two data sets are aligned, the reference layer is conveniently removed. The next step is to define the network topology and cleaning the data in AutoCAD.

Following, it a Geodatabase was defined in ArcGIS to convert the data to shape file after which the road network data is imported from AutoCAD. Topological rules are defined to check the network data once again. After validating and correcting the topological errors for the road network layer, the data is exported to a new feature class. Then, the 131 zone centers are added to the map as a layer. The road network is edited to connect the zone centers to the nearest perpendicular road. Finally, using this road network layer, network dataset is built using distance as an impedance factor between two central areas.

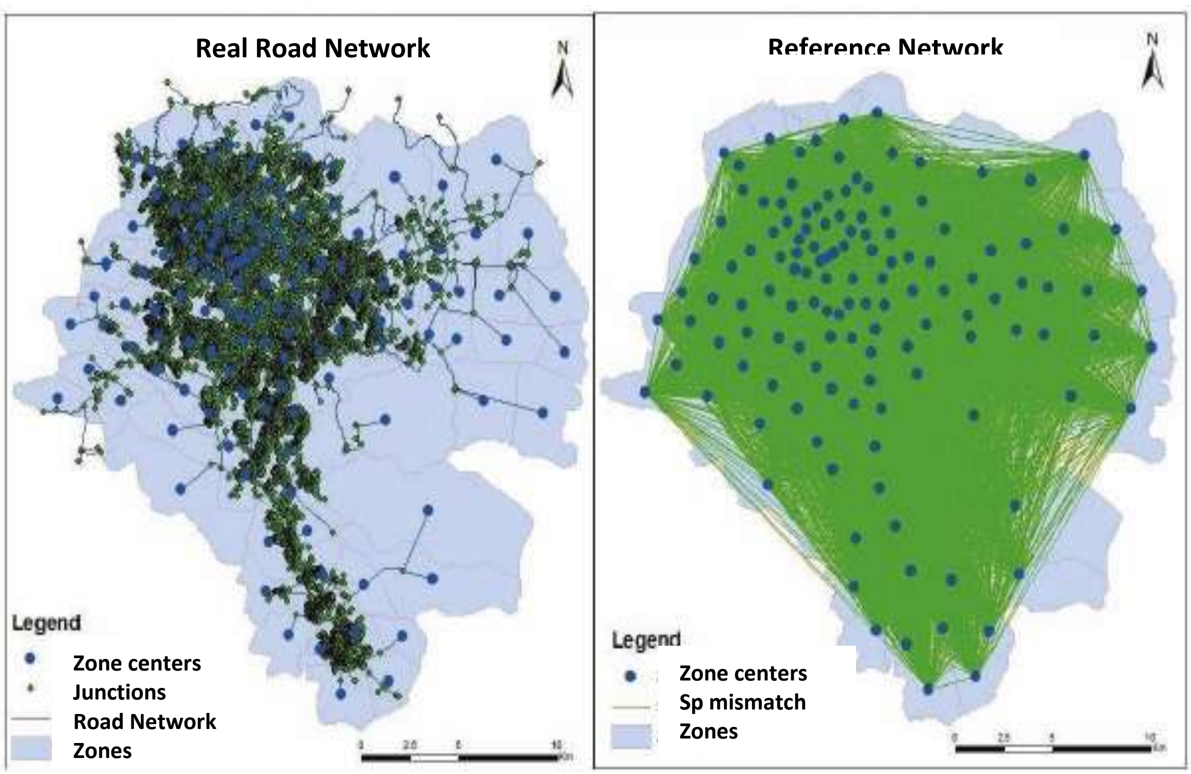


Figure 8: **Desire Lines and Reference Road Networks**

Source: *UTS (2006)*

The OD cost matrix is computed using ArcGIS Network Analyst Cost-OD-Matrix. Zone centers are used as origin and destination and the output is set to be sorted using zone number so that it would help to join with the zone data. As many as 17,161 desire lines were produced from each origin and destination (131 zones). The desire lines have important attributes including origin, destination and total distance on the existing network. The desire lines represent the Euclidean distance between zones, but they don't have this as an attribute (Figure 8). To add the shape length of the desire lines, these lines were exported to shape file. The exported desire lines are later used as the Reference Network for the spatial mismatch computation. The attribute table was then exported to excel file for further analysis.

CHAPTER FOUR

4. RESULT and DISCUSSION

4.1 Travel Demand Modeling

For travel demand modeling as is mentioned in the literature review part, it is basic to use some parts of four stage urban travel demand modeling (FSUTDM) for this research. By using the same procedure as FSUTDM, trip generation and trip distribution parts are computed. But, for assigning traffic, after assigning the trips to the links, the trips along each TAZ are computed and assigned to the zone. Each stage of the computation is discussed in following way.

4.1.1 Trip Generation

This is the first stage of the transport modeling. The number of trips generated by each zone (O) and attracted to each zone (D) is predicted based on socio-economic and house-hold data. There are two types of trip generation analysis; trip attraction (associated with trips attracted to non-residential end). And, Trip Production (associated with trips generated at residential end) with in this research, the trip generation model is adopted from the Urban Transport Study (2004, 2006 E.C) for Addis Ababa. The available demographic and socioeconomic data are aggregated at zone level. The city is divided into 131 Traffic Analysis Zones based on the smallest administrative unit, County (Kebele), and Kebeles were further subdivided to ensure homogeneity in the zone. Trip attraction and production are computed for each TAZ using Multiple Regression Model (Trans-CAD) based on household survey and depending on trip purpose. 20 equations were developed for trip production and 8 equations for trip attraction (The equations and R are given in Appendix B.2 and B.3). From these equations the following were adopted.

Table 5: **Regressions equation for trip attraction and production**

Trip production	**Equation**	**Symbols**
Work trip	1.46*w	W=number of workers
Educational trip	1.684*St	St=number of student
Other trip	0.199*Pop	Pop=population
Non home based trip	0.023*Pop	Pop=population
Trip Attraction		
Total work trip	1.57*E	E=Employment
Total educational trip	1.67*St	St=Number of student
Total other purpose trips	0.86*E	E=Employment
Total non home based trips	0.0695*E	E=Employment

Source: *Urban Transport Study (2006)*

The total attraction and production of trips from each zone is computed using these equations. Since the total trips produced by all zones should, in principle, be equal to the total trips attracted to all zones, matching the two values would be necessary. Assuming the production is more reliable, the attraction was matched to it using the following balancing factor.

Balancing factor $= \frac{\sum O}{\sum D}$

$\sum O$: The sum of trips produced by all zones, i

$\sum D$: The sum of trips attracted by all zones, j

4.1.2 Trip Distribution

The main purpose of this step is to develop a procedure that creates the trip linkages between traffic zones. In other words, trip distribution approximates the travel pattern, by distributing the production & attraction end of trips, into different traffic zones, based on some deterrence function. There are different models that can be used to model trip distribution. From these models, a common method in most studies is used in the Urban

Transport Study (2006), which is doubly constrained gravity model. The Gravity Model is based on Newton's Gravity Law. The basic principle is that the number of trips between two zones i and j is directly proportional to the number of trips produced in zone i, number of trips attracted to zone j, and inversely proportional to some function of the spatial separation of the two zones (Ortúzar & Williamson, 2011). The parameters in the gravity model are calibrated using Trance-CAD software by purpose of trip in the Urban Transport Study for Addis Ababa. The calibrated parameters are given in Table 6.

Table 6: **Gravity model calibrated parameters**

Number	Purpose	Parameters
1	Work purpose	α: 0.170513 β: 0.0382317
2	Education purpose	α: 0.306575 β: 0.0508996
3	Other purpose	α: 0.148312 β: 0.051476
4	Non home based purpose	α: 0.132755 β: 0.0575394

Source: *Urban Transport Study (2006)*

The deterrence function can be computed using travel time or distance or generalized cost as deterrence factors. In our case, since researcher does not have the travel time on each link in congested environment, it should be considering travel distance as impedance. To use distance as impedance the following assumptions are made:

1. Trip made between two zones is only dependent on the distance between them.

2. There are no barriers between origin and destination zones.

3. Trip length between zones is constant.

4. Trip makers are aware of the shortest path before making the trip to compute the OD

matrix certain steps are followed.

For the real network, the distance between centers of the 131 TAZs are computed using Network Analysis OD Cost Matrix. This gives the network distance between every TAZ as an attribute to the desire line (Euclidian distance). After this, the desire lines are exported to a shape file which added an attribute shape-length (the Euclidian distance between TAZ). In order to make computation easier, the data base file was saved in excel format.

In excel the output of ArcGIS which is in array form is converted to matrix using the pivot table function in Excel. The matrix generated is of two types, the first using network distance and the second using the Euclidian distance. These are saved in different work sheets. The next step is computing the OD matrix using the Gravity model.

Using the 8 deterrence matrices and O and D for every trip purpose from the output of equation was computed for every trip purpose.

The second step is to produce the following output using employing, o = 1 and o as it is. This iteration continues until the total T converges to the actual production and attraction. The acceptance criteria should be less than 5% between the two (Zuidgeest &Maarseveen, 2011). For both T 0.025% difference is attained after 8 iterations which are much less than the acceptable value.

4.1.3 Traffic Assignment to the Links

The last step in the four-step transport modeling is to assign the trips produced using gravity model to the links in the road network considering the travel cost on every links. Here the assignment is done in two ways. The Euclidean network based method assigns the network based and Euclidian based trips on the reference network. This method is adopted from Grishchenko (2011). The improved method assigns the network based trips on the real network and Euclidian based trips on the reference network.

Euclidean Network Based Assignment: after computing the trips from a zone to each zone, a 131 by 131 size matrix is obtained using both Euclidian and network distances. To assign these trips on the reference network, the matrices had to be converted to array which produces 17161 rows. This value is equal to the rows in the attribute table of the reference network. The trips computed by Euclidian and network are stored in a similar table and named 'Euclidian trip (T)' and 'Network trip (T)' respectively.

The trip table is then exported to ArcGIS and joined with the reference network. The Reference network is then exported to a shape file to make the new attributes permanent.

Real Network Based Assignment: in this method trips computed using the Euclidian are assigned to the reference network and the ones computed by the real network are assigned to the real network. Assigning to the reference network is done using the same procedure as the first method. The assignment on the real network is done by all-or-nothing method for case of simplicity. In all-or-nothing assignment all the trips from any origin to any destination is assigned to single minimum cost path between them (Ortúzar & Willumsen, 2011). This method assumes that all trip makers are aware of the shortest route before making the trip and cost of travel stays the same. Traffic is assigned to links without considering the capacity of the link and congestion levels. This method has some limitations because it ignores the fact that cost on link is a function of volume and that when there is congestion multiple paths may be used. A program was developed in Python script using this method. As one of the outputs of this research a python program was developed using the following algorithm (the code is given in appendixA.1).

1. Form graph G from all link with weight, link length and link number

2. Select zone centers from the nodes as origin and destination.

3. Find the nodes in the shortest path between origin (O) and destination (D). This will give the

node from the nearest to the far.

4. Create graph H as path from the nodes in the shortest path and add attribute T

5. Print the edge, trips on that edge and OD id in excel.

Before using this program we have to prepare the node and link data in MS-Excel. First to find which links end with which nodes, then the junctions and the real network are spatially joined in ArcGIS. This output database is exported to MS-Excel and organized in a way that shows the nodes that form a link (refer to appendix E.1).

Output of this program does not include the link number, therefore another script is written in python using the following algorithm (the code is given in appendix A.2).

1. Form graph G from all edges with weight edge length and edge number

2. If edge is in the shortest path get edge number

3. Print edge and edge number.

The link numbers are added to the output of the assignment and the total trip on each link is summed using pivot table in excel. Finally the assignment table was exported to ARCGIS and joined with the real network.

These values show the total trips per hour that pass through each link by all modes and hence, they do not show the volume of passenger trips by the different modes available to make the trip. To compute the number of vehicles, a modal split analysis needs to be undertaken; where the total trips should be multiplied by percent share of each mode (Walking, Car, City Bus, Mini bus and others). The modal percentage shares are given in Table 7, excluding trips made by walking, for all the other modes, trips are divided by occupancy factor for the mode and converted to common unit, namely, the Passenger Car Equivalent (PCE) that are shown in table 7, Finally, we divide the values obtained by 2 to take into account the two way journey that is made from home to work (or other place or from work to home).

Table 7**: Occupancy and Equivalency factors**

	Mode Percentage	**Occupancy**	**PCE factor**
Walk	**60.5**	**-**	**-**
Car	**4.7**	**2**	**1**
City Bus	**10.9**	**50**	**3**
Mini Bus	**20.6**	**10**	**1.5**
Others	**3.3**	**6**	**1.3**

Source: *Mekbib (2007)*

4.1.4 Trips through Each Zone

In the preparation for the spatial mismatch assessment trips that pass through each zone is computed. Here, two methods were used; Euclidean Network Based Assignment, which assigns both Euclidian and network based trips on the reference network and Network based assignment which assigns the network based trips on the real network. The two methods are discussed in the following sections.

Euclidean Network Based Assignment: Following the method applied by Grishchenko (2011) the reference network is intersected with TAZ in ArcGIS using Analyst Tool intersect. Since the reference network has 17,161 lines, which is more than the capacity of the software, it was divided into 10 new feature classes. After intersection is performed the database is exported to excel and joined in one table.

The flow that passes through every zone using the “Euclidean flow” and “Network flow” is summed up using pivot table in excel. This table is then imported to ArcGIS and joined with TAZ layer.

Real Network Based Assignment: the same analysis is done for the reference network assigning the Euclidean based flow. After joining the output of the trip assignment to the real network layer, this layer is intersected with TAZ layer. Here due to the effect of junctions which cause double count of one OD pair, the researcher cannot add the total trips intersecting each zone. To make sure one OD pair is added only once, two tables are produced in Microsoft access. One containing the link id, OD id and trips on each link involved in that OD pair. This means in this table, it should have edges that connect each OD pair and trips between the OD pairs. The other table is the output of intersection of the real network with TAZs which contains links that pass through each zone (link id and zone id). Since the two tables have link id in common, using the link id the two tables are joined Many-to-Many, refer appendix E.3. Inner join was used to get the links that only exit in both tables. The following Structured Query Language (SQL) is applied to get the OD pairs that pass through each zone and trips. Sheet 1 contains the zone to link data and Sheet 2 contains link, flow on each link and OD id.

SQL

```
SELECT Sheet2.*, Sheet1.*

FROM Sheet2INNER JOIN Sheet1 ON Sheet2. Link_Id = Sheet1.Link_Id;
```

The output Query is exported to an excel file and pivot table is formed by setting the zones as row and OD_id as column. The values were set as the average of the flow. Then the total flow is summed for each zone. This table was exported to ArcGIS and joined with the *zone* layer.

4.1.5 Disaggregated Zones

In the zoning of Addis Ababa there is irregularity in terms of the size of zones. Their size ranges from0.3 to 37 km^2. In the larger zones where settlement exists only in a few parts of the zone equal values are assigned to the whole zone. This affects the SMI by exaggerating its' value. To avoid this problem and increase accuracy, the zones are further divided into smaller units. While dividing one must consider the computational complexity and the acquired level of accuracy. The demographic and socio economic data are distributed considering the type of land use characteristics. The methods used are discussed below.

First a 1km^2 grid is prepared in AutoCAD 2010 and exported to ArcGIS. In ArcGIS the *zone* layer, which contains 131 *zones,* is divided into smaller chunks using split polygon from topology editor and the grids as splitting layer. By taking the smallest zone size (0.3 km^2) as the minimum zone size, polygons smaller than this value were merged to the nearest polygon considering the original zone shape and size not greater than 2 km^2 to maintain spatial uniformity. Some zones remain undivided. 671 zones were formed with smallest zone size 0.3 km^2 and maximum of 1.7 km^2.

The next step was to compute the demographic data for these zones. Since the original zone shape is maintained each polygon falls in to one zone. To distribute the zone data to the disaggregated zones land use characteristics is considered. ArcGIS overlay function spatial join is used to find the land use of each polygon. The new zone layer was set as target feature, land use layer as join feature and the joint operation was set as one-to-many. From this, one zone will have many land use characteristics taking the dominant land use and visualization in Google Earth land use type was assigned to the *zone*.

In the land use layer there are 11 land use types. The ranks used for each type are given in table 8. By using these ranks and visualizing the settlement pattern of each zone in Google Earth the demographic data is divided among the new zones. Some of the Reserved and Green areas do not have settlement in them. The transport terminal represents the airport, in this area settlement is low due to government restriction but number of employees is high. After distributing the data, the excel table is joined with the new *zone* layer. The new zones and their share of population are explained on Table 9.

Table 8**: Land Use Ranks**

Land Use Type	POPULATION	STUDENTS	WORKERS	EMPLOYEES
Central	1	1	1	1
Resident	2	2	2	4
Industry	3	3	3	2
Social	4	4	4	5
Housing	5	5	5	7
Mixed	6	6	6	7
Transport	7	7	7	3
Quarry	7	7	7	6
Industry	7	7	7	7
Green Area	8	8	8	7
Reserved	8	8	8	7

Source: *CSA, 2010*

Transport modeling and creating the reference network is done using the same procedure as the old zoning system except for some modifications in trip assignment. The trip assignment program is written to read files from excel sheet, but in excel only 255 rows can be read at a time. Since we have 671 new zones the O-D matrix is composed of 671 rows and columns, a file that can handle more rows is needed. The program is modified to read file from text file and print the output in CSV file. The two separate programs used to find the trip assignment and get the link id are joined to reduce computational time. The output contains the link id, trip on each link and Origin-destination pair id.

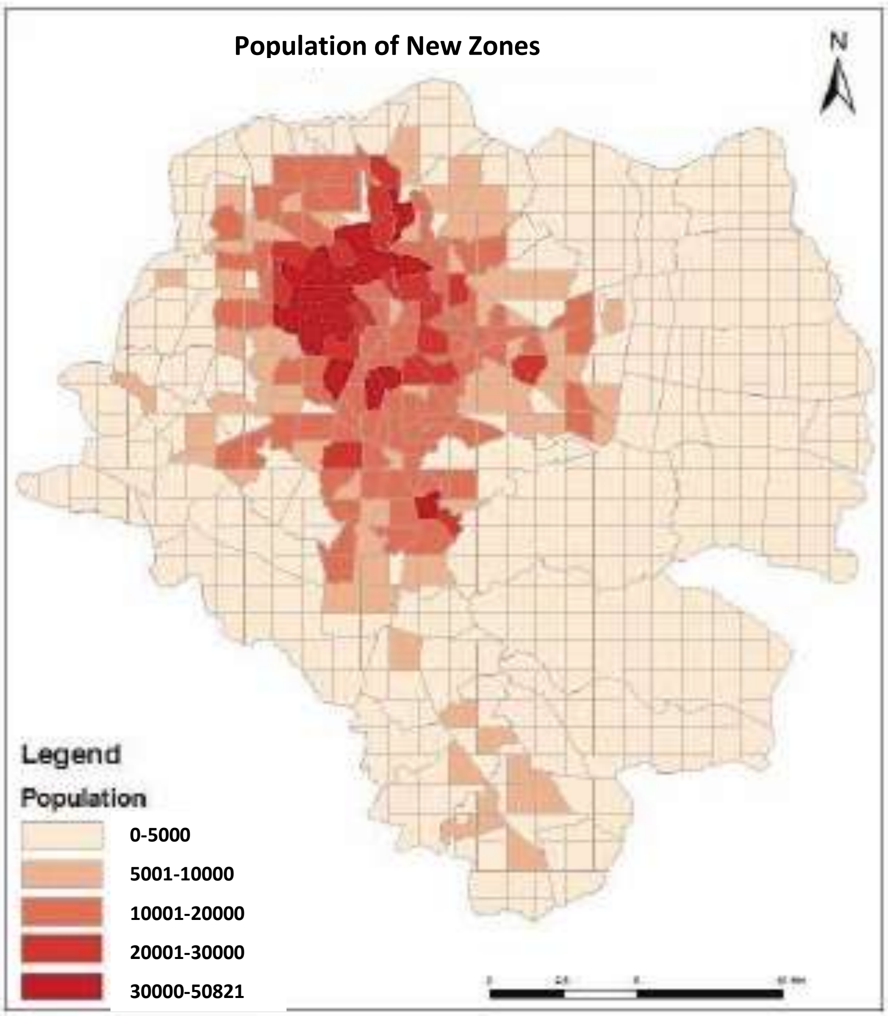


Figure 9: **Population distribution among disaggregated zones**

Source: CSA, 2010

To compute the desired flow and actual flow passing through each zone, intersecting the reference network with the zones was not possible because intersect function ArcGIS can only handle 2100 lines at a time. In our case there are 450,241 lines connecting each origin and destination. To solve this problem the reference network is divided in to 12 feature classes each containing 37,520 cells. One–to– much spatial join function is performed to find the lines passing thought each zone. The output database is exported to excel. In excel these lines were matched with the OD array. Total desired trips are then summed for each zone.

Total trip passing through each zone using the real network is calculated with the same procedure as the old zoning system except here since the number of OD pairs is much larger and the output of the trip assignment contains 60 tables. These tables are imported to Microsoft Access and related to the Zone- link table.

4.2 Transport Demand Modeling

4.2.1 Trip Generation

The first step in the four step transport modeling is Trip Generation. Depending on land use characteristics of zones and socio-economic properties exhibited at the household level, the intensity of travel demand and trip ends are estimated. This step classifies each 'trip making potential' of the TAZ into attraction and production levels using multiple regressions models.

Using the regression models, trip production and attraction for each zone are calculated. The trips are stratified into four based of trip purposes. These are work trips, education trips, other purpose trips and non-home based trips. As shown in table 9, the education trips share the highest percentage of trips, with about 45% and 44% in both production and attraction category respectively while the non-home based trips only account for 2 %

of total production and attraction levels.

Table 9: **Trips Share by Purpose**

Trip Purpose	Production	Percentage Production	Attraction	Percentage Attraction
Education Trip	1,522,127	45	1,455,240	44
Work Trip	1,139,027	34	1,182,073	35
Other Trip	618,769	18	647,505	19
Non-Home Based	71,516	2	52,327	2
Total	33,514,40	100	33,371,46	100

Source: *CSA, 2007*

By aggregating the 131 zones into the 10 sub city zones, the share of trip for each zone by purpose is shown in table 10, From the total trips attracted, *Kirkos* sub-city being the CBD, takes the higher share. *Akaki-Kality* sub-city, which includes most of the peripheral areas of the city, takes the lowest values for both attraction and production. *Bole* and *Nefas Silk* sub-cities take the higher values for work and education trip productions respectively.

Table 10: **Trip Shares of Sub-Cities in Addis Ababa (% of city)**

Sub city	**Production**				**Attraction**			
	work	Education	Other	Non-home	work	Education	Other	Non-home
Addis Ketema	11	11	11	11	13	11	13	13
Akaki Kality	5	7	6	6	6	7	6	6
Arada	10	8	10	10	12	8	12	12
Bole	13	7	10	10	10	7	10	10
Gulele	11	11	11	11	9	11	9	9
Kirkos	11	12	11	11	18	12	18	18
Kolfe	9	10	9	9	6	10	6	6
Lideta	10	10	10	10	8	10	8	8

Nifas silk	10	14	11	11	9	14	9	9
Yeka	10	10	10	10	9	10	9	9
Total	100	100	100	100	100	100	100	100

Source: *CSA (2010)*

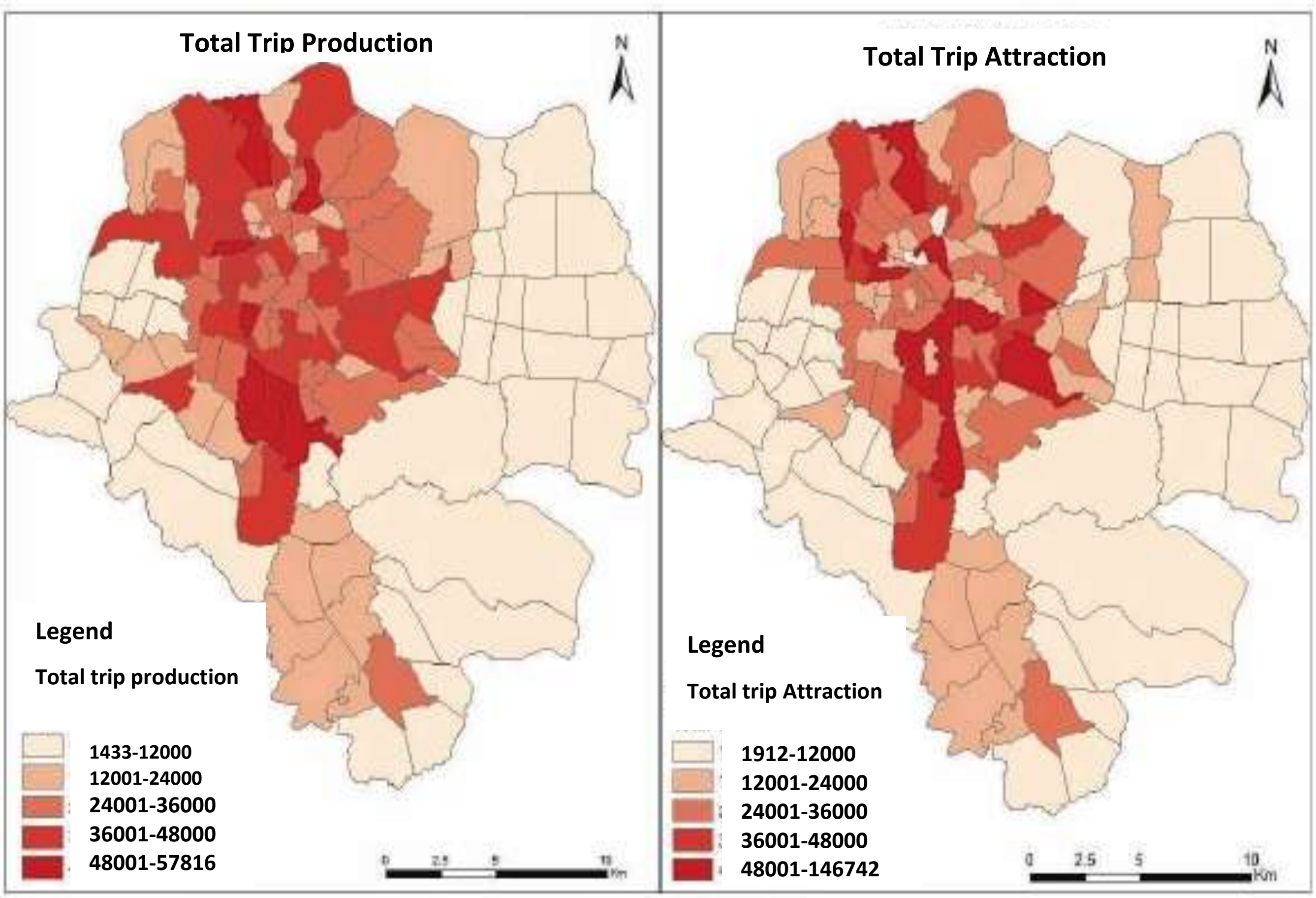


Figure 10: **Total trip generations**
Source: *CSA (2010)*

From Figure 10, it can be observed that total trip production ranges from 1433 in zone 110 to 57817 in zone 89. Whereas, Trip attraction level ranges from 1903 in zone 110 to 146177 in zone 35. Zones 35 and 26 (locally known as Merkato and Piazza) have high trip attraction values as they are main business centers of the city. The range of trip attraction values is much larger than production. This shows that activities responsible for attraction levels; mainly jobs and shopping centers are located in the Central Business District around the center of the city and its vicinity.

4.2.2 Trip Distribution

In this phase of transport modeling, the spatial pattern of trips in terms of potential travel demand between origin and destination is predicted. Trip Distribution stage determines where the trips produced by a zone are destined to and the proportion of trips that destine themselves to other zones. The gravity model is used to compute the proportion of trips from and to each zone where the impedance factor used is distance without considering effects like congestion.

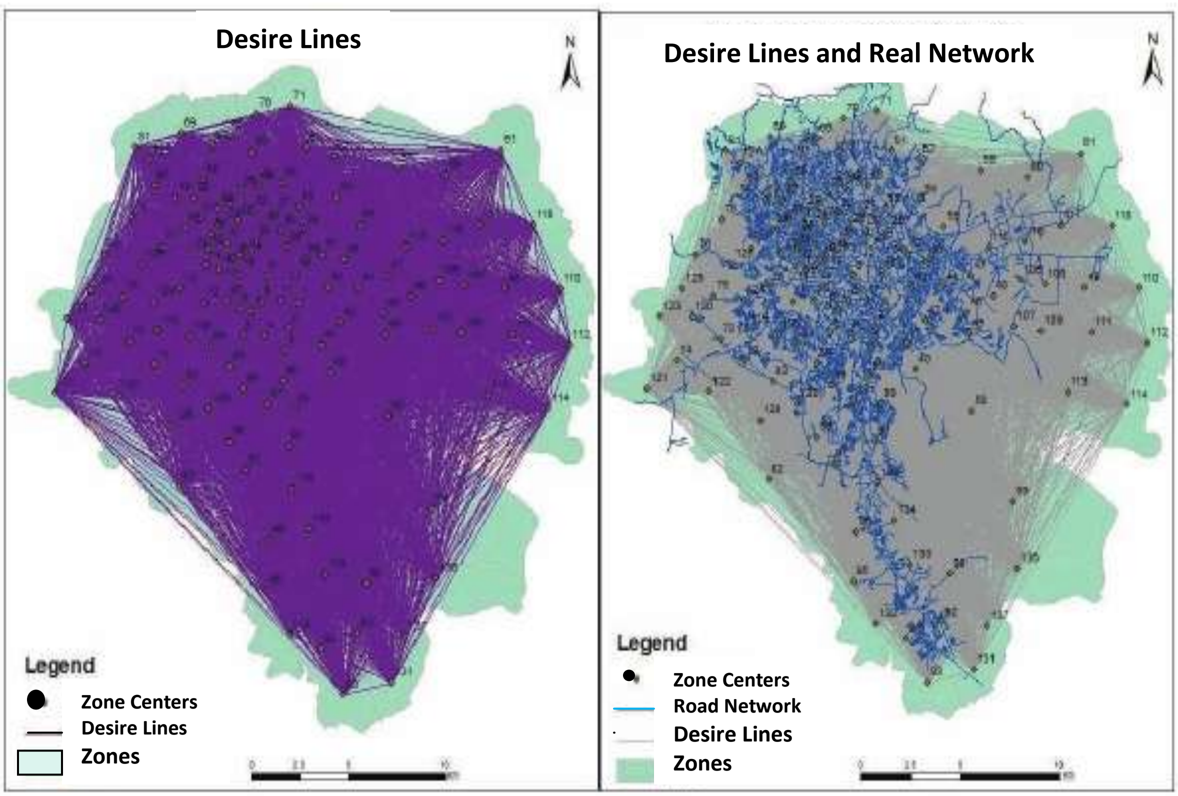


Figure 11: **Desire lines and real network**

Source: *CSA, 2010*

The desire lines that connect the OD pairs are shown in figure 11. To link each of the 131 origins to each of the 131 destinations 17,161 desire lines needed to be produced.

By overlaying the existing network onto the desire lines for travel demand and visualizing the spatial pattern of the desire lines and real network, it can be seen that some zones are disconnected or people have to travel a long way to reach their destination using the real network specially, the peripheral zones in the South and Eastern part of the city. However, I understand that the mismatch between the desire lines and the existing network only shows those areas that are disconnected without actually considering the magnitude of travel demand quantitatively in these areas.

Considering only the distance people travel to reach their destination, the researcher note some large differences between Euclidian based network (based on the desire lines) and the real network. For example, from zone 76 to 56 the Euclidian distance is only 1.6 kilometers while network distance is 16.6 kilometers, which is 10 times longer in absolute terms. This is quantified further in this study by using the mobility index. Since the Gravity Model is used to compute trip distribution that considers travel distance as the impedance factor, the use of Euclidean versus real distance for the purpose of trip distribution will affect the resulting proportion of trips computed using the two different networks.

Euclidian distance based and Real network distance based trip distribution is computed using the Gravity Model considering each trip purpose (Work, Education, Other and Non-home based), where a total of eight tables could be produced. The Total Euclidian based trips and Total Network based trips were computed by adding the trips computed for each trip purpose that reduces the number of output tables into two. A total of

3,335,677and 3,335,693 trips were produced by the Euclidian and Network based distances respectively. The researcher note the difference observed between the two values is very small and could have been computing errors resulting from rounding off. The trip generation model has generated the total number of trips by all-purpose is 3,344,293; which is only a 0.25% deviation in both cases from the sum of trips generated from the OD Matrices.

4.2.3 Traffic Assignment

In this step, the O-D trip matrix is loaded onto the network. The trip distribution patterns computed by using Euclidian and network distance as impedances are loaded to the reference network. The number of person trips on links range from 0 to 5267 person-trips per hour. These values represent the desire flows on the reference network. Since the reference network is very dense in certain places, visualization is difficult. However, Figure 12 shows the links that have trips more than 1000 person-trips per hour.

The CBD area and the North-South corridor have more than 1,000 trips per hour in both cases. In the network based trips, there is high desire of flow between zones 98, 99 and 136 whereas this value is lower in the Euclidian based trips case.

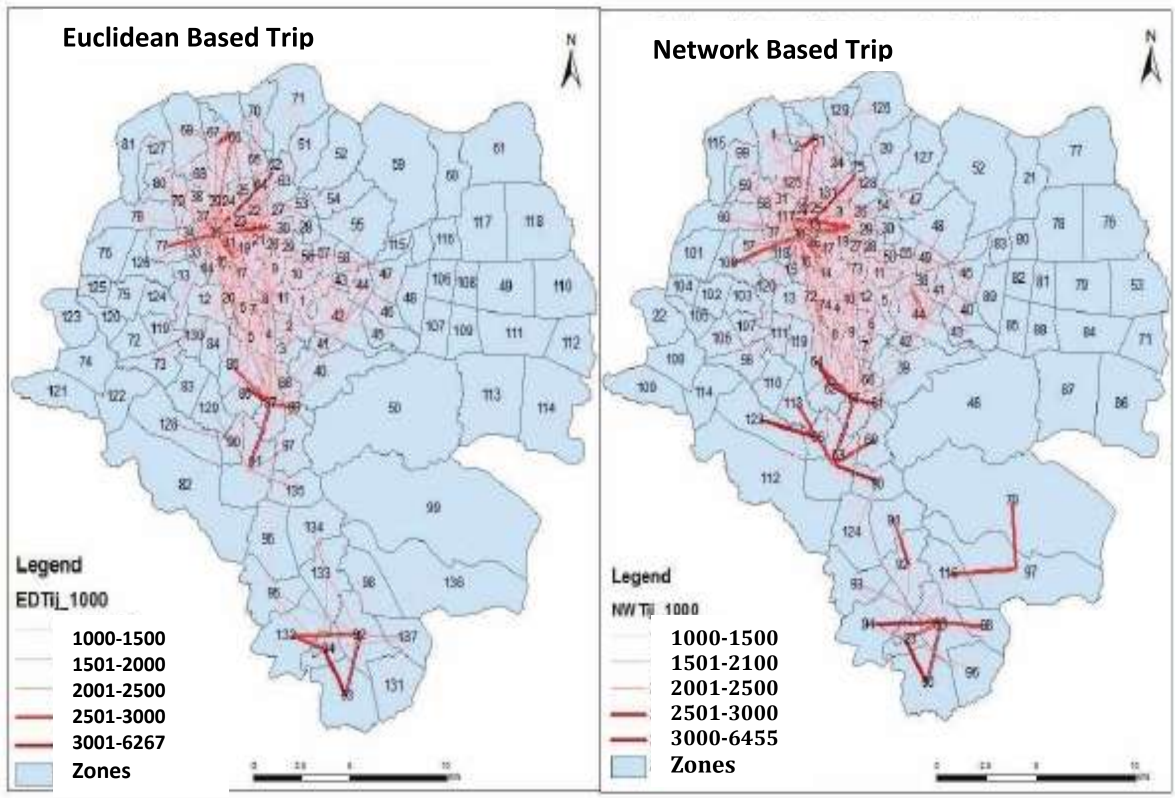


Figure 12: **Links with trip greater than 1000 trips/ hour**

Source: *CSA, 2010*

The output of the traffic assignment on the real network using the all-or-nothing (AON) algorithm assigned the trips to only 5,257 links from a total of 14,534 links. This is because the other links are not in the shortest path of any OD will not be assigned any traffic in the AON assignment. One of the reasons for this is that, the researcher has used a detailed network where all type of roads is included in the model whereas the zonal aggregation in spatial sizes is large. With this size of aggregate zoning only major roads up to a certain level of hierarchy should be included for assignment or, alternatively, if it is necessary to assign the traffic on a detailed network, the zones should be disaggregated to use AON assignment.

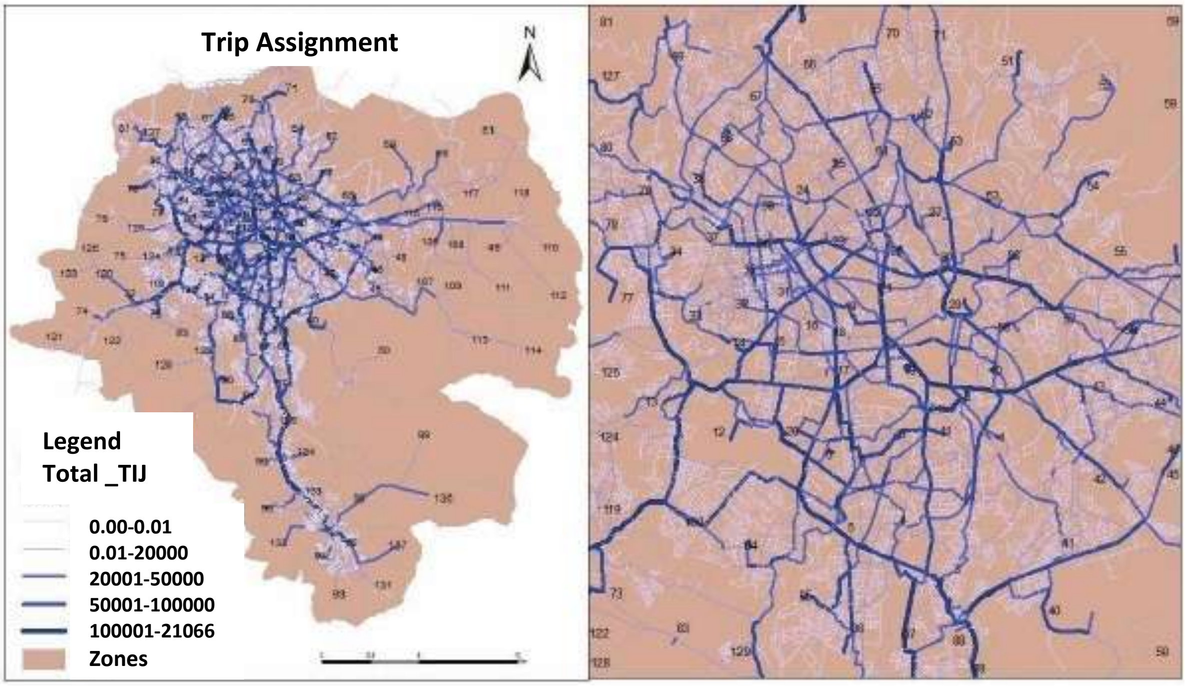
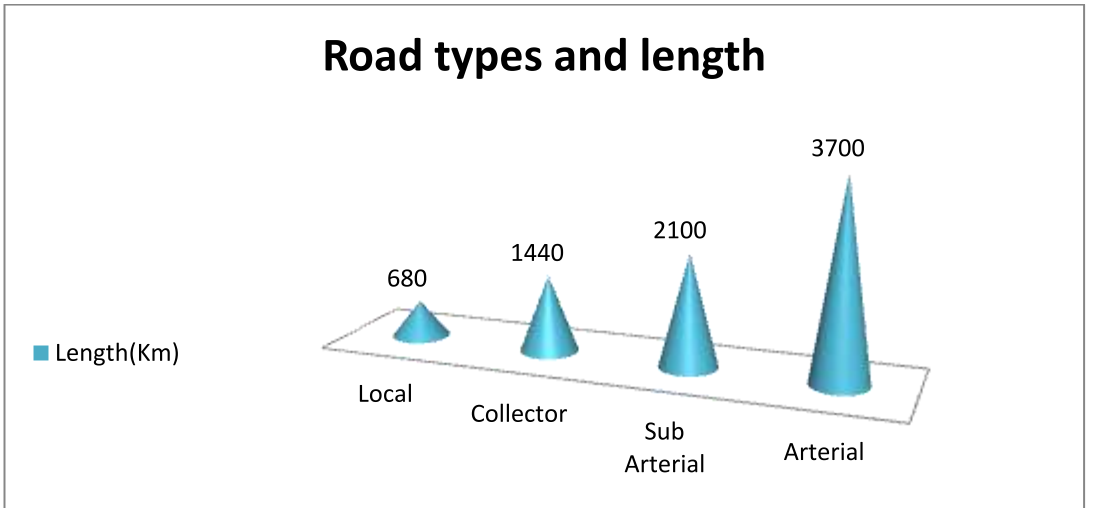


Figure 13: **Trip assignment on the real network using all modes (trips per hour) Source:** *UTS (2006)*

In figure 13, high values can be seen on the links that connect the South corridor (locally known as Kaliti) and the East (Megenagna) corridor to the CBD. Within the CBD the links that connect zone 21 in all directions especially with zone 9 (Churchill Road and Ras Desta roads) and zone 30 with 52 are noted to have exhibited a high traffic level. The North-South corridor is the main import export corridor of the city. The Churchill road is the main road that connects the main business area, Piazza, to other parts of the city. From the traffic assignment exercise, the number of vehicles per hour assigned on the major routes; East-West and North-South corridors range from 2,000 to 4,500 and particularly on the Churchill road at the center of the CBD, a traffic level of 2,000 to 3,000 is computed. Some of the roads were assigned zero level of traffic because the AON assignment does not assign traffic on the network if it does not form the shortest path between the TAZ centroids. The UTS (2004, 2006) has noted that, the ring road has the maximum capacity which is 3700 vehicles per direction (refer to figure 13).

The roads in the central areas have lower hierarchy than ring road and have capacities less than this value. Even if, the researcher consider the highest capacity of the road network and compare it with the model output it shows that some roads carry traffic more than its capacity.



	Local	Collector	Sub Arterial	Arterial
Length(Km)	680	1440	2100	3700

Figure 14: **Clustered chart of the road types and their length**

Source: *AACRA (2013)*

4.2.4 Mobility Index

One of the effectiveness measures of a road network is the so-called Mobility Index (MI). This index compares the existing network structure with an ideal network that connects origins and destinations with directed route (Euclidian distance). This is because the impedance considered in this research is only distance. The output of this analysis gives values MI ranging from 0 to 8.21. Zero value for the MI corresponds with a situation where within zone distance is zero. For an ideal network, the MI value should be one, but since this cannot be achieved it need to have some tolerable value. From Network Study for Ethiopia (2000, 2001), MI values less than 1.41 are within the tolerable range. Whereas, values greater than 1.41 shows links that needs improvement. According to this analysis, 76% (Table 11) of the total OD pairs have an MI value oflessthan1.41.

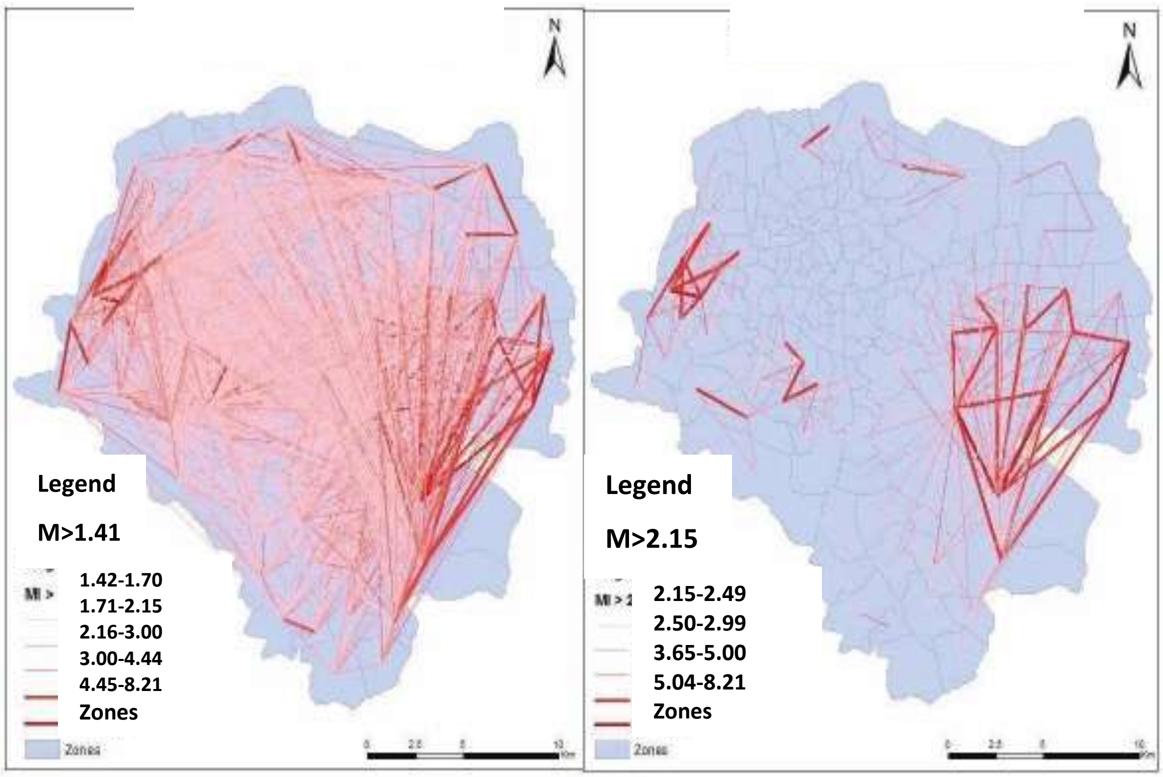


Figure 15: **Links with Mobility Index greater than 1.41**

Source: ERA, 2001

Figure 15, shows the plot of the MI in all the zones where higher values are observed in the peripheral areas. This means, even though the zone centers are close to each other, due to an inefficient network, passengers have to travel longer distances to reach their destination as a result of the cross shaped structure of the network.

Table 11: **Mobility Index**

MI Range	Frequency of zones		Cumulative Frequency	
	No	% of total	Absolute	%
0-1.41	131	0.76	131	0.76
1.41-2.82	12606	73.46	12737	74.22
2.82-4.23	4240	24.71	16977	98.93
4.23-5.64	158	0.92	17135	99.85
5.64-7.05	16	0.09	17151	99.94
7.05-8.46	10	0.06	17161	100.00

Source: ERA, 2001

4.2.5 Road Density

Road density can be measured as the ratio of the total road network in an area to the land area or to the total population in that area. Given similar network topology, in different zones, higher road density (road per area) implies a higher availability of alternative routes (Jenelius, 2009). Also, this implies higher directedness and connectivity levels within the network. The road density investigates the network structure only considering the supply side whereas the road density per unit of population measures the availability of network distance per person.

Figure 16, shows maps of the road density in the study area. The road density per unit of population shows there are some areas without road; specially, in areas that are situated at the periphery of the city. Even though the population is low in these zones, there is some demand as can be seen from the density per population plots. The road per area shows higher values in the CBD but this is not true for the road density per population due to high population in the CBD. The settlement structure of the city dictates network design within the city, and hence, more road infrastructure exists in areas where there is higher population, though the vice versa could as well be true. There is high value of road per population in zone 49 and 117, an area locally known as Ayat which is fast developing.

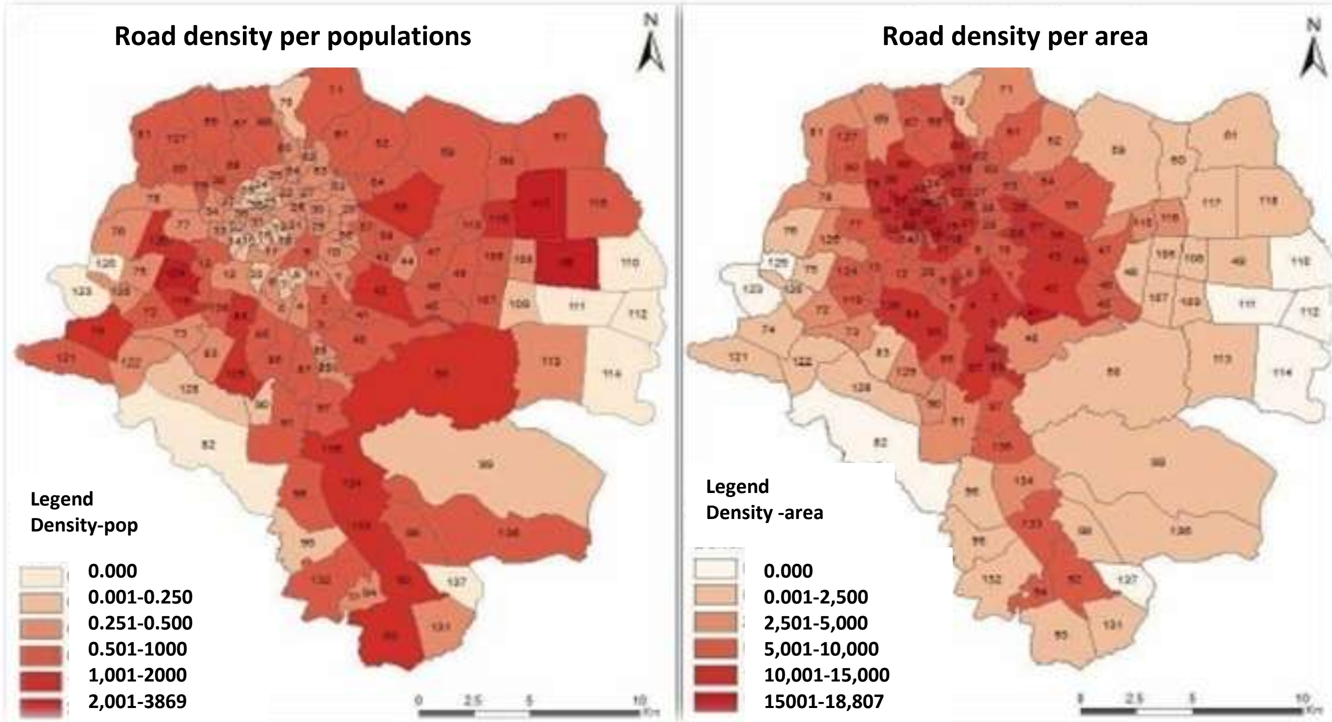


Figure 16: **Road density, road length per population in the left (km/1000person) and road length per area in the right (km/km2). (Source:** *ERA, 2012).*

From the figure16, the researcher conclude that the zone 82, 110, 111, 112,114, 123 and 125 locally known *CMC* have low road infrastructure availability both with respect to road density per population and per unit area. Most of the peripheral zones have low infrastructure availability. When considering spatial equity, zones in the peripheral regions have very low share of roads while the central areas considerable share. The same is true when considering equity by share of road density per person.

4.2.6 Proximity to the Road Network

One of the parameter that shows the availability of transport infrastructure is its proximity to the end users. Proximity measures how many people can access the infrastructure within certain distance.

Considering a uniform distribution of population over the area of each zone, the population density of the zones is computed. A simple buffer analysis is used to measure the proximity of the population from the infrastructure. According to this analysis, 87% of the populations are within a distance of 250m to any type of road infrastructure and 73% of the population can access paved roads within 250m only. Due to the concentration of the road network and dense population, 96% of the population in the CBD area can access the road network within 250 m distance.

As shown in figure 16, the availability of road network in some areas is very poor. For example, for zone 82, 99, 110, 111,112, 113, 114 and 136 more than half of the population in these zones can access any kind of road network only if they travelled more than 1000 meter distance. If we assume public transport hub is available at the end of the closest paved roads, 87.1% of the population can access it within 500 meters distance and people living in the above mentioned zones need to walk more than 1 km to access these facilities. Armstrong-Wright and Thorez (1968) suggested that the walking distance to these facilities should not be greater than 500m. From this, the researcher can conclude that these zones have very low level of road infrastructure availability. Looking at the proportion of road network availability to income levels figure 18, 96.8% of the high income population can access any type of road with in 500m, 90% for medium income and 93.8% for low income. To access the paved roads 90.5% of high income, 85% of medium income and 85.7% of low income the population travel to reach to paved road infrastructure. Even though the difference is small, locations with a high income level are more privileged.

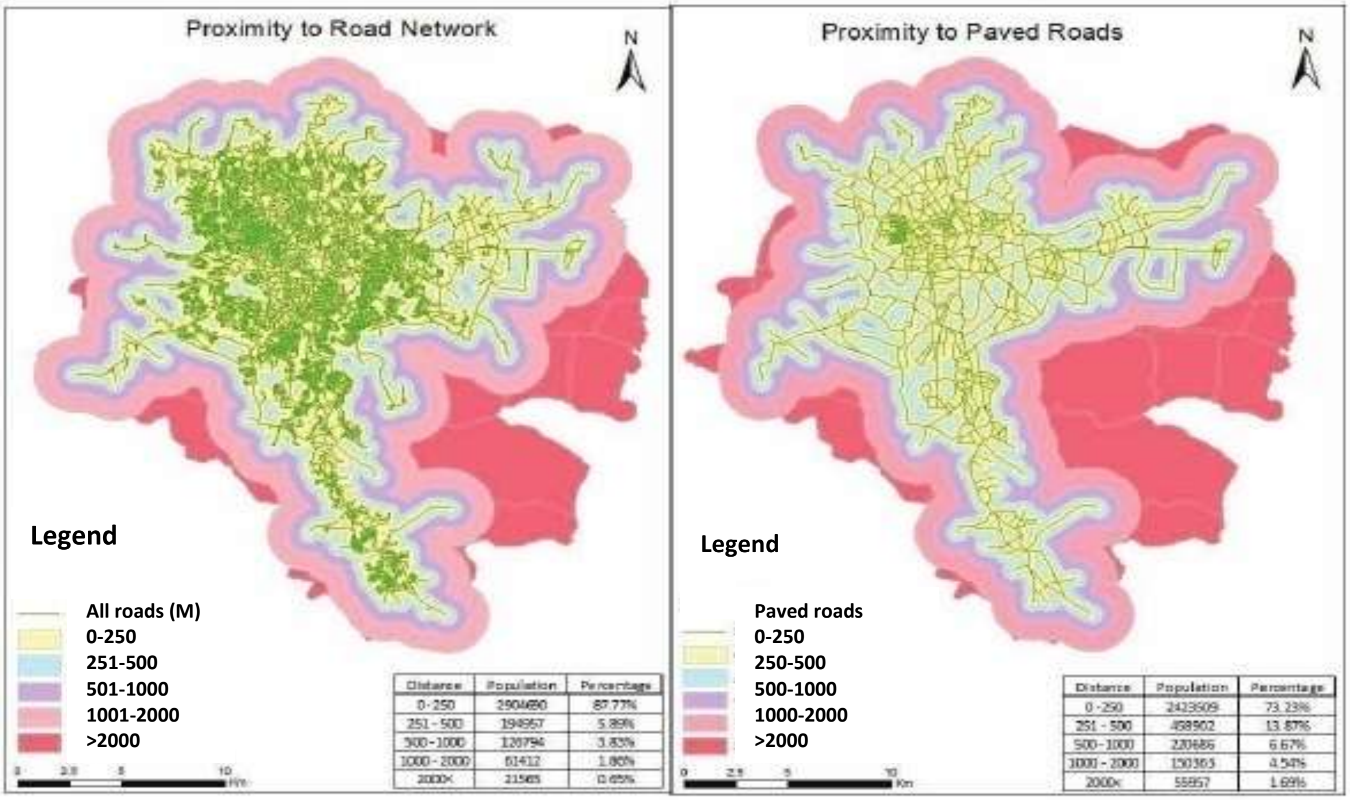


Figure 17: **Income level and proximity to roads**

Source: *AACRA (2013)*

4.2.7 Spatial Mismatch

4.2.7.1 Euclidean Network Based Assignment

By intersecting the link flows with the zone the trips that pass through each zone using the reference network and real network are computed. Assigning both Euclidian and network based trips on the reference network, total trip passing through each zone are plotted as can be seen in figure 18, For the Euclidian based trips zone 6, 9, 15, 17, 21, 31, 35 and 42 have values greater than 350,000 trips. For Network based trips zones 15 and 42 are excluded from this value. These zones are situated in the CBD and the high values are exhibited due to high demand resulting from large population and activities. Even though, there is a difference between the highest values of the two cases, the highest values correspond to zone 35 locally known as Merkato. This zone is the largest market of the city. Due to their remoteness, low population and low activity, the periphery zones have lower values (between 3270- 70000). Zone 112 has the smallest value inbothcases.

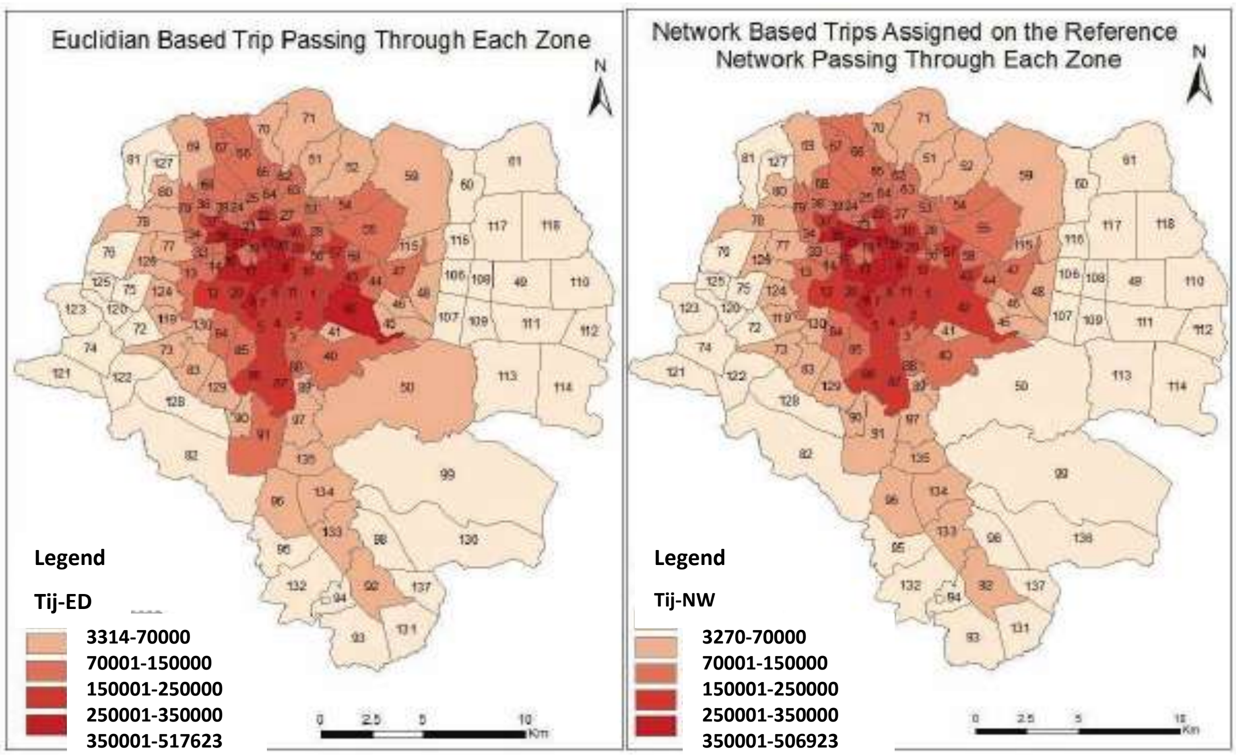


Figure 18: **Spatial mismatch indices using reference network**

The Spatial Mismatch Index (SMI), which shows the difference between the Euclidian based and network based trips passing through each zone are computed with two methods. In this case SMIs are computed by assigning Euclidian based and network based OD matrices on the reference network. SMI1, which is computed by dividing the two values ranges from 0.92- 1.485. Higher values correspond to higher mismatch and lower values show lower mismatch. Decision of threshold for inadequate areas depends on the decision makers and vision of the city. In figure 18, SMI 1 values are mapped by using geographical intervals. Higher values can be observed in the periphery areas especially in zone 50 and 99.

SMI 2, on the contrary, computes the difference between the Euclidian based and network based trips, and had values ranging from -4718 to 26,851. Higher negative and higher positive values indicate high mismatch areas. Threshold values for inadequacy should be set by decision makers. In figure 19, SMI 2 values are mapped using quantitative intervals. Higher values can be observed in south east part of the city and some central areas. Zone 50 and 99 are also included.

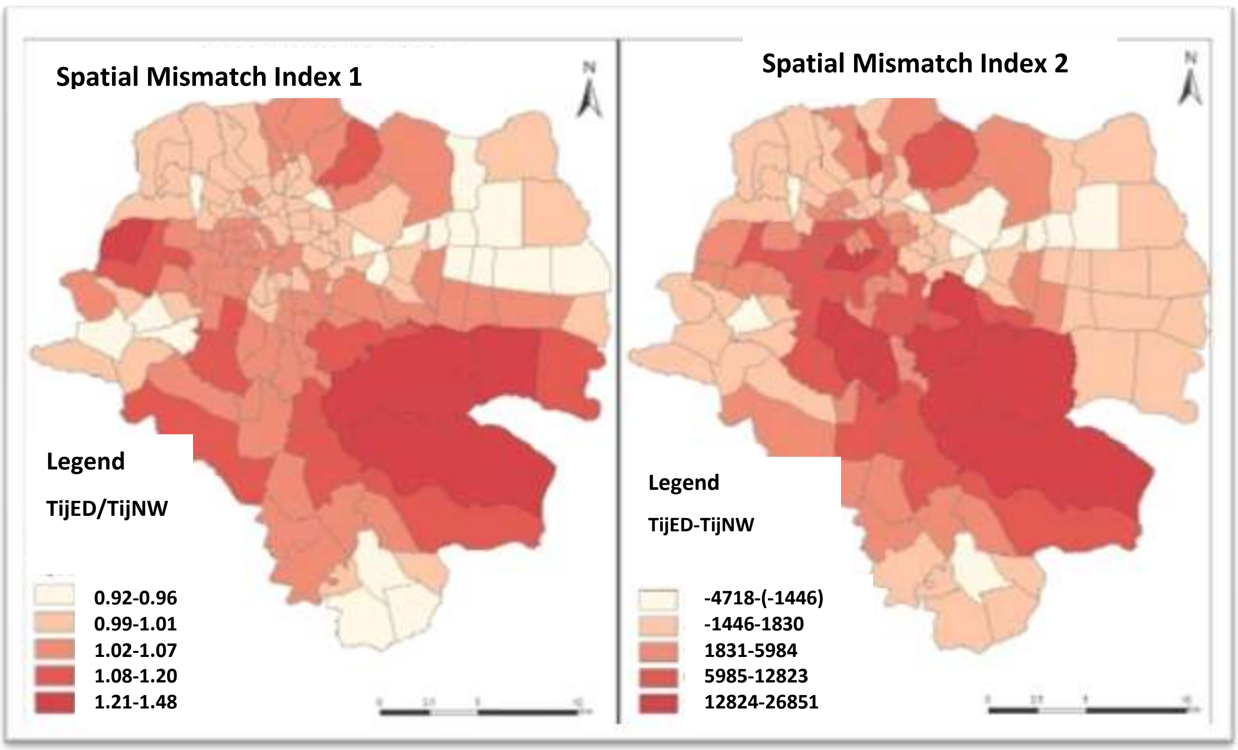


Figure 19: **Spatial Mismatch Indices using original method**

From these indicators, the researcher can conclude that some of the periphery zones especially zone 99 and 50 lack road infrastructure. But this method assigns trips made by the real network on the reference network; this diverts from the actual trip pattern and exaggerates the SMI value for each zone.

4.2.7.2 Real Network Based Assignment

In this method, to compute total Euclidian based trips and network based trips passing through each zone different methods are used. In the reference network, since one link connects one OD pair, the trips through each zone can be computed by intersecting the reference network layer with TAZ layer.

But, in the real network case, one link can form shortest path of more than one OD pairs; therefore, intersecting them with TAZs may cause a double counting of OD pairs passing through the zone as noted above. To avoid this, the total trips passing through each zone is computed by joining links connecting each OD pair and links passing through each zone.

The trips that pass through each zone range 3314 to 517,623 for Euclidian based and 3,219 to 1,936,240 for network based trips. As shown in figure 20, in both cases higher values can be observed in the central areas. Due to their remoteness and low demand, these values decrease as one moves to the peripheral areas. For the Euclidian based trips, zone 35 (locally known as Merkato) has the highest value.

This zone is the main business district of the city with high population and employment opportunities. In the network based trips, zone one (locally known as Bole) has the highest value. This is due to the fact that this zone belongs to the CBD and many OD pairs pass through this zone. Figure 20, shows the OD pair distributions that pass through each zone. In an ideal situation, the traffic flow through the zones using both Euclidian and real network based trips should be equal, i.e. at ideal condition where the value of SMI 1 would be one and SMI 2 would be zero, the researcher would expect that the real network is composed of only shortest path routes based on Euclidean distance. But in real world, Euclidian based network remain only ideal for different reasons; including technical (route alignment), physical (topography, right-of-way) and economic ones. By taking the difference between the trips assigned on the Euclidian network with that on the real network, the researcher had noted that both the maximum and the minimum values of these indicators actually correspond to two scenarios where infrastructure inadequacy is exhibited.

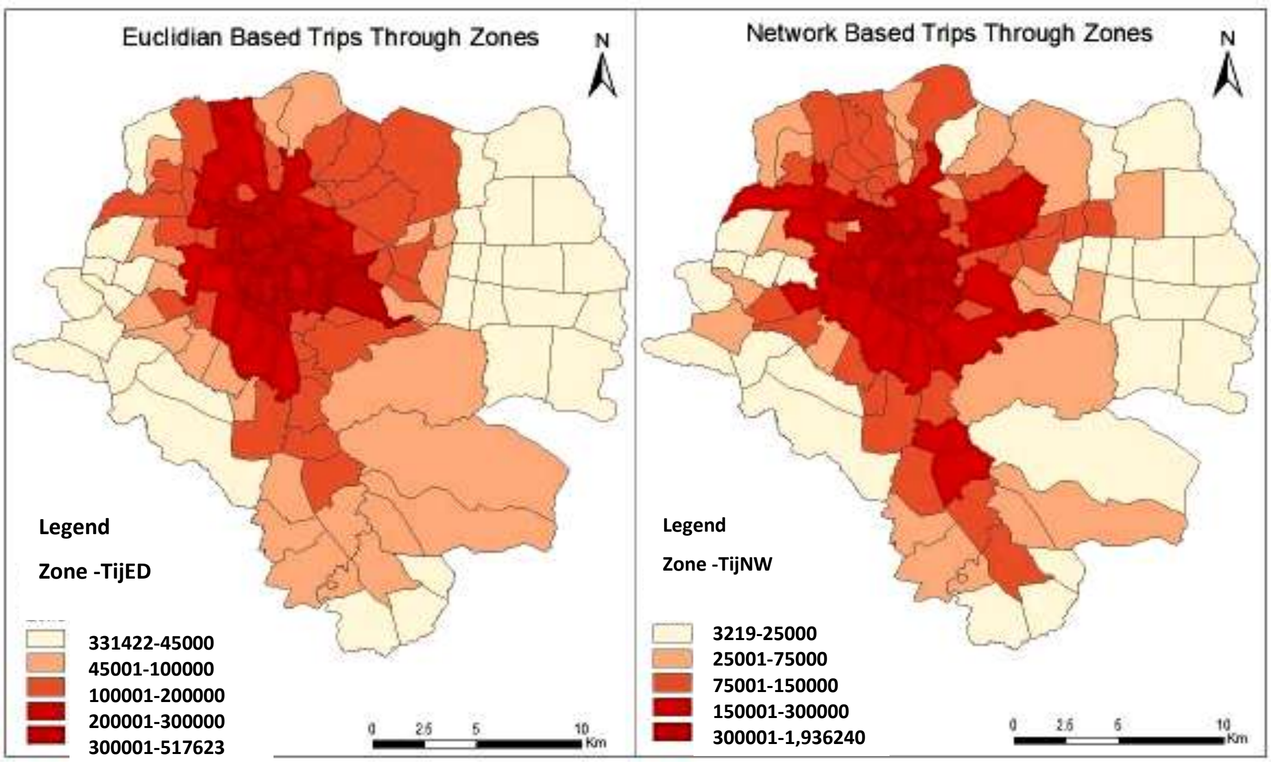


Figure 20: Trips passing through each zone by assigning Euclidian based trips on the reference network (left) network based trips on real network (right).

Source: CSA, 2010

1. Areas with very low values show that the networks in these areas carry more demand than it has capacity and need some kind of improvement. The improvement can be manifested in the form of diverting the traffic by constructing new connections, traffic management or even by providing more public transport.

2. Areas with high values show there is considerable amount of demand but the road infrastructure either need significant capacity improvement or it does not exist at all. Since the trip assignment used in this research assigns the trips to the shortest path, higher values also correspond to the areas that may have network but the links of the network within a particular zone do not form the routes that connect the ODs through the shortest path. That means the network is configured in such a way that it is obvious to the demand in these zones and as such, the network within the particular zone is, in a way, not efficient.

The results of SMIs are shown in figure 21, the values for SMI 1 range from 0.16 to 9.55 and the map prepared by dividing these values quantitatively. The output shows lower mismatch values around the CBD, East, West and South of the city. The zones with SMI 1 values of less than one actually follow a corridor showing a specific pattern in the network. In the extreme East zones (zone 118 and 110) even though these zones have lower demand, the existing network is very small to support it. Higher mismatch values can be observed mostly in peripheral zones, and some central area.

Looking at the results of SMI 2, the mismatch levels are also presented in figure 21, SMI 2 shows a larger range from -1,621,160 to 188,786 and this map is produced by dividing values greater than and less than zero quantitatively. Here also the CBD areas have lower value showing that the network in this area has high load. Some low mismatch values can be observed in the CBD but mostly in the North part of the city. The negative mismatch values in the central areas are situated next to higher values. This shows that due to inefficient networks the trips are diverted to the higher value zones which cause high traffic load on the network of these zones.

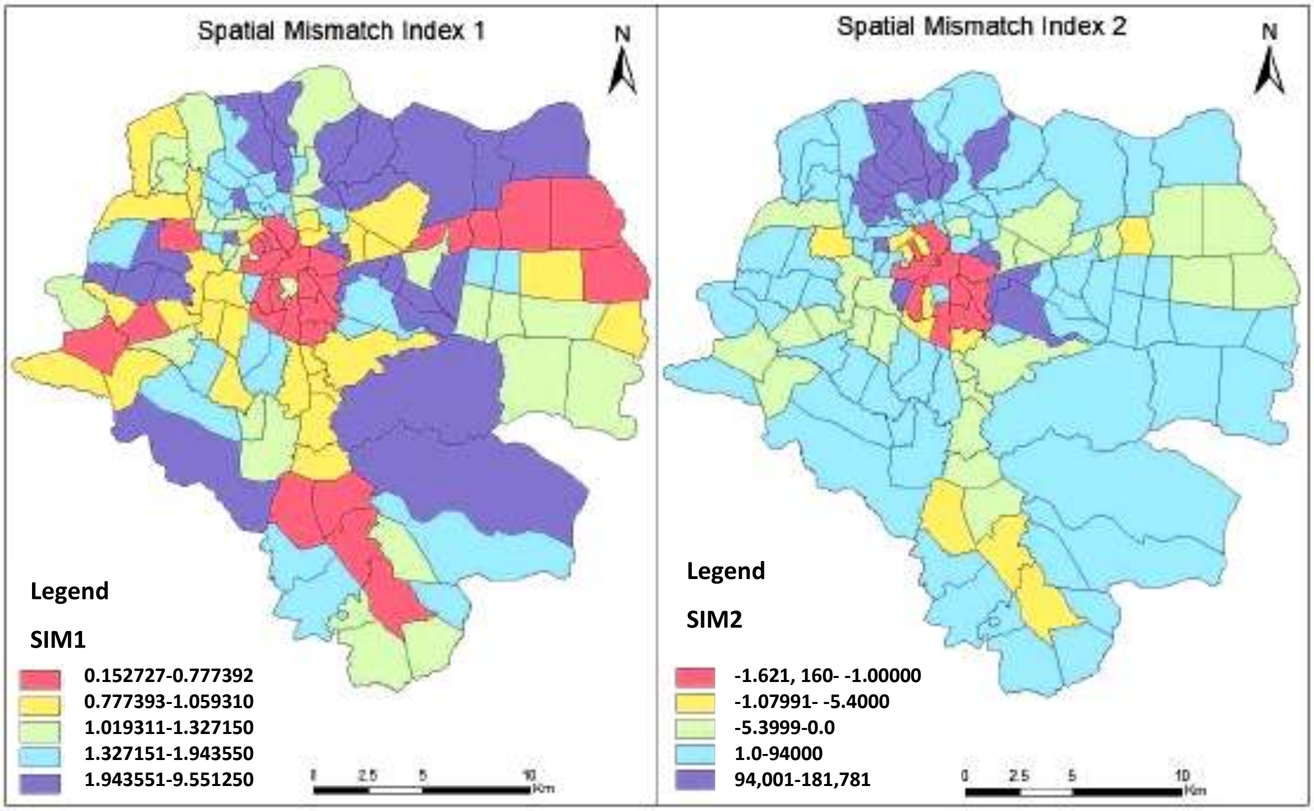


Figure 21: **Spatial mismatch indices using the improved method**

In this method, since the size of these zones is large and unequal, it is not able to identify the corridor that requires improvement and those corridors to be added. Therefore, these zones are further disaggregated into smaller zones to ensure spatial equity and get more accurate results.

4.2.8 Real Network Based Assignment with Disaggregated Zones

The original sizes of the zones are reduced to smaller units ranging 0.3km^2 to 1.7 km^2. Population and demographic data are divided among the zones considering the size and land use of each sub division.

High population is observed in the central areas and it decreases as we move away from the center (refer figure 16). Some green areas and reserved areas have zero population.

After modeling transport demand, the trips are assigned on the real network. The output of trip assignment on the links also shows high values around the central areas; the North-South and East-West corridors.

The SMIs are shown in figure 22, SMI 1 values ranges 0.127 to 181,907, low values (red color) are observed along the north-south corridor, East- West corridor, the central areas and some are scattered to periphery areas. These show areas with capacity issue. Higher values are observed in the peripheral areas where road infrastructure is lacking.

SMI 2 values range from -227,123 to 55,138, the high values and low values are located near each other (red and blue) except for some places. Negative values can be observed along North-South corridor, East-West corridor and central areas. High values are observed in areas where there is considerable amount of demand; mostly, near to North-South corridor. It can be visualized there is settlement near this corridor but road density is low. This index also shows there is less spatial mismatch in peripheral areas which have low travel demand. The high values and low values being next to each other show that since these areas either lack network at all or there exists inefficient network, the traffic in this zone is diverted to the higher value zones causing high load in this areas.

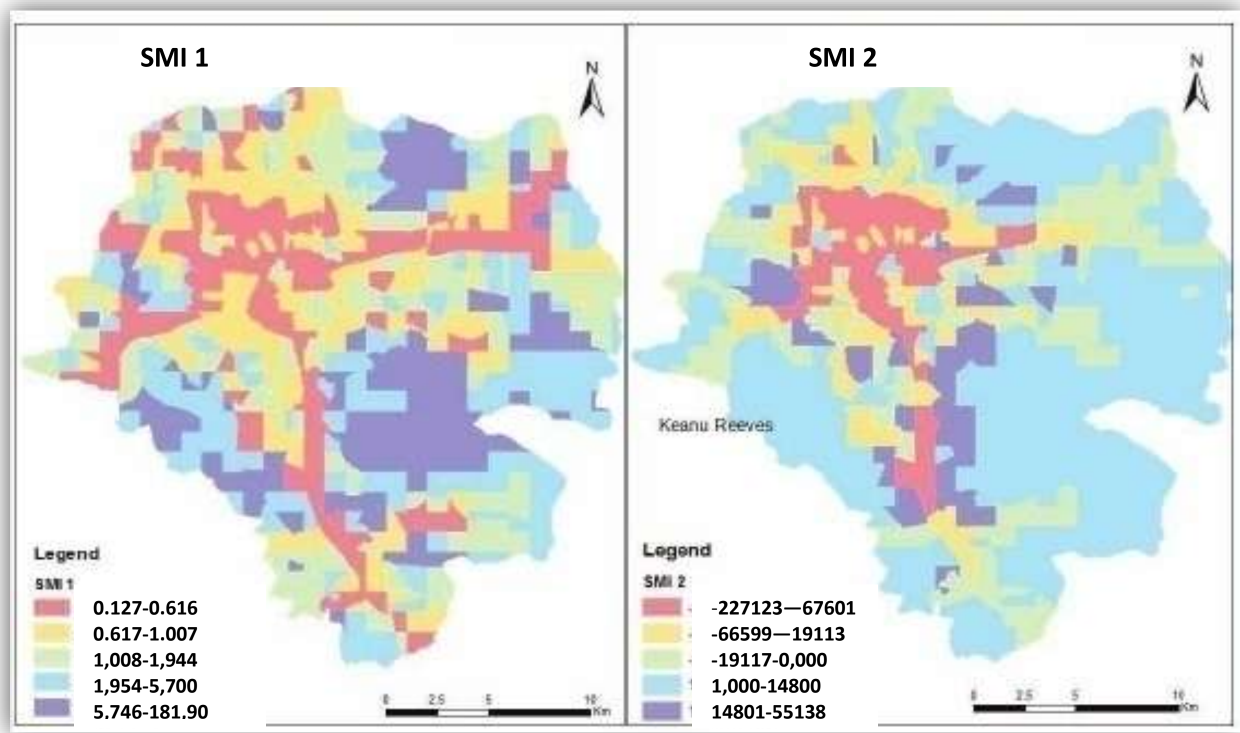


Figure 22: **Spatial mismatch indices for disaggregated zones**

Source: *CSA, 2010*

4.2.9 Identification of Missing Infrastructure

From the output of the SMIs we have three types of inadequacies identified that can be manifested in the form:

1. Areas with roads carrying more traffic loads than capacity

2. Areas with roads those are not efficient because they are not the shortest paths for particular OD pairs

3. Areas that lack road network despite the presence of demand. The first type of inadequacy is mostly observed in the central areas, north-south and east-west corridor with respect to both indices. The second type of inadequacy can be observed only by scrutinizing SMI 2, in the western region of the city. The third type of inadequacy is exhibited in both Indices, and observed in the peripheral areas of the city.

Areas where the third type inadequacy is observed require the development of more road infrastructures. However, it is still unclear as to which particular transport networks merit to be developed. These links were identified by connecting the zones with higher SMI values and those that are located next to each other. Priority should be given to the links connecting zones with higher SMIs. To increase network connectivity, the links are connected to the nearest network. The Missing Links are identified using the SMIs are shown in figure 24.

Using from the figure 24: more missing links are identified in the south east part of the city. Most of the roads that should be given priority are located in zone 50 and 99. Some also exist in the Northern part. To improve connectivity and construct well developed network structure, the links identified using both SMIs were combined the recommended network is given in figure 24:

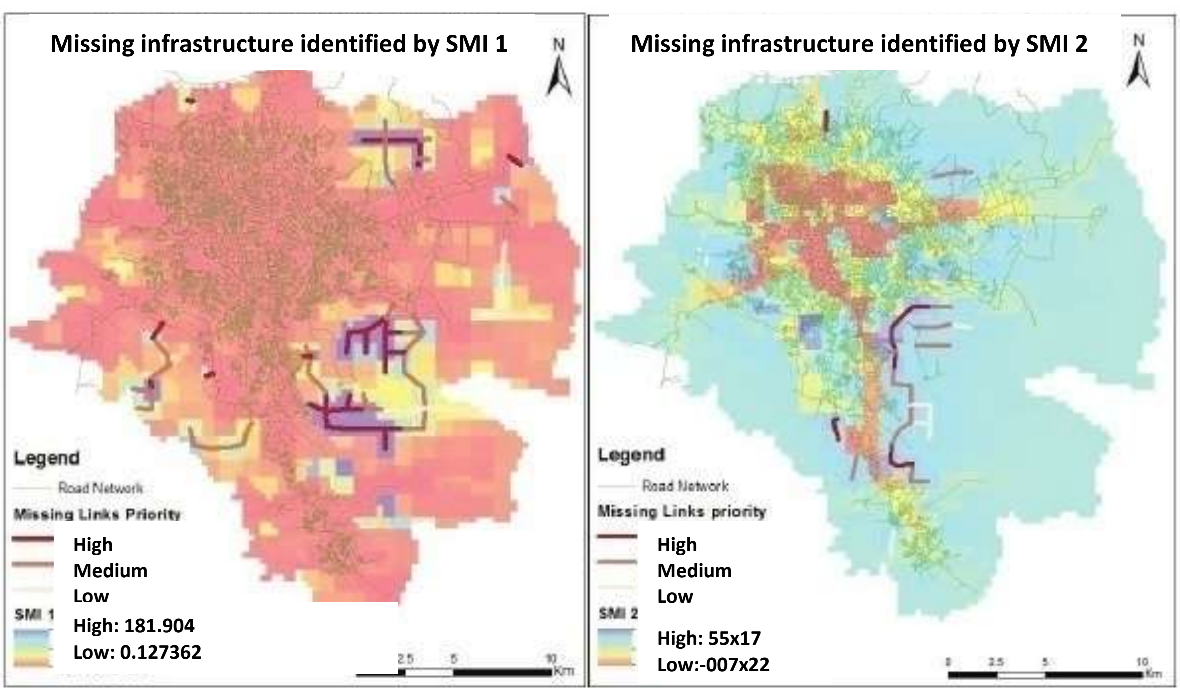


Figure 23: **Identified Missing Links**
Source: *(Adopted from Negussie, 2000)*

For developing countries where fund is one of the constrains, after identifying the missing infrastructure using different indicators, re-prioritization can be done by using Sufficiency Index and the network can be developed gradually(Negussie, 2000). This index is adopted from Negussie (2000).

Population served by the link is the number of people that can access the link in a day. It depends on terrain type where the link falls, length of road and population density. The connectivity factor is generally assumed to be 1 if the link is important in obtaining coherent network by connecting to the current network and 0.5 other wise. The constriction cost is calculated by multiplying the link length by per km cost.

By calculating the OD matrix after adding the links and assigning the trips, trip on the link can be calculated. The connectivity factor and construction cost stays the same. Using SI priorities given for the links identified is shown in figure 24.

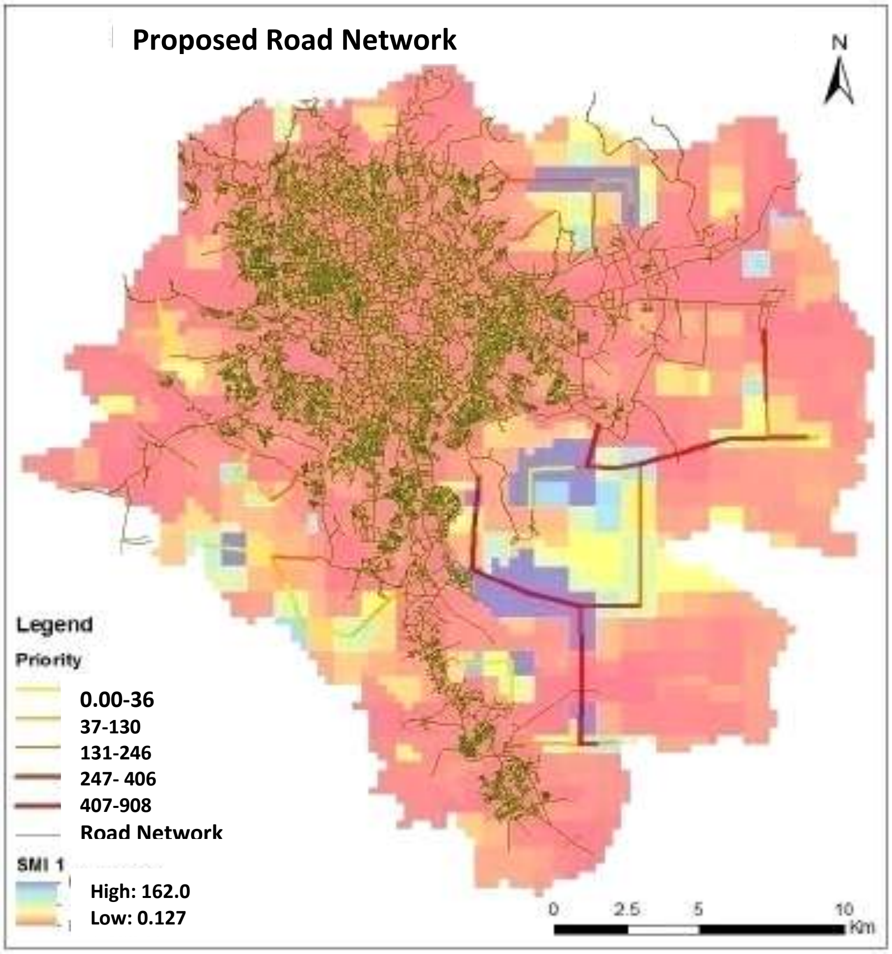


Figure 24: **Proposed Road Network**

4.3 Comparison of current network structure with the proposed network using Network structure indicators

As mobility of people is affected by the network structure, several measures and indices can be used to analyze network performance and compare different transport networks at specific area and time Comparing the current network and recommended network using network indicators like detour index, gamma and alpha index the following results were obtained.

Alpha and Gamma Indices: measure the connectivity of a network. The value of these indicators range from 0 to 1, where values close to zero indicate poorly connected network and values close to one indicate well connected network. Comparing the values of Alpha and Gamma Indices of current network and recommended network did not show that much of improvement (refer to table 12). The current road network has 13,718 links and 9,976 nodes and the proposed one has13, 796 links and10, 011 nodes. This means the links and nodes in absolute value have increased with 0.57% and 0.37% respectively. Correspondingly, the alpha and gamma indices increased by 0.57% and 0.22% respectively i.e. the indices had increased by less than 1 %. This is due to the detail of the network used for the analysis which is a fairly detailed; it includes roads even with roads less hierarchy. The links that are added in the recommended network are not as detailed as the current network but they are only possible corridors that will further be detailed into a road network by determining the design alignment of the roads in later stages. So Hence, as compared to the current network, very few nodes and links are added in the recommended network, which makes it difficult for the Alpha and Gamma Indices to capture and appreciate the recommendations made in the improvement of the network. Even though this is the case, we note that the connectivity has improved in the latter case, creating suitable and improved situation for the mobility of goods and passengers as a result of the identified missing links.

Table 12: **Network structure Indicator**

Index	**Current Road Network**	**Recommended Road Network**
Alpha	**0.136**	**0.137**
Gamma	**0.458**	**0.459**
Detour	**0.748**	**0.790**

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

In this particular project, the researcher had modeled the transport system to estimate the land use transport interaction to ultimately determine the level of infrastructure that is required to support the economic activity in the study area. This can be used as an effort to develop a comprehensive transport plan for the city. By synthesizing various geographic, socio-economic, infrastructure and land use planning aspects with current travel patterns as observed in the city, key mobility access can be identified that can assist to make an informed decision on infrastructure development.

Based on the case study for Addis Ababa, it is observed that had higher trip production and attraction is exhibited in the central area. These areas are characterized by high population and important socio-economic activities of the city including freight terminals, employment centers and schools. In some zones within the CBD, the attraction potential is much higher than the production level, corresponding to nature of the city where economic activities are concentrated at one location.

The road density, expressed as length per area, is found to be high in the central areas. As settlements in Addis Ababa are mainly established along the road network, the road length per unit person in the central areas is observed to be low. Proximity to the roads within the central areas is less than 500m, allowing more people to access these roads. However, in the outskirts, people have to travel more than 1km to access the existing road infrastructure, indicating the inadequacy of the system.

The overall conclusion obtained from the indicators show that there is less road infrastructure in the peripheral regions of the city and the central area clearly had a capacity limitation. Even though, the master plan for the city produced in 2006 recommended some roads in peripheral regions of the city, from these roads only some of them are considered for implementation. The capacity limitation problem in the central areas is also recognized from the studies and actually the master plan recommends Light Rail Transportation to be developed in the North-South and East-West corridors and upgrading of some roads.

Comparing the current network to the recommended network using structural network indices, the values of alpha and gamma indices has shown less than 1% improvement. The detour index which measures the spatial efficiency of network has improved by 5.6%. Since the mobility of people is dependent on the efficiency of a network the researcher can conclude that the recommended network will create suitable situation. Finally, the traffic assignment model used in this research can be readily used for developing countries like Ethiopia where versatile packages for traffic modeling and spatial data analysis are lacking.

The developed computer program using a Python script can be used to perform the traffic assignment that can be efficient estimates of the prevailing travel pattern on the large transportation network. While working with this model, assumptions like:

A) All trip makers are aware of the shortest route before making the trip

B) Cost of travel stays the same with respect to the flow assigned to the link because the link travel time is not considered but the travel distance only. Due to the fact that this model assigns traffics only on the shortest path that connects a pair of two ODs all links in the network are not involved but only those that form the shortest path.

C) The other limitation of this model is that it actually considers vehicle queue as vertical ones since it does not consider the actual carrying capacity of the road as a function of traffic flow as standard traffic assignment exercise requires.

These assumptions, though limiting, are not reasons to invalidate the modeling exercise adopted in this project, since they can be used for long term planning purposes without introducing substantial errors in forecasting.

5.2 Recommendations

The master plan development of Addis Ababa shows, the peripheral areas are reserved for further extension of industrial and residential land use, but in these areas the road network is not well developed, which created obstacle on the mobility of peoples. And currently, there is significant amount of demand in these areas. Even though road network development was planned in these areas, it is not implemented due to unknown reasons.

More attention is given in diverting the traffic from the central areas to the ring road by constructing new link or upgrading the existing roads. This eases the traffic load in the central areas but since the ring road has longer distance, the network is not efficient in respect to cost (considering distance as cost). The ring road also does not offer suitable provision for pedestrians.

As such, had recommended upgrading of the road and introduction of low priced mass transport system in the central areas and development of new roads in the peripheral areas based on the priorities that the researcher have set.

The main idea of this project is to investigate the current transport network of Addis Ababa city, and the researcher identified inadequate infrastructures in the network which cause unbalanced spatial accessibility to all groups.

This project had identified inadequacies which need further development and improvement. The models used in this research only consider the spatial aspect of travel cost i.e. distance as impedance, but more inclusive and testy results can be obtained by considering the temporal characteristics like that of resettlements.

More reliable results can be obtained by using traffic assignment models that also consider the capacity of a road, while computing the spatial mismatch to identify inadequate infrastructures. This opens an opportunity for further research

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