Evaluating Transport Network Structure: Case Study in Addis Ababa, Ethiopia

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February, 2012

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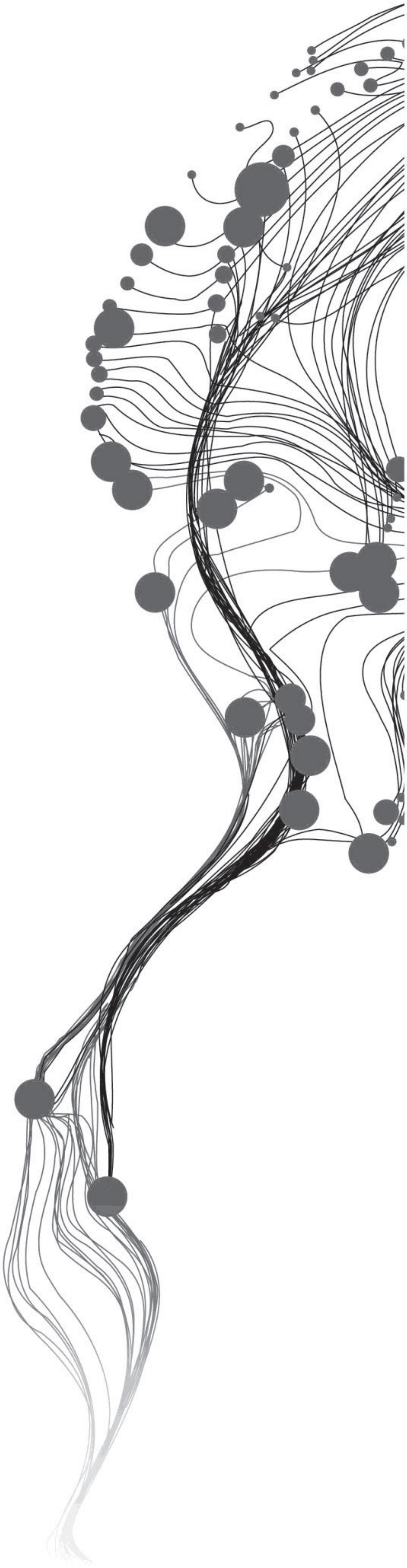

Evaluating Transport Network Structure: Case Study in Addis Ababa, Ethiopia

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Enschede, The Netherlands, February, 2012

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Geo-informatics

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ABSTRACT

Addis Ababa, the administrative and financial capital of Ethiopia, is experiencing continued growth and change. Enabling change is more complex and has many ramifications that need to be optimized and balanced by promoting sustainable growth. To facilitate rapid change and development, the Ethiopian National Urban Transport Policy (ENUTP) requires ensuring adequate, efficient and high quality transport infrastructure to guarantee effective mobility of goods and people. Although the proposed ENUTP objective seeks to achieve these goals, there are challenges which slow it down, the most significant being inadequate infrastructure in the current network arising from certain constraints.

This research identified inadequate infrastructure by analysing the spatial mismatch within the current road network measured against Network and Transport indicators developed to evaluate how well the existing network serves prevailing demand for travel. Further, we have evaluated the existing network structure against pre-determined transport planning objectives that allow the realization of the ENUTP objectives including accessibility, equity and efficiency by using indicators such as road density, mobility and proximity indices.

The Spatial Mismatch Indicator, central in this research, is operationalized by comparing the traffic assigned on the 'Reference Network' that is developed by using the Euclidean distance between the centroids of the Traffic Analysis Zones (TAZ) with that on the existing network. We have identified, evaluated and interpreted the existing mismatch by developing Spatial Mismatch Indices (SMI) that were reckoned using three methods to assign the traffic demand to the available supply. These are Euclidean Network-Based Assignment, Real Network-Based Assignment and finally, Real Network-Based Assignment with Disaggregated TAZs. In all the three methods, the spatial pattern of travel demand on the network is predicted by adapting several components of the classical Four-Step Transport Modelling approach, widely applicable in analysis of large networks. Following the execution of the trip generation model using regression models, the trip distribution is done based on the Gravity Model. Later, we have assigned the trips on the network using a basic All-Or-Nothing (AON) assignment.

In the Euclidean Network-Based Assignment method, the traffic is assigned to the Euclidean Network corresponding to the directed straight lines connecting the OD pairs. In the Real Network-Based Assignment methods depicted above, the network based trip distribution matrix is assigned to routes connecting the O-D pairs using AON assignment. The spatial mismatch at TAZ level, then, is reckoned as the total number of trips passing through each TAZ using the reference and real networks. The results of the implementation allow us to identify and evaluate inadequacy of infrastructure in the evaluated network and later distinguish the missing road infrastructure that will improve the existing performance.

The research shows that there are inadequate levels of infrastructure in parts of the current road network of Addis Ababa, particularly the peripheral areas suffer from lack of roads and roads in the central areas have capacity limitation. The research has indicated that spatial mismatch and missing road infrastructure can be better identified and evaluated by using disaggregated and spatially equalized TAZs more efficiently. Further, recommendations are made to improve the current road network structure considering connectivity and accessibility objectives that enable the realization of the ENUTP. Depending on the cost of construction and the access they open for development, the identified missing infrastructure is compared with the existing network for meeting the said objectives and later prioritized to produce a sensible transport plan based on improving spatial mismatch for decision makers.

Key words: Network structure evaluation, Spatial mismatch, Addis Ababa.

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank my supervisors Dr. Ir. M.H.P. Zuidgeest and Dr. O. Huisman for their excellent guidance, critical comments and encouragement throughout my research time. They have shared their knowledge unreservedly and this work is made possible as a result of their thoughtful steering through the course of the research. It is a wonderful experience working with them and I am grateful for their friendship and advice.

The data used in this thesis are gathered from cooperative offices in Ethiopia. I would like to give especial thanks to the Planning & ICT Department of ERA for welcoming me to their office and their kind help in readily availing available data. Also I would like to thank the staff of Afri Geo Information Engineering Plc, Ato Mohammed Nuru for his kind cooperation with data acquisition.

The unlimited cooperation of ITC Student Affairs Office, especially, Ms. Bettine Geerdink and Ms. Theresa van den Boogaard have been marvellous during my stay. My dear friends who have been sharing their experience and thoughts with me throughout the study period have been wonderful. Specially, I would like to thank, my dear friend, Hari Krishna Dhonju, who has been very helpful whenever I experienced programming difficulties. I would like to thank everyone who has participated in making this thesis successful.

Most especially, I thank my family and my husband, Beteseb; words alone cannot express what I owe them for their continuous encouragement and patient love that enabled me to complete this thesis. Beteseb, thank you for choosing to share your life with me.

Even though the help and participation of all was very helpful, but without Jesus none of it would have been real. Thank you Lord, no one has been patient with me, eased my pain and loved me as you have.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. General Introduction

With the ever increasing level of urbanization, the issue of developing an efficient strategy for urban transportation has been considered in numerous scientific and technical works, especially in the context of developed countries (Pratelli & Brebbia, 2010). The definition and eventual appraisal of various strategies for the future development of urban areas represent a demanding task that requires versatile experience in traffic engineering, planning and economics. Eventually, the decision-maker needs to be aware of the multi-dimensional impacts of various planning and management measures on the efficiency of the transport system towards meeting certain objectives to make an informed choice between the available options (Keshkamat, Looijen, & Zuidgeest, 2009).

When we look at the transport planning and decision making strategies of cities of developing countries most of the times, planning decisions are made based on pure speculation and it is hard to explain how decisions are made that affect the road network plan. Due to this fact cities grow in uncontrolled manner and evolve into more and more inefficient transport networks. It is clear that these cities need a strategic plan that deals with the overall structural and capacity of the road network and with the transport land use interaction in urban areas.

The essence of urban transport planning is to provide adequate and equitable recourse among the population. In developing countries with limited funds to distribute resources equally and to stick within the available funds planning strategies that identify most in need areas and prioritising these areas is needed. One of the methods that allow us to identify the unprivileged and neglected area is by evaluating the current transport supply with respect to demand.

Many researchers agree that major changes in transport network structure affect patterns of urban development and location of social and economic activities, households and employment centers. In the other hand major change in land use influence the trip making behavior of people, destination and mode chose (Waddell, 2011). The network structure also affect accessibility and destination choice of travelers (Huang & Levinson, 2011).For developing cities where the road network is the dominate mode of transport land use transport relationship is highly coupled. The road network provides access to different activities like businesses, education and employment opportunities (Murray, et al. 1998) and people make trips to join these activities. It has major influence in the economic development by opening virgin lands for agriculture and deliver agricultural products to the market, it serves as freight transportation for land locked countries.

However the road network in most developing countries suffers from many problems like; high accident levels, inadequate infrastructures both in capacity and availability, poor quality infrastructure and mismatch between demand and supply. These are caused by high urbanization, city growth and lack of proper transport planning strategies. 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 road network and identify areas with inadequate infrastructure (Davidson & Davidson, 1998). In this research context inadequacy can be distinguished in two ways:

1) Infrastructure exists but has low capacity and

2) Infrastructure does not exist at all

The current performance can be measured by assessing the accessibility, level of mobility provided by the network and by analysing the efficiency of the network in comparison with ideal network. Accessibility in this context is ease to reach certain destinations from a particular origin using transport network and efficiency in terms of minimized cost. Geographic Information Systems can be used for better understanding of accessibility and also be used in automatic identification of missing infrastructure in existing network structures (Zuidgeest, Rouwette, & Jong, 2009).

1.2. Motivation and Problem Statment

In light of the fore-going, Addis Ababa, the administrative and financial capital of Ethiopia, is experiencing continuous growth and change. Change is experienced in all dimensions of the city but different parts of the city grow at different rates. Economically, the city is transforming from a predominantly administrative and service center into an industrial and financial center. Due to the rapid economic growth and change, there is high mobility of goods & passenger which leads to high transportation demand. However, the existing transport system is characterized by high accident levels, high traffic congestion, negative environmental impacts, unsafe public transport and low accessibility levels. Main causes for these problems link with poor infrastructure including road and public transport network, poor interaction between land-use and transport planning, inadequate road infrastructure and low transport network density.

The transport sector being the backbone to the economic growth of the nation, road network remains the basic and critical component of transport system in the city. Addis Ababa has a radial form of road network which is shaped by five major roads radiating out of the Central Business District (CBD) into the outskirts. However, the 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 hierarchical system is missing, still the road network could be classified into a hierarchical system comprising of arterial, sub-arterial, collector and residential access roads. As described in the Urban Transport Study (2004/2006) the road network in Addis Ababa suffers from many inadequacies including absence of a balanced hierarchical system, capacity limitation, absence of infrastructure and low density among others.

There are not many studies undertaken to analyze the transportation problem for Addis Ababa transport network and where the network design itself may be the cause of the problem. However, some published sources which analyze the transportation problem of the city include Urban Mobility in Three Major Cities by the World Bank (The World Bank, 2002). In this study, the transport system of the city was analyzed and remedial measures are proposed to improve the performance of the transport system and the future planning and management of transport infrastructure. Once again, The World Bank, in collaboration with Addis Ababa Roads Authority and Ethiopia Road Authority (Ethiopian Roads Authority, 2004/2006), has clearly noted that the current road network is inefficient and measures should be taken for improvement in capacity, efficiency, etc. However, both these papers did not analyze the problem based on an objective evaluation of the spatial structure of the existing transport network.

The vision of transport plan for the city is "affordable transport, enhanced access and mobility". The world bank report on Three Major Cities (The World Bank, 2002) has noted that even though the city has low urbanization in the continent, it suffers from urban mobility problems. Due to population growth the city expanding rapidly but the road network fails to serve the newly developed areas. The public transport is limited to certain parts of the city due to unavailability of road network. So most of trips are made are by foot and restricted to some regions. In the most of peripheral areas of the city due to absence of road infrastructure accessibility is very low. Some of these areas are new developed real estates and areas that provide agricultural products to the city. As pre the UTS (2004/2006) plan some of these areas are reserved for future industrial development.

1.3. Research identification

1.3.1. Research Problem

The above sections reveal that the current transport infrastructure of Addis Ababa may be inadequate with respect to travel demand. GI based network indicators can be developed to assess and evaluate inadequacy within the network structure. From the literature available, there are established indicators that can assess networks in general, but most of them do not consider travel demand. Further, limited GI based network indicators are available to identify inadequate infrastructure in an existing road network. GI based network indicators can be developed to assess network structure. Hence these indicators can identify infrastructure with low capacity and missing connections. As such, improvement should be recommended in line with the vision of the city **'affordable transport, enhanced access and mobility'.**

1.3.2. Research Objectives

To develop GI based indicators to evaluate road network structure in relation to potential travel demand and recommend improvement in network structure.

Sub-objectives:

1. To identify potential travel demand and current network.
2. To develop indicators to assess the existing road/transportation network structure.
3. To identify which network based indicators can be used to identify inadequate infrastructure for prioritization and define road hierarchy for Addis Ababa.

1.3.3. Research Questions

The research objectives identified above are translated into the following specific research questions:

1. To identify potential travel demand in current network.
   - What models can be used for estimation of travel demand in urban area?

2. To develop indicators to assess the existing road/transportation network structure.
   - Which network based indicators should be developed to assess the structure of current transport network?
   - How to evaluate the current network based on the pattern of travel demand?
   - How to combine network indicators and spatial nature of demand to evaluate structure of transport network?

3. To identify which network based indicators can be used to identify inadequate infrastructure for prioritization and define road hierarchy for Addis Ababa.
   - How to identify inadequate infrastructure in existing road network through assessment of the network indicators?
   - How to identify inadequate infrastructure based on pattern of travel demand and available transport network supply?
   - How to prioritize infrastructure based on their rank in achieving pre-determined transport objectives?

1.4. Conceptual Framework

Transport system is combination of demand and supply. Travel demand is generated by the desire of people to join activities. It depends on the socio-economic activity of the people, land use characteristics and accessibility of zones. Trips made also vary depending on the purpose of the trip, time at which the trip is made, person type; socio-economic activity like car ownership, income and household size, and the modal choice. From Urban Transport Study (2004/2006) trip by purpose (employment, home based, education and other trips) is considered. Transport supply includes infrastructure, services and transport networks. For this research we will only consider the transport network. Combining travel and transport supply, the network structure will be evaluated that requires us to set up criteria that can be used for this purpose.

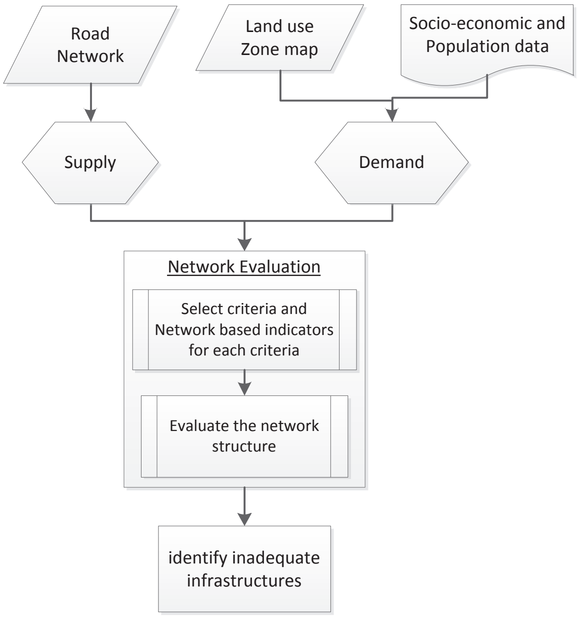


Figure 1-1) Conceptual Framework

1.5. Thesis structure

The overall thesis is organised under six chapters as follows: Introduction, Literature review, Study area description, Methods, Results and Discussion and Conclusion and Recommendations.

Chapter 1gives brief introduction of the research, identifies research problems, defines research objectives and questions related to the objectives.
Chapter 2 briefly review literature on transport network modelling, criterion that are used to evaluate transport network structure and travel demand modelling.
Chapter 3 describes the study area based on its topography, socio-economic characteristics, demography and land use
Chapter 4 presents the research approach and data collection methods used to reach the objectives of this research are explained.
Chapter 5 discuss the results of transport modelling and evaluation of the current network. Furthermore results of the spatial mismatch assessment are provided.
Chapter 6 identification of in adequate infrastructures are discussed and interpreted.
Chapter 7 provides the discussion, conclusions and recommendations made based on the results of the research.

1.6. Research Design

The following flow chart depicts the logical steps carried out in the course of the research.

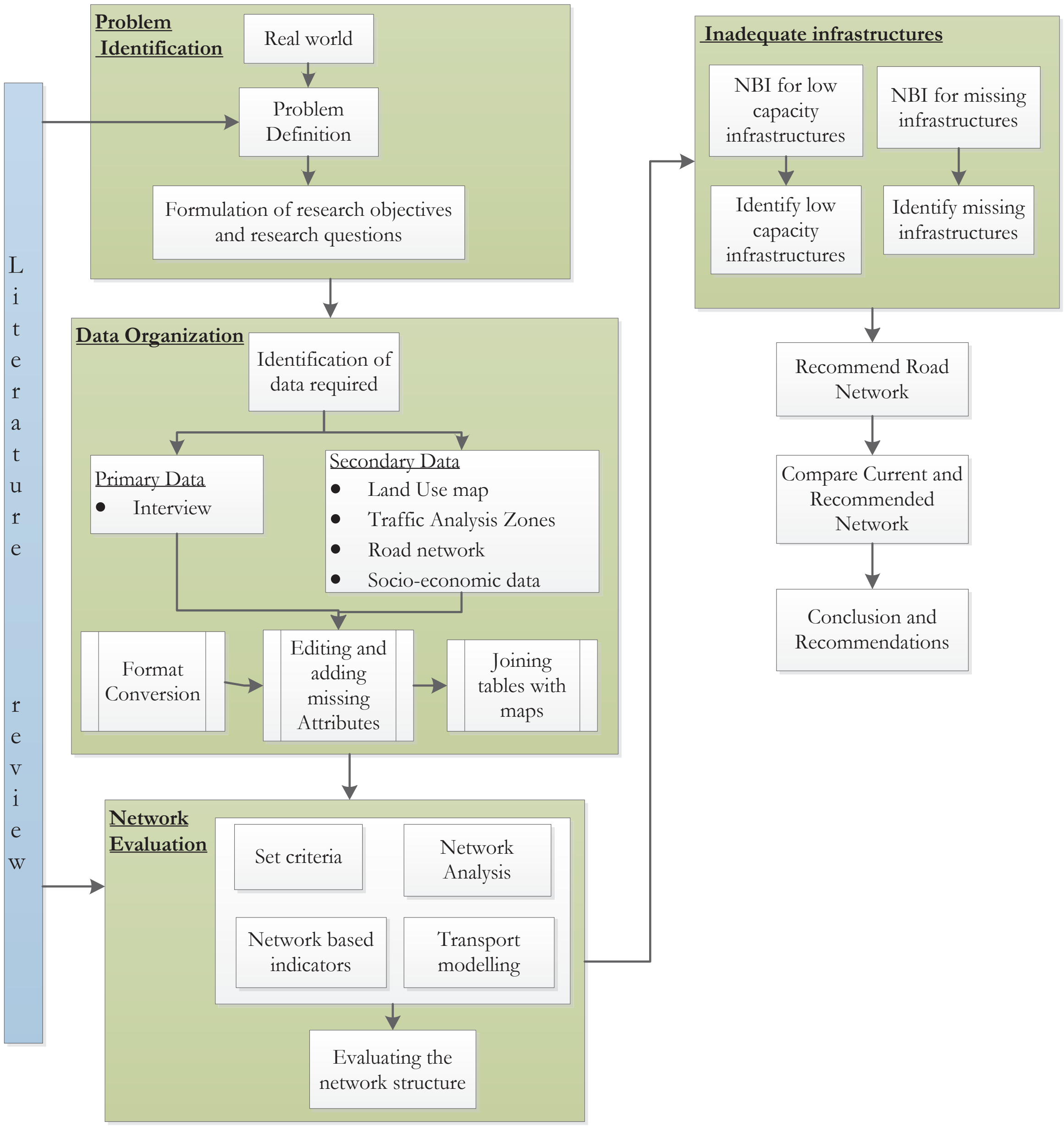


Figure 1-2) Research design

2. LITERATURE REVIEW

2.1. Introduction

One of the factors that affect urban form to a great extent is transport network structure. The settlement of people may be depending on the availability of transport infrastructure or transport infrastructure may be constructed where demand is at most. In either way they affect each other. The availability and quality of road infrastructure affects the quality of life, economic and business activities and strengthen the economy of a region. Transport infrastructure plays important role in the economy; especially for developing countries it opens access to agricultural lands, markets, health centers, schools and so on. All in all, it facilitates mobility in urban areas and improve quality of life (Gwilliam & Kenneth, 2002).

There are many important decision-making problems in transport network planning. One of them is due to the nature of transport networks projects that are planned for long-term, decisions on investment also need long-term perspective (Santosa & Joewono, 2005). Especially developing countries with limited funds need to spend the money effectively and satisfy the areas which are in need. Evaluating the current road network with respect to the current demand will help decision makers to understand how much the network satisfies the demand and identify which areas need more attention for future development plan.

The current performance of road network, can be evaluated based on the structure of the road network (Xie & Levinson, 2007), the access and mobility it provides (Gutierrez, el al.,1998; Liu & Zhu, 2004) demand and supply equilibrium (Bell & Lida, 1997) by measuring the capacity of the network (Chen et al., 1999) and by assessing the spatial mismatch between demand and supply(Grishchenko, 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 inadequate infrastructures (Davidson & Davidson 1998). The absence of one or more network links, especially those that have high travel demand, could lead to overall poor performance of the network in terms of overall system travel time and optimization of supply (Bell, 2000; Chen et al. 2002; Smith et al. 2003 cited by (Scotte et al. 2006)). Network effectiveness indicators, which compare the real road network to geographically perfect network (direct link), can be used to identify these areas (Davidson & Davidson, 1998).

In the interest of improving the performance characteristics of a network, a combination of demand and network structure related indicators are required. From the previously developed methods, even though there are GI based indicators that are useful to study transport network structure, the ones that consider travel demand are few. Those that consider spatial behavior of demand have been applied to bicycle networks (Zuidgeest, el al.,2009), freight networks (Grishchenko, 2011) and public transport (Abate Abreha, 2007). Further, limited methods are available to identify and prioritize inadequate infrastructure in existing road network.

In this study, the current transportation network structure of Addis Ababa will be evaluated by using network indicators to analyze the existing pattern of travel demand and the structure of the network supply. The literature review is organized in such a way that; it first briefly reviews transport network modelling, second part identifies indicators to evaluate the transport network, in the third part Travel

Demand Modelling will be discussed and at last, transport network contribution to economic growth will be discussed.

2.2. Modelling Transport Network

Transport demand modelling will help us in understanding the travel pattern, which itself provides an understanding of the relationship between urban structure and the transport network (Timmermans et al., 2003). Travel demand takes place at a certain time and space. To capture the spatial and temporal nature of travel demand the supply side of transport system (road infrastructure) can be represented by network.In the past decades, advanced methods have been developed in order to analyze more complex transportation network problems and propose solutions. These models can be used in either of the following types:

1. Static (relating to states or conditions) or dynamic (relating to processes),
2. Computational or non-computational,
3. Quantitative (with numbers) or qualitative (without),
4. Spatial or non-spatial,
5. Empirical (based directly on data) or synthetic (based on a relationship derived from the data) (Ortúzar & Willumsen, 2011).

The use of each type depends on, among others, the context of analysis, the purpose of the exercise, accuracy and certainty required, the level of detail, statement of the problem, availability of computing tools and availability of time and resource to carry out the analysis (Button & Hensher, 2000). Ideally, we would like the model to be appropriately detailed, accurate, appropriately sensitive, economical and easy to use. However, very few models have all these qualities; trade-offs have to be made in the light of the requirements of the exercise (O'Flaherty, 1997); (Bruton, 1993). To analyze real network considering land use and socioeconomic data, a model which can handle large spatial data is needed. Even though transport is dynamic in nature modelling large real networks usually is done on the basis of static models, as is done in this study.

From these models, GIS is able to handle huge data and analyze a variety of network-related problems by itself and can also be integrated with other methods for transport network analysis by providing a spatial database and mapping platform (Kuby, 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 transport networks can be represented by directed graph with nodes and links where the nodes represent junctions while links indicate homogeneous road sections between nodes (Zuidgeest & Maarseveen, 2011).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 (Kuby, et al., 2005).

Since the late 1950s, several network based indicators/measures have been developed to analyze transport 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 transport network. Once this demand is realized, it becomes spatial interaction which flows through transport network.

To capture the spatial nature of demand, sciences like Transport Geography which considers the spatial perspective of socio-economic, industrial and settlement frameworks (which are main factors of transport demand) within the transport network development and transport system operates (Hoyle & Knowles, 1992) can be useful. This field analyzes land use-transport interaction as spatial interactions in transport are derived from land use (Hensher, el al.2004). The transport network considers spatial organization of the transport infrastructure and terminals as its basic structural elements, links and nodes respectively (Taaffe, Gauthier, & O'Kelly, 1996).

In this study, the current transportation network structure of Addis Ababa will be evaluated by using network indicators to analyze the existing pattern of travel demand and the structure of the network supply. A methodology which will assist in rationalizing the network by identifying and prioritizing the required infrastructure is developed and implemented in for Addis Ababa Transport Network. The recommended transport network that follows will be compared with the existing one based on pre-determined transport planning objectives.

2.3. Network Evaluation Indicators

Evaluation of transport system should be based on defined development objectives of the city. Evaluating criterion is set depending on the goal of development of each city. Criteria and indicators may differ significantly depending on many factors such as city type, regional transportation vision, or travel behaviour even between modes (Derrible & Kennedy, 2011).

2.3.1. Mobility

Transport networks are intended to move people and goods to where they need to go quickly and affordably(Sohail, Maunder, & Cavill, 2006).The movement of people and goods is affected by cost and the safety of travel. Mobility is the ability to move people and goods. Increasing the efficiency and effectiveness of transport network will increase mobility. In developing countries with low infrastructure both cost of travel and safety are major factors affecting mobility. Mobility measures indicate the quality of movement and the quantity being moved (Zuidgeest, 2005).

Efficiency of a network can be indicator for the mobility offered by the network. An ideal road network is the one, which provide the most direct route between an origin and destination at the desired speed. In order to measure the efficiency of the road network, a mobility index is defined. Mobility index is defined as the ratio of travel time by the physical route (speed determined by the type of the road) between an origin and destination and the travel time by the airline distance at desired speed (Ethiopian Roads Authority, 2000/2001).

$$Mobility\ Index\ (MI) \quad = \frac{Travel\ time\ by\ the\ physical\ route\ between\ origin\ and\ destination}{Travel\ time\ by\ the\ airline\ distance} \qquad (2.1$$

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 will be 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, 2000/2001). If the road network can provide a mobility index in this range for travel between all regions, then the road network is considered to have provided excellent level of connectivity and mobility.

2.3.2. Equity

Equity refers to the distribution of resources (in this case transport network) and if the distribution is considered appropriate (Litman, 2011). In transport equity is a diversified concept and the analysis may be difficult because there are various ways to categorize people, number of resources to consider and various ways measuring these resources. Broadly speaking equity in transport can be categorized in to two types (Geurs & Ritsema van Eck, 2001).

1) **Horizontal Equity:** focuses on the distribution of resource between individuals or groups with comparable needs and abilities. Equal individuals or groups should share equal resource, pay equal cost and must be treated in the same way.
2) **Vertical Equity:** is concerned with the distribution of resources between individuals or groups that differ in ability and need. From this definition transport networks are equitable if they favour socially and economically disadvantaged groups. Social, Economic and Spatial equities are considered.

The development plan of a city should be prepared with due consideration of equity requirements. 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 we will consider Spatial and socio-economical equities.

In planning road networks, it is very important that the road network is equitably developed in all zones, in order to promote general economic and social development objectives. The main consideration in the evaluation of new road projects is generally the economic viability. As a result, less developed areas with low traffic generation are often either not taken up or given low priority, further increasing the disparity in development. There should be equitable development of the road network to ensure that the road network will facilitate the development of all zones.

2.3.3. 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) have revised literatures on the theoretical definition and measures of accessibility and in 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 analyse the impact of motor way development in regional development.

One of the goals of transport system is to increase mobility and access to facilities. Even though the definition of accessibility varies depending on its application(Curl, et al., 2011), based on this context, it can be generally defined as the ease with which certain destinations can be reached from a particular origin using specific mode of transport (O'Sullivan, et al., 2000). It can be measured by the mobility the transport system provides and density of opportunities that can be accessed within a certain time or distance. It depends on the spatial distribution of activities, the origins of demand and transport system connecting the origins and destinations.

The other important function of the road network is to provide linkage and open access to major centers, by giving connectivity to all economic centers, to sub city headquarters and national and international entry points like airports and freight hubs. By providing good connectivity the road network will contribute to the economic growth, increase accessibility and people mobility.

2.3.4. Transport Infrastructure Availability

One of the important factors affecting the performance of the transport 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. Especially road length per area and road length per unit population indicate the accessibility of the road network. This indicator is rather important in the context of Addis Ababa because, as is the case with many developing cities, given the deprivation of the society from enjoying acceptable levels of transport accessibility, some areas may be justified to have a specific link constructed purely on social basis as opposed to economic ones.

2.3.5. Spatial Mismatch

The idea of spatial mismatch was first developed in U.S.A in the late 1960s' to assess the availability of jobs in black neighbourhood. Since then 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; S McLafferty, 2001)and to analyse transport mode chose and ethnic groups(Patacchini & Zenou, 2005). Considering the jobs as supply and employees as demand, this concept is used to analyse the spatial difference that exists between demand and supply.

The concept of spatial mismatch has not that much been applied in evaluating transport network evaluation. Grishchenko(2011) used this indicator for freight network assessment in Europe. This indicator compares trip distribution among traffic analysis zones considering the resistance (impedance) travellers 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. This will be computed using both resistances experienced using directed route (Euclidian network) and real network. From Rouwette (2005) cited by Grishchenko (2011)the spatial mismatch function is defined as the difference ($\Delta Tij1$) between network based ($\Delta TijND$) and Euclidean based ($\Delta TijED$) trips equation (2.2) and the second function takes the ratio between them ($\Delta Tij2$) equation (2.3).

$$\Delta Tij1 = \Delta TijED - \Delta TijND \quad (2.2) \quad \text{Spatial mismatch index 2}$$
$$\Delta Tij2 = \Delta TijED / \Delta TijND \quad (2.3) \quad \text{Spatial mismatch index 1}$$

2.4. Transport Demand Modelling

Transport demand modelling was first developed in U.S.A during the 1950's. Its' important techniques were developed in mid 1970s. After years of research and experimentation it is recognized as part of transport planning process (Ortúzar & Willumsen, 2003). Since then it has been developing to solve many transport problems by providing information for evaluation, development and implementations of future transport planning proposals.

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

Demand is driven from the need for travel of people. People will travel to reach to different activities from the place of residence to their jobs, shopping areas, schools or even others. Travel demand models should reflect the reasons for travel is to make part in activities and specially activities that are not present at the current position (Button & Hensher, 2000). The spatial separation of activities over space makes demand to take place over space. To deal with the spatial nature of demand is to divide study areas in to zones together with transport network (Ortúzar & Willumsen, 2003).

There are number of travel demand models used in urban transport studies. In this research we will adopt some parts of the Four Stage Urban Travel Demand Model. This model is the conventional method for Urban Transport Planning System (UTPS), where the distribution of land use in terms of population and employment allocation is done exogenously. This modelling approach is popularly known as sequential travel demand modelling which has four stages (refer figure 2.1), namely;

1. Trip Generation
2. Trip Destribution
3. Modal Split and
4. Trip Assignment

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 pattern and population, spatial distribution of economic oppurtunity (employment) and socio economic characteristics of the population in the study area.

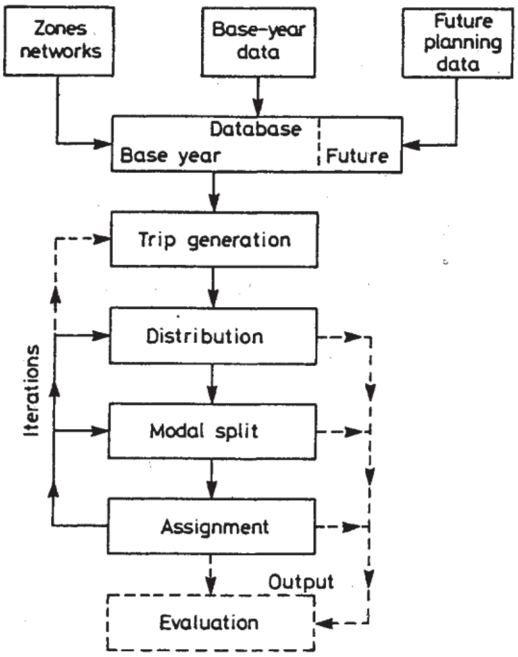


Figure 2-1) The classic four stage transport modelling(Ortúzar & Willumsen, 2011)

In this research, we will use the several components of the Four-Step Transport Model (FSTM) for the analysis of travel demand on the road network. As standard traffic modelling exercise on large networks suggests, the study area will be partitioned into TAZ to quantify the demand using the first sub-model of the FSTM, namely, Trip Generation model will be 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, we will consider all modes of transport, to make the trip, therefore, the modes will not be split and the OD Matrix will have considered all the available modes. At this stage, the third sub-model of FSTM, Modal Split shall have been modelled and implemented to estimate the trips that are made using the different modes of travel. We have adopted the modal split results obtained from the Urban Transport Study (2005) for the purpose instead of modelling our own Modal Split Analysis due to lack of data and limited time for the research. 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 has 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. Finaly trips passing through each zone will be computed by corrosponding OD routes passing through them. The following section discusses these transport modelling steps in greater detail.

2.4.1. Traffic Analysis Zones

Urban transport modelling depends on traffic analysis zones (TAZs) as its basic unit of analysis(You, Nedović-Budić, & Kim, 1998).The centroids of TAZs are 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 centroid.

Before performing a transport model, we 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). The choice of TAZ size also depends on the type of analysis to be undertaken and the statement of problem involved. For instance, studies for traffic management and corridor choice need fairly disaggregated zones, requiring the introduction of many zones for the analysis whereas larger zones can be used in strategic studies that occasionally do requires lesser number of zones to be dealt with under the study.

2.4.2. Trip Generation

Trip generation and distribution are in the first step of transport modelling where the characteristics of the traveller and land use activities are evaluated, calibrated and validated to produce non-equilibrium measure of travel demand (Button & Hensher, 2000).The main purpose of this step is to process and estimate the total number of trips generated and attracted by each area unit (zone) in relation with the land use and the socio-economic characteristics of each zone(Ortúzar & Willumsen, 2011). Trips made may vary depending on the purpose, time of the day and person type. Trips by purpose include; work trips, education trips and others. Based on the time of the day trip is made it can be categorized as peak and off-peak. Socio-economic character is also another factor that affects the trip making behaviour of a person.

This model estimate the total number of trips produced or originated from a zone and attracted to each zone. There are three approaches commonly used in the trip generation analysis: regression analysis, trip rate analysis, and cross-classification analysis. These approaches establish statistical relationship between number of trips produced and land-use characteristics of the zone and socio-economic character of households.

2.4.3. Trip Distribution

The next step in travel demand modelling is trip distribution. Since we know total trip production and attraction potential of each zone, in this stage, the next information we want to know is where this trips go to and where the attractions comes from. Trips are distributed over the zones depending on the cost (impedance). Impedance may be time, money or distance or even combination of factors (Mark Zuidgeest & Maarseveen, 2011). This model is destination choice model that generates trip matrix (O-D matrix) T_{ij} for each trip purpose utilized in the trip generation model and network attributes (inter-zonal impedance)(Button & Hensher, 2000). There are many trip distribution models, however, for this research Gravity Model is adopted.

Gravity Model

This model is mostly used when base year OD is not provided or important changes take place in the land use and transport network. The model is mainly based on Newton's Gravity Low and assumes trip making behaviour is influenced by external factors like total trip ends and distance travelled (Ortúzar &

Willumsen, 2003). After many experiments and researches it was concluded that the effect of distance on trip making could be modelled better by decreasing function with the following equation.

$$T_{ij} = \alpha O_i D_j f(c_{ij}) \qquad (2.4)$$

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

α is balancing factor

$f(c_{ij})$ is the deterrence function or impedance function. This function decreases as travel cost or distance (time) increases. There are three versions of impedance functions that are usually used. In the UTS(2004/2006) the deterrence function used is combined function.

$$f(c_{ij}) = (c_{ij}{}^{-\beta}) e^{-cij\propto} \qquad \text{Combined deterrence function} \qquad (2.5)$$

Where: c_{ij} is the generalized cost, time or distance of travel between origin i and destination j.

2.4.4. Traffic Assignment

This step is performed in the subsequent part of transport modelling 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 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.

Mekbib (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 modelling and spatial data analysis are lacking for long term planning. AON assignment is also useful in areas where major mode of transportation is walking. In this study all-or-nothing assignment will be carried out by developing computer program. The step adopted is as follows.

1. Input data consist of network topology, link length, OD matrix converted to array.
2. For each origin-destination pair, find the shortest route
3. Assign the volume to the links forming the shortest route between the OD pairs
4. The output: Link number and volumes on each link

2.5. Contribution to Economic Growth

Transport is a key requirement for economic and social development to take place. Its' absence causes isolation, backwardness and poverty. The World Bank World Development Report (2002)on 'Urban transport and poverty reduction' notes, that in some cases halving of transport costs has increased volume of trade by a factor of five. Equally dramatic examples could be taken from improving social welfare and skill levels through improved health and education.

"Transport infrastructures are, if not the engine, then the wheels, of economic activity" (The World Bank, 1994).It raises the productivity of an area for example by reducing the time and effort needed to bring agricultural products to market, by providing access to schools, job opportunities and medical center. In the previous years there have been many debates whether transport infrastructures cause growth or economic growth cause transport infrastructures investment. But they all agree that there is high correlation between them. In this research it is assumed there is a positive relation between economic development and transport network performance.

Road network development has a major influence on the distribution of population, location of industries, exploitation of resources and provision of social service (Geurs K.T. & J.R, 2001). In long term it may stimulate land-use shifts, increase demand and behavioural shifts (M. Zuidgeest, 2005). Due to construction of new transport infrastructures new trips may be generated and people may change their mode of transportation. For example if a road is constructed in a place where the dominate mode of transportation is walking, due to the new road vehicles will start accessing that area. People may change their mode of transport from walking to public transport or privet cars.

Since road networks are designed for long term, understanding of how the existing network serves the different sectors of economy as well as identification of economically potential areas where lack of road network is holding back the development is essential. This can be done by analysing the accessibility of different opportunities, resources like mining, social services and schools.

3. STUDY AREA

3.1. Introduction

Addis Ababa is the capital city of Ethiopia. Due to its historical, diplomatic and political significance for Africa, it is often referred as "the political capital" of Africa. Geographically it is located at the center of the country. It is located in the plateau of mountain ranges at a height of 2000 to 5000m above mean sea level. Its topography ranges from rolling to hilly area with relatively steep gradients and numerous rivers stream valleys.

Addis Ababa city Administration extends over 540 sq. kms with 10 sub-cities and 99 kebeles for administrative purpose. As per the master plan from UTS (2004/2006) the administrative units are further divided in to 131 TAZs. The city has experienced spatial spread mostly towards the Southern, Eastern and South Western parts of the main city. The spatial spread is mainly guided by topography and road network development. After the construction of the ring road, new settlements were observed around South Eastern part of the city. In the past decades, the two sub-cities of Bole and Nefas Silk Lafto have experienced substantial development.

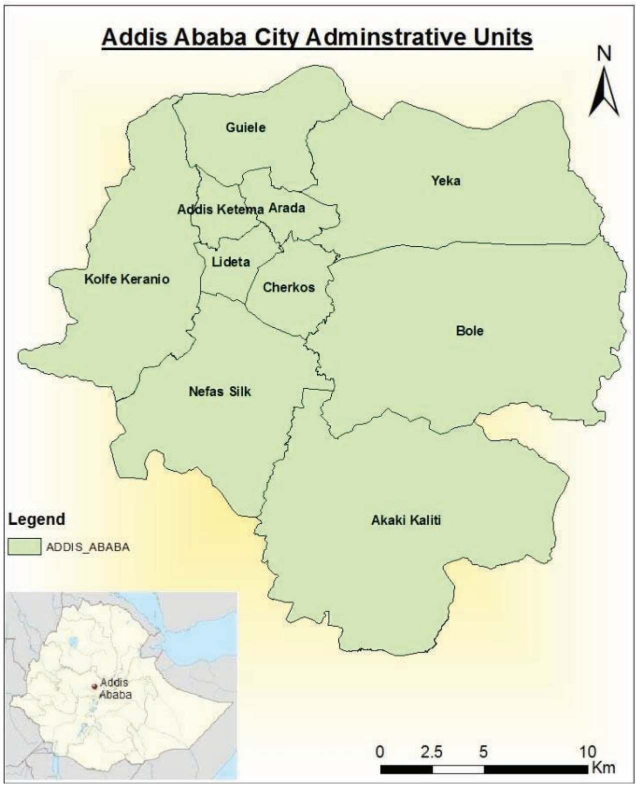


Figure 3-1) Administrative units of Addis Ababa

Recently the city has been experiencing a continuous growth and change. Change is experienced in all dimensions of the city but different parts of the city grow at a different rate. Economically, the city is transforming from a predominantly administrative and service center into an industrial and financial center. Due to the rapid economic growth and change, there is high mobility of goods & passenger which leads to high transportation demand. However, according to the UTS(2004/2006) report the existing transport system is characterized by low availability of road where the share of roads in land use pattern is low at about 7% where as an efficient system needs 20 to 25%.

3.2. Population and Socio-economic Characteristics

The mobility of people depends on their socio-economic status and demographic characteristics. Therefore studying these two factors will help to understand how much and why people travel. Studying the socio-economic and demographic characteristics of the study area will help to know how much and why people travel. The following sections discuss the pertinent socio-economic characteristics of the study area which are the factors that determine the level of demand for mobility exhibited in the area.

3.2.1. Population

Based on the census data in 2007, the population of Addis Ababa was about 2.7 million out of the national population of 73.9 million. The total administrative area is considered to be urban. Therefore, this counts for 23% of the national urban population (inception). The population of the city as compared to the total population of Ethiopia is shown in table 3.1. This data shows that the population in the city has doubled since 1984. The last population estimates indicate that the population growth of Addis Ababa is maintained at 2.1%.

	1984	1994	2007	2010
Addis Ababa	1.4	2.1	2.7	2.9
Ethiopia	39.9	53.1	73.9	77.5

Table 3-1) Population of Addis Ababa as compared to Ethiopia

Depending on the population density, residential area can be generally classified in terms of higher density central areas and lower density on the periphery. The following table outlines the residential population for 2007 and 2010 for each of the 10 sub-city zones. The four central sub-cities have relatively equal distribution of population. Even though these areas only count for 8% of the total city area, population contained in then accounts for 32% of the city residents.

Sub City Zone	2007	2010	Area (square km)	Density (pop per sq km)
Central Area Total	889,705	947,880	41.12	23,052
Lideta	201,613	214,796	9.18	23,398
Cherkos	220,991	235,441	14.62	16,104
Arada	212,009	225,999	9.91	22,805
Addis Ketema	255,092	271,644	7.41	36,659
Peripheral Area Total	1,848,543	1,969,415	485.87	4,053
AkakiKaliti	181,202	195,273	118.08	1,654
Nefas Silk-Lafto	316,108	335,740	68.3	4,916
KolfeKeraniyo	428,654	456,219	61.25	7,448
Gulele	267,381	284,865	30.18	9,439
Yeka	346,484	368,418	85.98	4,285
Bole	308,714	328,900	122.08	2,694
Addis Ababa Total	2,738,248	2,917,295	**526.99**	**5,536**

Table 3-2) Addis Ababa Population by Sub-City (source inception report)

From the 2007 census data the population was split between 48% males and 52% females. 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(2004/2006) there were about 786,000 employed people.

3.2.2. Income

Based on the census in 2007, there were 652,000 households with average household size of 4.1. The level of income is low and average household monthly income is about 31 Euros (725 Ethiopian Birr). Nearly 50% of the population is below poverty line with income less than 20 Euros per household per month and 23% are in absolute poverty with less than 13 Euros per month.

In figure 3.2 the income levels are divided in to three classes, high, medium and low. 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 characterised by slum settlement. In recent years, even though the government have been working on reducing the slum from central areas, some 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.

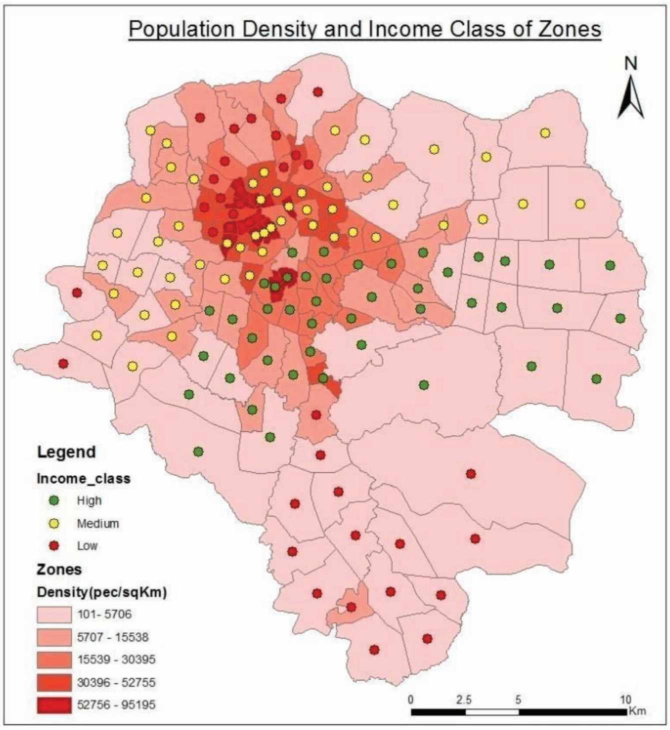


Figure 3-2) Income levels and population density

3.3. Land Use

An analysis of the location and intensity of land use within a spatial context provides a basis for understanding the spatial context of mobility within the city. An overview of the study area for which this assessment has been undertaken is identified in the following table through the land use distribution prepared as part of the City Master Plan (2002-2010). The land use distribution of the Study as per the

Structure Plan is presented in Figure 3.3. From the total land use, the road network takes only 7% indicating poor level of network development.

Major Components of the Structure Plan	Area (ha)	Percentage
Mixed use (Housing) Built up	16,274	31.3
Mixed use (Housing) Expansion Area	6,974	13.4
Existing Industry	1,244	2.4
Proposed Industry	1,777	3.4
Center (CBD & Sub CBD's)	1,276	2.4
Existing Social Services	495	1
Proposed Social Services	600	1.2
Road Network	1,975	3.8
Transportation	989	1.9
Forest Open Spaces	12,176	23.4
Agricultures	7,175	13.8
Reserved Area	1,045	2
Total	52,000	100

Table 3-3) Land use proportions (source UTS (2004/2005))

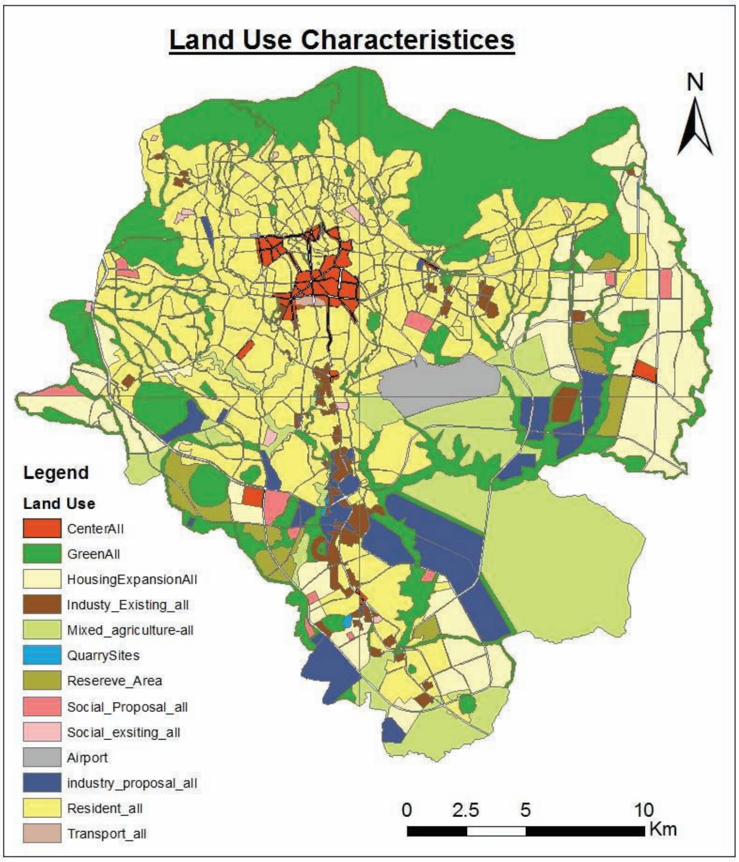


Figure 3-3) Land use

The land use distribution as per the Master Plan, shows that most of the development of the city is mixed with no well-defined residential, commercial and industrial areas. The main commercial center and industrial employment centers can be identified as being concentrated on three key areas in addition to main road corridor strip development. The main commercial center of the city lies mostly with in Addis Ketema sub-city mainly in an area locally known as Merkato. The major land freight terminals are situated within this area. The upmarket commercial center and most of governmental services lies in Arada sub-city mainly in an area locally known as Piazza. Industrial areas are mainly located along the North-South road corridor. Land use and urban dynamics of the city is shown in appendix D.6

3.4. Transport and Road Network

The main components of Addis Ababa transport system are, the road network, city bus, mini bus taxis, small amount of private vehicles and large pedestrian. The road network provides the means for travel through the city. The problems associated with transport in the city, specifically lack of proper transport planning and management of traffic are felt to be pressing. According to Urban Transport Study (2004/2006) the availability of road is poor. The share of roads in land use pattern is low at about 7% where as an efficient system needs 20 to 25%. The road network also suffers from inadequacies like absence of balanced hierarchy, capacity limitation and low connectivity (Ethiopian Roads Authority, 2004/2006). In the CBD area where there is intense generation of traffic by all modes, links capacity is limited due to destined traffic volumes on street and on street parking.

The road network has radial form which is shaped by five major roads radiating out of the Central Business District (CBD) into the outskirts. The ring road has added an orbital shape. Though proper hierarchy is missing still the road can be identified in to four categories; Arterials, Sub-arterials, Collectors and Local or residential roads. As up to July 10, 2010, AACRA had a total paved road network length of about 642 Km covering above four categories of roads. The distribution of road network length provided by AACRA is given in table 3.4.

Arterial roads: As per the master plan 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 vehicle traffic from the general traffic stream. The ring road is included in this category.

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.

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.

Local roads: these are access links to residential or business areas.

The two predominant types of public transportation in the city are, Anbessa City Bus Enterprise, which serves 30 – 35% of public transport users and mini-bus taxies, cover 30%. More than one third of the total population is pedestrian models shares are given in table 3.5.This is not only because the society can't afford to use existing facilities, but also because the level of service of public transportation is low.

Uncontrolled and rapid horizontal expansion and poor road infrastructure of the city (narrow road, limited network extent, no pedestrian walk way etc.) are major contributors for low level of service. Especially in the newly develop parts of the city western, people have to walk long distance to reach these services.

SI .No.	Road hierarchy	Unit	Total Length	Length in 7m width	No. Of Bridges	Pavement Status
1	Arterial	km	308	1,195	108	Very Good
2	Sub Arterial	km	108	242	44	Very Good
3	Collector	km	100	100	49	Good
4	Local	km	126	126	31	Good
Cumulative		km	642	1,662	232	
Gravel Road		km		1,662		
Total Road Coverage(Length)		km		3,324		

Table 3-4) Road hierarchy (Source AACRA)

Mode	Percentage
Walking	60.5%
Privet Car	4.70%
City Bus	10.90%
Mini Bus	20.60%
Others	3.30%

Table 3-5) Transport modes and percentages (Source UTS (2004/2005))

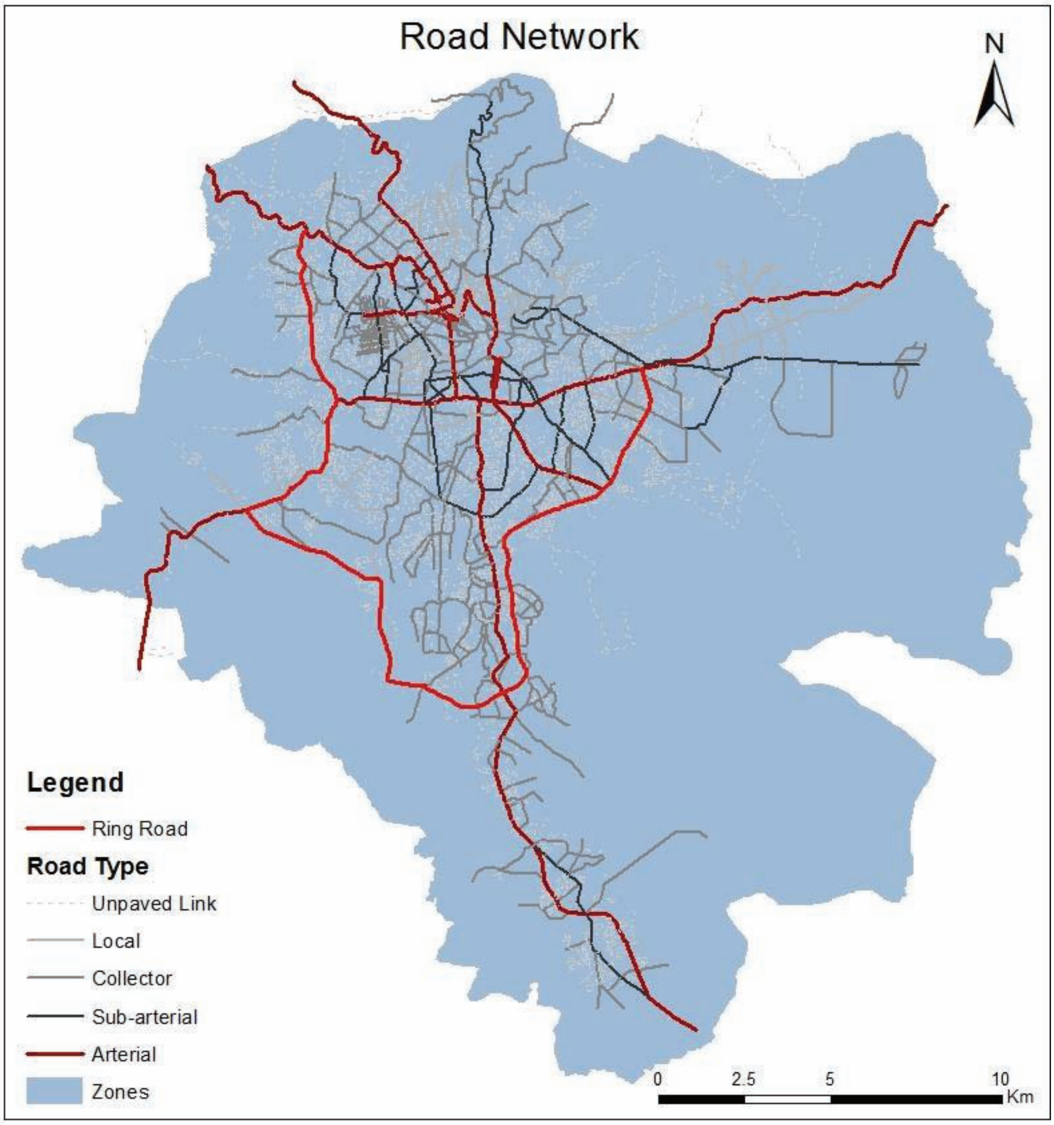


Figure 3-4) Road network and hierarchy

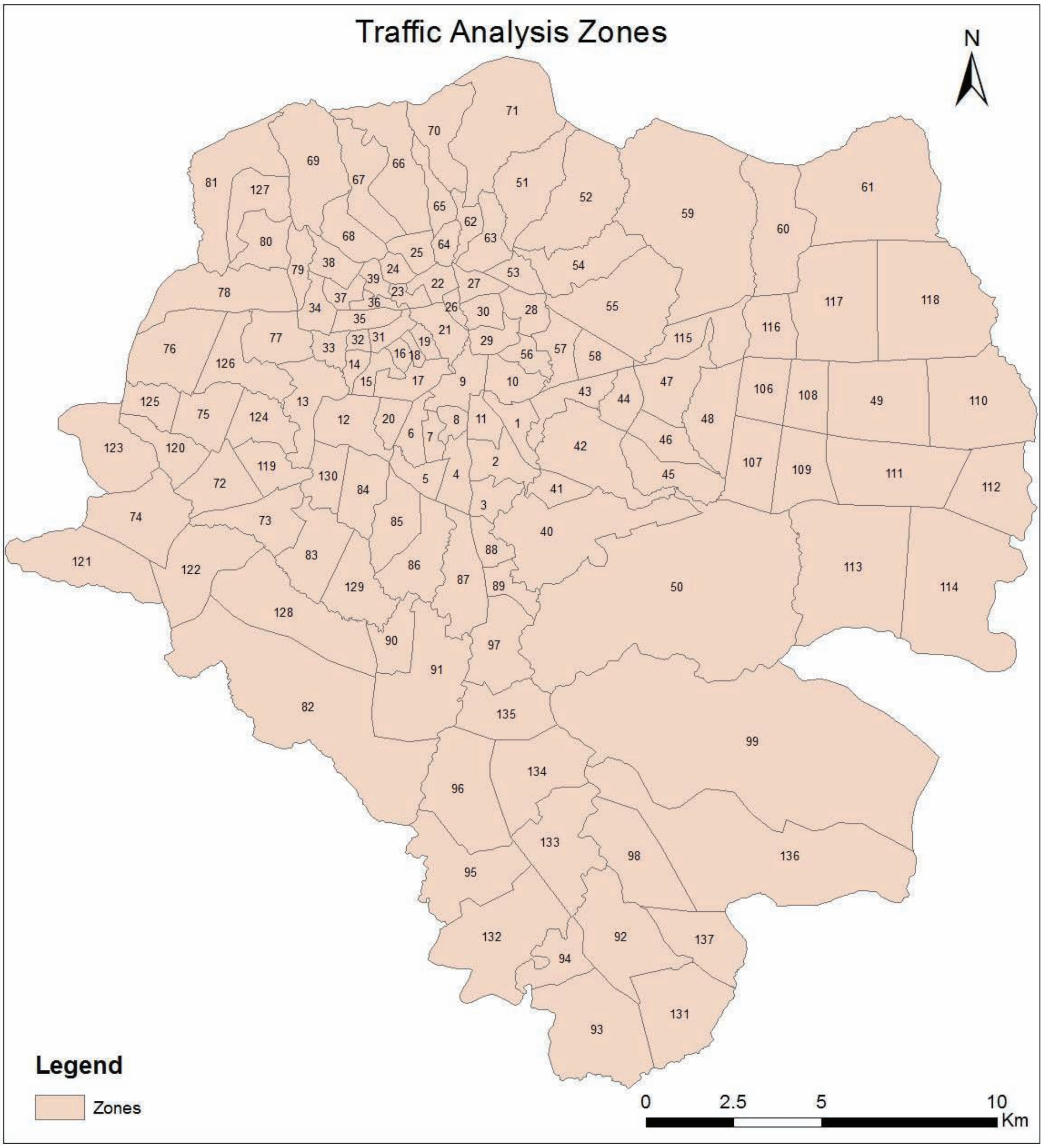


Figure 3-5) Traffic Analysis Zones

4. METHODOLOGY AND MATERIALS

The previous chapters have identified the problems related to transport and the road network of Addis Ababa, the methods that can be used to evaluate and identify these challenges and a brief description of the study area. This section will focus on the data and methods required to analyse and evaluate the network.

GIS is increasingly becoming a useful tool in transport planning and decision making process. The capacity of GIS in handling huge real world data makes it versatile to process and analyse transport problems. As this is the case in our research, we will use GIS as the main tool for evaluating the transport network in order to identify inadequate infrastructures. In this section, we will first discuss the input data required and their acquisition. The data gathered and the organised interviews with different government officials and professionals in Addis Ababa to gather information about the current practice of network evaluation in the city during the field work will be discussed. Techniques and software used in data processing and insuring its quality are the other topics this section will focus on. In preparation for the evaluation, the network dataset will be built using software such as ArcGIS 10 and AutoCAD map 2010. Last step will be generating the travel demand based on the models generated in the UTS (2004/2006), for Addis Ababa.

4.1. Data Acquisition

Before acquiring the data used in this research, the data that are useful, the type of data and the availability of data is evaluated before the field work did commence. The types of data used in this research comprise of two types, i.e. primary data and secondary data (more description is given in the next sections). The data identified is given in table 4.1. The following section focuses on description of the data used and it's preparation for further analysis.

Data on Travel Demand	Available Maps
Socio-economic	Land use
Demography	Existing road network
	Planned Road network in master plan
	Traffic Analysis Zones
	Sub-city boundaries
	Building foot prints

Table 4-1) Data required

4.1.1. Primary Data

The primary data are collected by visiting relevant offices governmental and private consulting offices in Addis Ababa. Interviews with government officials and professionals is conducted to acquire experience on the current practice of network design in Addis Ababa, the criteria used for evaluation current transport network, location of infrastructure with low capacity and areas which are suffering from inadequate infrastructure.

The first visit was made to Ethiopian Road Authority (ERA) that is responsible for planning, design and implementation of federal roads in Ethiopia. Six government officials were interviewed; from these three are working on a currently on-going project for the proper traffic management of the city of Addis Ababa (Interview questions are available in Appendix C). Information is gathered on available criteria to evaluate transport network. However, ERA is primarily responsible for federal roads and its' mandate on the Addis Ababa road network, which is the interest in the context of this research, is limited to the organization and evaluation of transport planning studies for the city. This is due to absence of a transport planning department in the Addis Ababa City Road Authority (AACRA).

The second visit was made to AACRA that is responsible for planning, design and implementation of roads in the city of Addis Ababa. As mentioned above, due to absence of a planning department, roads are planned by consultants that are organized by ERA. After interviewing three government officials from this office, it is concluded that similar criteria are used to evaluate and prioritize road network in the city is used as the federal highways. The AACRA is currently implementing projects identified in the master plan made in 2004/2006 (Urban Transport Study, 2004/2006) which is designed for a target year of 2020. Their main aim is to connect the CBD to the ring road to reduce the traffic congestion in the central area.

As per the field work plan, identifying areas suffering from inadequate infrastructure is part of the interest through the interviews. It is noted that the periphery of the city and the newly developed suburb areas including Eastern, South Eastern and Western areas do not have sufficient infrastructure with respect to demand. The North – South corridor which is the main import export corridor of the city and CBD (mainly Merkato) area suffers from high congestion levels due to conflict between freight and passenger vehicles during the use of the said road.

The next visit was made to private consultancy offices including SABA Engineering, one of the consultancy offices that took part in the Urban Transport Study (2004/2006), Intercontinental Consultants and Technocrats (ICT), currently studying transport management for the city and Afri Geo Information Engineering Plc. Even though professionals were willing to help in SABA Engineering, we were able to find only one professional who participated in the study UTS(2004/2006). In ICT we were able to contact and share experience with three professionals currently working on Transport Management project.

4.1.2. Secondary Data

The sources and formats of the data collected are given the table 4.2 below.

Data	Source	Format	Remark
Socio-economic data	ACCRA (urban transport study, 2004/2006)	Excel	Aggregated at sub-city level
Demographic data	ACCRA (urban transport study, 2004/2006)	Excel	Aggregated at sub-city and TAZ levels
Land use map	ACCRA and BEST Consulting Engineers	AutoCAD	The map include the master plan for the city

Data	Source	Format	Remark
TAZ Sub - city	ACCRA Abate Abreha (2007)	Shape file	This map is originally obtained from ACCRA in AutoCAD format and converted to shape file by Mr. Abate, former student of ITC.
Current Road network	Afri Geo Information Engineering Plc.	Shape file AutoCAD	The paved roads were obtained in AutoCAD form and the Unpaved roads were in shape file.
Master Plan Road network	ICT	AutoCAD	This map contains the roads according to master plan till 2020.

Table 4-2) Secondary data collected and sources

4.1.3. Data Preparation

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.

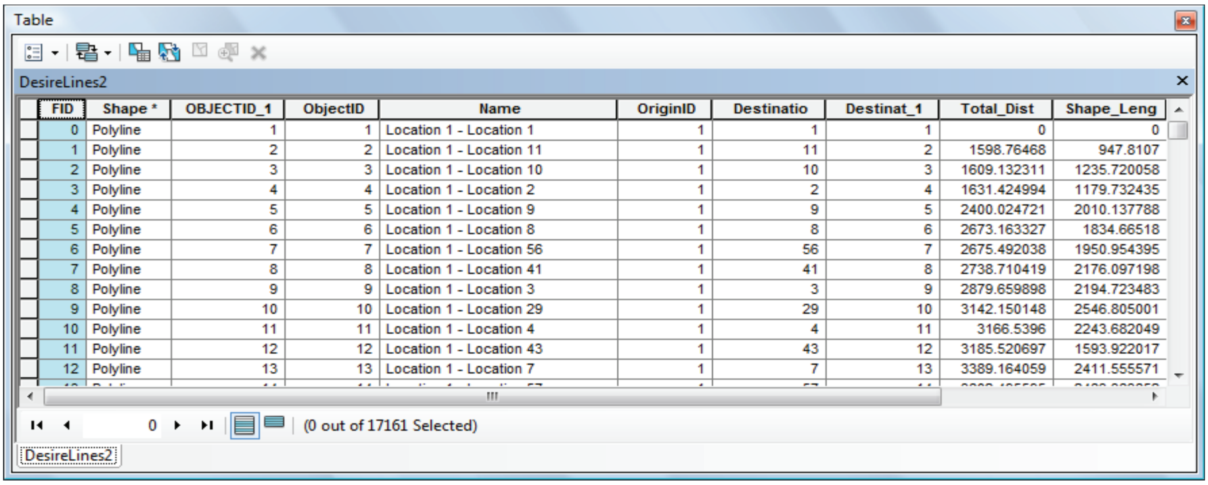
In this research since we are using ArcGIS software for analysis the available data in AutoCAD format are converted into ESRI shape files. Before exporting these files to ArcGIS the data was cleaned and topological rules are defined in AutoCAD Map 2010. There is a three meter shift between the paved roads and the total road network. This was also corrected in AutoCAD by taking the paved road as reference. Last but not lest all shape files are transformed to Ethiopia coordinate system which is WGS1984 zone 37 N.

4.2. Building 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, 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 centroids.

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. 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 4.1). 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 (refer section 5.5). The attribute table was then exported to excel file for further analysis as described below.



Table

DesireLines2

FID	Shape *	OBJECTID_1	ObjectID	Name	OriginID	Destinatio	Destinat_1	Total_Dist	Shape_Leng
0	Polyline	1	1	Location 1 - Location 1	1	1	1	0	0
1	Polyline	2	2	Location 1 - Location 11	1	11	2	1598.76468	947.8107
2	Polyline	3	3	Location 1 - Location 10	1	10	3	1609.132311	1235.720058
3	Polyline	4	4	Location 1 - Location 2	1	2	4	1631.424994	1179.732435
4	Polyline	5	5	Location 1 - Location 9	1	9	5	2400.024721	2010.137788
5	Polyline	6	6	Location 1 - Location 8	1	8	6	2673.163327	1834.66518
6	Polyline	7	7	Location 1 - Location 56	1	56	7	2675.492038	1950.954395
7	Polyline	8	8	Location 1 - Location 41	1	41	8	2738.710419	2176.097198
8	Polyline	9	9	Location 1 - Location 3	1	3	9	2879.659898	2194.723483
9	Polyline	10	10	Location 1 - Location 29	1	29	10	3142.150148	2546.805001
10	Polyline	11	11	Location 1 - Location 4	1	4	11	3166.5396	2243.682049
11	Polyline	12	12	Location 1 - Location 43	1	43	12	3185.520697	1593.922017
12	Polyline	13	13	Location 1 - Location 7	1	7	13	3389.164059	2411.555571

0 (0 out of 17161 Selected)

DesireLines2

Figure 4-1) Attribute of desire lines

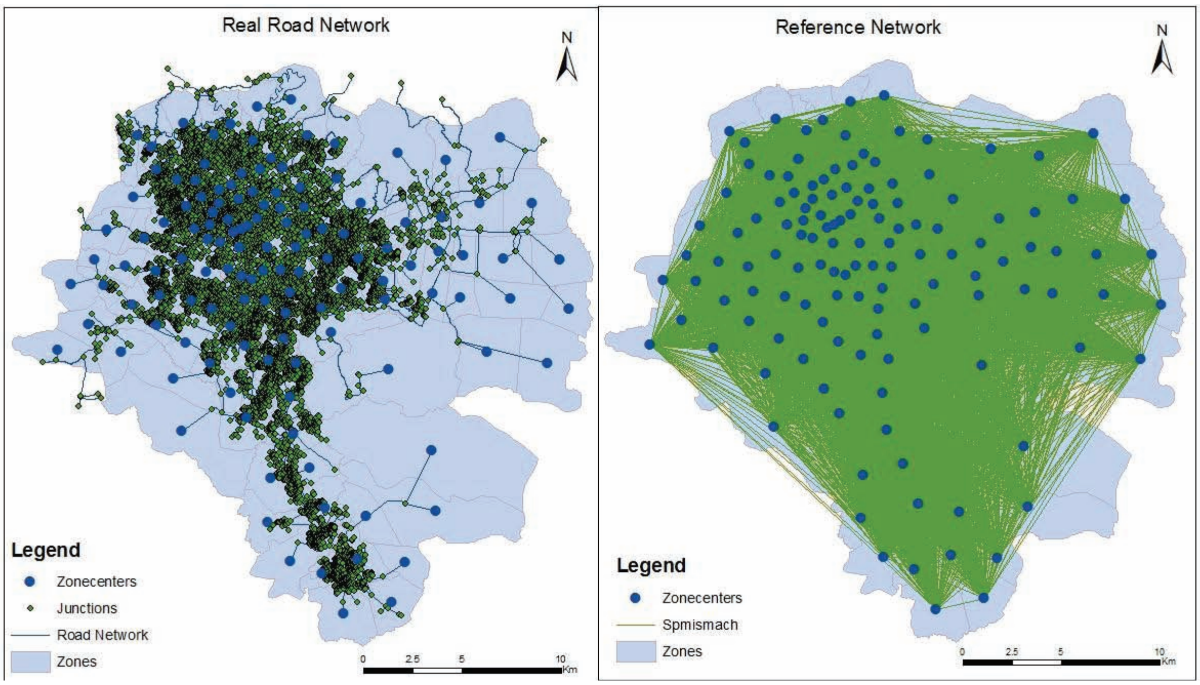


Figure 4-2) Real and Reference road networks

4.3. Travel Demand Modelling

As mentioned in the literature review part section 2.4 this research will adopt some parts of the Four Stage Urban Travel Demand Modelling (FSUTDM). Trip generation and trip distribution parts will be computed using the same procedures as FSUTDM but for assigning traffic, after assigning the trips to the links, the trips along each TAZ will be computed and assigned to the zone. The computation of each stage is discussed in the following sections.

4.3.1. Trip Generation

This is the first stage of the transport modelling. The number of trips generated by each zone (O_i) and attracted to each zone (D_j) is predicted based on socioeconomic and household data. There are two types of trip generation analysis; Trip Production (associated with trips generated at residential end) and Trip attraction (associated with trips attracted to non-residential end). In this research, the trip generation model is adopted from the Urban Transport Study (2004/2006) for Addis Ababa.

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. The demographic and socioeconomic data is also available aggregated at zone level. Trip attraction and production are computed for each TAZ using Multiple Regression Model 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^2 are given in Appendix B.2 and B.3). From these equations the following were adopted.

Trip Production	Equation	Symbols
Working trip	1.48 x W	W = Number of workers
Educational trip	1.684 x St	St = Number of students
Other trip	0.199 x Pop	Pop = Population
Non home based trip	0.023 x Pop	Pop = Population
Trip Attraction		
Total work trip	1.57 x E	E = Employment
Total educational trip	1.61 x St	St = Number of students
Total other purpose trips	0.86 x E	E = Employment
Total non-home based trips	0.0695 x E	E = Employment

Table 4-3) Regression equation for Trip attraction and production(source Urban Transport Study (2004/2006))

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.

$$\text{Balancing factor} = \frac{\sum_i O_i}{\sum_j D_j} \qquad (4.1)$$

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

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

4.3.2. Trip Distribution

The second step in transport modelling is 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 (2004/2006), 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 & Willumsen, 2011). The equation can be written as:

$$T_{ij} = A_i B_j O_i D_j f(c_{ij}) \quad (4.2)$$

$$A_i = 1/\sum_j (B_j O_i D_j f(c_{ij})) \quad (4.3)$$

$$B_j = 1/\sum_i (A_i O_i D_j f(c_{ij})) \quad (4.4)$$

$$f(c_{ij}) = e^{-cij\propto}(c_{ij}{}^{-\beta}) \quad (4.5)$$

Where

T_{ij} = Trips from zone i to zone j

A_i and B_j = Row and column balancing factors factor

O_i = Production from zone i

D_j = Attraction to j

$f(c_{ij})$ = Cost deterrence function from zone i to zone j expressed as $e^{-cij\propto}(c_{ij}{}^{-\beta})$

c_{ij} = Travel time/ distance/ generalised cost from zone i to j

α, β = Parameters to be calibrated

The parameters in the gravity model are calibrated using TRIPS software by purpose of trip in the Urban Transport Study for Addis Ababa. The calibrated parameters are given in table 4.4.

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

Table 4-4) Gravity model calibrated parameters(source Urban Transport Study (2004/2006))

The deterrence function can be computed using travel time or distance or generalized cost as deterrence factors. In our case, since we don't have the travel time on each link in congested environment, we will 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 will add an attribute shape-length (the euclidian distance between TAZ). An example is shown in figure 4.1. 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 deterrence function is computed for both distances using equation 4.5 and the given parameters for each trip purpose. This means 8 deterrence matrices are produced; 2 for each trip purpose (trip purpose is given in table 4.4).

$$f_{ed}(ed_{ij}) = e^{-edij\propto}(ed_{ij}{}^{-\beta}) \qquad 4.5(a)$$

Where $f_{ed}(ed_{ij})$ = Deterrence using Euclidian distance for each trip purpose .
ed = Euclidian distance between TAZs in kilometers.
α, β = Parameters for every trip purpose.

$$f_{nd}(nd_{ij}) = e^{-ndij\propto}(np_{ij}{}^{-\beta}) \qquad 4.5(b)$$

Where $f_{np}(np_{ij})$ = Deterrence using network distance for each trip purpose.
nd = Network distance between TAZs in kilometers.
α, β = Parameters for every trip purpose.

The next step is computing the OD matrix using the Gravity model. Without using the balancing factors, equation 4.2 simplifies to;

$$T_{ij} = O_i D_j f(c_{ij}) \qquad (4.6)$$

Using the 8 deterrence matrices and O_i and D_j for every trip purpose from the output of equation 4.1 in 4.3.1, T_{ij} was computed for every trip purpose. The total T_{ij} using the euclidian and network were summed up as shown below in equation 4.7a and 4.7b respectively.

$$T_{ij(ep)} = O_{ip} D_{jp} f_{ed}(ed_{ij}) \qquad (4.6a)$$

$$T_{ij(np)} = O_{ip} D_{jp} f_{nd}(nd_{ij}) \qquad (4.6b)$$

$$T_{ij(e)} = \sum_{p=1}^{4} (O_{ip} D_{jp} f_{ed}(ed_{ij})) \qquad (4.7a)$$

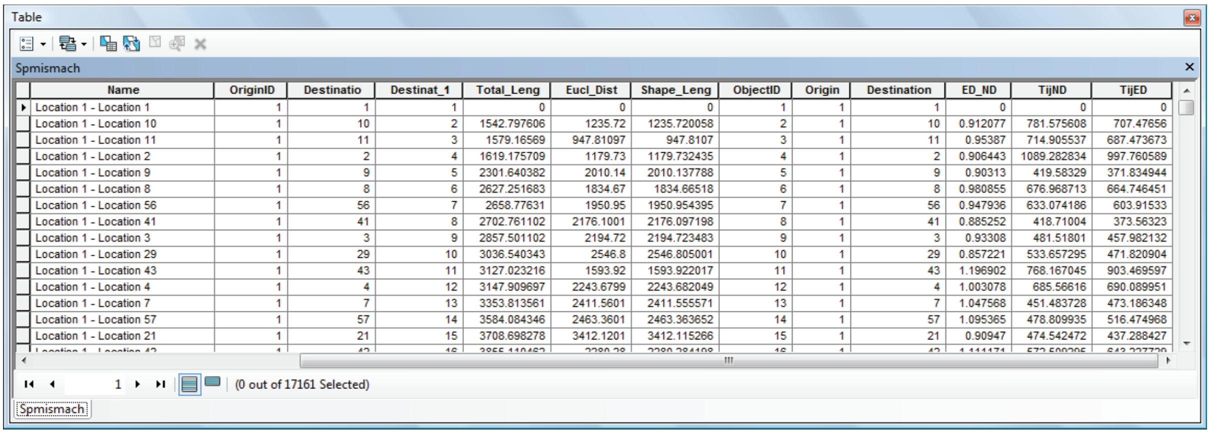
$$T_{ij(e)} = \sum_{p=1}^{4} (O_{ip} D_{jp} f_{nd}(nd_{ij})) \qquad (4.7b)$$

The final step is to solve row and column balancing factors. Using equation 4.3, B_i = 1 and A_i , the first gravity model output is produced. The second step is to produce the following output using equation 4.4, employing, A_i = 1 and B_i as it is. This iteration continues until the total T_{ij} converges to the actual production and attraction. The acceptance criteria should be less than 5% between the two (Zuidgeest & Maarseveen,2011). For both T_{ij} 0.025% difference is attained after 8 iterations which is much less than the acceptable value.

4.3.3. Traffic Assignment to the Links

The last step in the four-step transport modelling 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_{ijED})' and 'Network trip (T_{ijND})' 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.



Table
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Name	OriginID	Destinatio	Destinat_1	Total_Leng	Eucl_Dist	Shape_Leng	ObjectID	Origin	Destination	ED_ND	TijND	TijED
Location 1 - Location 1	1	1	1	0	0	0	1	1	1	0	0	0
Location 1 - Location 10	1	10	2	1542.797606	1235.72	1235.720058	2	1	10	0.912077	781.575608	707.47656
Location 1 - Location 11	1	11	3	1579.16569	947.81097	947.8107	3	1	11	0.95387	714.905537	687.473673
Location 1 - Location 2	1	2	4	1619.175709	1179.73	1179.732435	4	1	2	0.906443	1089.282834	997.760589
Location 1 - Location 9	1	9	5	2301.640382	2010.14	2010.137788	5	1	9	0.90313	419.58329	371.834944
Location 1 - Location 8	1	8	6	2627.251683	1834.67	1834.66518	6	1	8	0.980855	676.968713	664.746451
Location 1 - Location 56	1	56	7	2658.77631	1950.95	1950.954395	7	1	56	0.947936	633.074186	603.91533
Location 1 - Location 41	1	41	8	2702.761102	2176.1001	2176.097198	8	1	41	0.885252	418.71004	373.56323
Location 1 - Location 3	1	3	9	2857.501102	2194.72	2194.723483	9	1	3	0.93308	481.51801	457.982132
Location 1 - Location 29	1	29	10	3036.540343	2546.8	2546.805001	10	1	29	0.857221	533.657295	471.820904
Location 1 - Location 43	1	43	11	3127.023216	1593.92	1593.922017	11	1	43	1.196902	768.167045	903.469597
Location 1 - Location 4	1	4	12	3147.909697	2243.6799	2243.682049	12	1	4	1.003078	685.56616	690.089951
Location 1 - Location 7	1	7	13	3353.813561	2411.5601	2411.555571	13	1	7	1.047568	451.483728	473.186348
Location 1 - Location 57	1	57	14	3584.084346	2463.3601	2463.363652	14	1	57	1.095365	478.809935	516.474968
Location 1 - Location 21	1	21	15	3708.698278	3412.1201	3412.115266	15	1	21	0.90947	474.542472	437.288427

1 (0 out of 17161 Selected)
Spmismach

Figure 4-3) Attributes of reference network.

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_i) and destination (D_j). This will give the nodes from the nearest too far.
4. Create graph H as path from the nodes in the shortest path and add attribute T_{ij}.
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, 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 4.5. 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 4.5. Finally, we divide the values obtained by 2 to take into account of the two way journey that is made from home to work (or other place or from work to home). The output map is shown in appendix D.1.

Mode	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

Table 4-5) Occupancy and equivalency factors (Mekbib, 2007)

4.4. 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. The network based flow is assigned to the real network using the python given in appendix A.1 and A.2. 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, we can't 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 we 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). The two tables are shown in appendix E.2. 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.

4.5. Disaggregated Zones

In the zoning of Addis Ababa there is irregularity in terms of the size of zones. Their size ranges from 0.3 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 1.7km^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 join 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 4.5. 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 shown in figure 4.8.

Land Use Type	POPULATION	STUDENTS	WORKERS	EMPLOYEES
Center	1	1	1	1
Resident	2	2	2	4
Industry Existing	3	3	3	2
Social Proposal	4	4	4	5
Mixed agriculture	6	6	6	7
Housing Expansion	5	5	5	7
Transport Terminals	7	7	7	3
Quarry Sites	7	7	7	6
Industry proposal	7	7	7	7
Green Area	8	8	8	7
Reserved Area	8	8	8	7

Table 4-6) Land use ranks

Transport modelling 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. The scrip is given in Appendix A.3.

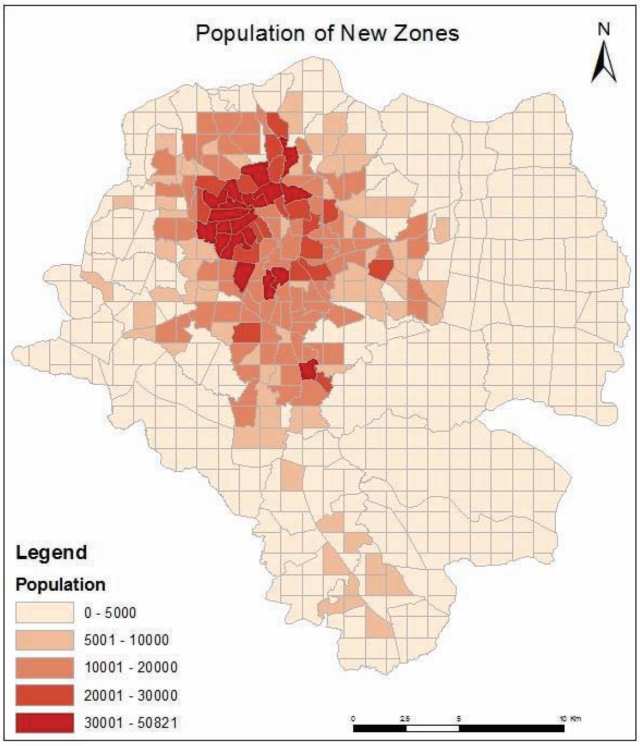

Figure 4-4) Population distribution among disaggregated zones

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 divided in to 12 feature classes each containing 37,520 cells. One–to–many spatial join function is performed to find the lines passing thought each zone. The output database is exported to excel. In excel this lines were matched with the OD array. Sample and the procedures followed are shown in appendix E.4. 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. After Spatial Mismatch Indices are computed using equations 2.2 and 2.3.

4.6. Summary of Methods

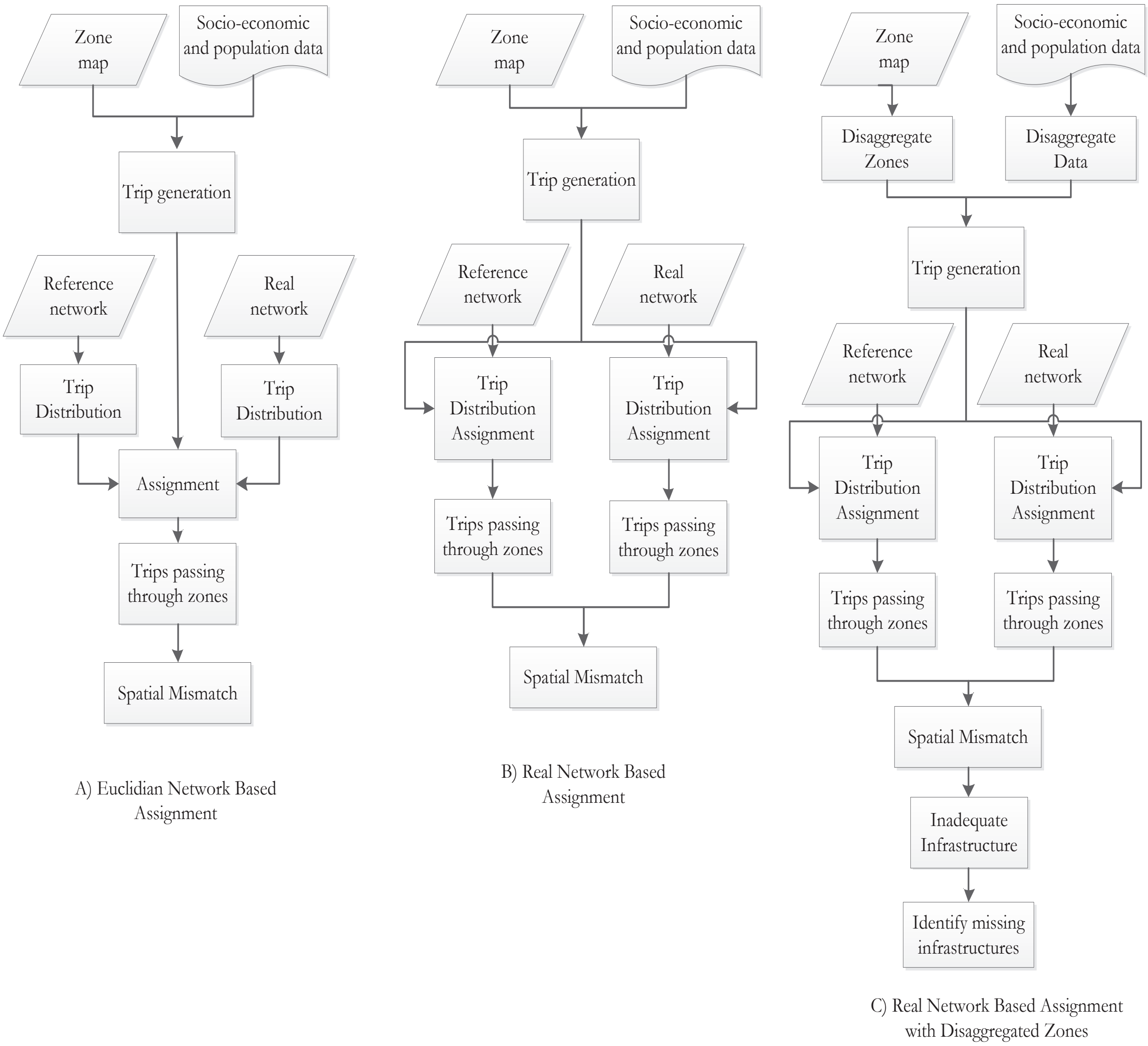

Figure 4-5) Summary of Methods

5. EVALUATION OF EXISTING NETWORK

In this chapter results obtained from the travel demand models and evaluation of the transport network using the indicators as identified in chapter 2 will be discussed. The results of the three sub-models of the transport model; Trip Generation, Trip Distribution and Traffic Assignment, are implemented in this research and will be discussed and interpreted. The performance of current network will be evaluated based on road density, proximity to the roads and spatial mismatch assessment. The outputs will be mapped and interpreted. Based on these outputs areas with inadequate infrastructures will be identified.

5.1. Transport Demand Modelling

5.1.1. Trip Generation

The first step in the four step transport modelling 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 in Chapter 4 in table 4.3, trip production and attraction for each zone are calculated. The trips are stratified by four kinds of trip purposes. These are work trips, education trips, other purpose trips and non-home based trips. As shown in table 5.1, 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 percent of total production and attraction levels.

Trip Purpose	Total Production	Percentage Production	Total Attraction	Percentage Attraction
Work Trip	1139027	34%	1182073	35%
Education Trip	1522127	45%	1455240	44%
Other Trip	618769	18%	647505	19%
Non-Home Based Trip	71516	2%	52327	2%
Total	3351440	100%	3337146	100%

Table 5-1) Trip Share by purpose

By aggregating the 131 zones into the 10 sub city zones, the share of trip for each zone by purpose is shown in table 5.2. From the total trips attracted, Kirkos sub-city being the CBD, takes (not surprisingly) the higher percentage. 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.

SUBCITY	PRODUCTION				ATTRACTION			
	Work	Education	Other	Non-home	Work	Education	Other	Non-home
Addis Ketema	11%	11%	11%	11%	13%	11%	13%	13%
AkakiKality	5%	7%	6%	6%	6%	7%	6%	6%
Arada	10%	8%	10%	10%	12%	8%	12%	12%

SUBCITY	PRODUCTION				ATTRACTION			
	Work	Education	Other	Non-home	Work	Education	Other	Non-home
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%
KolfeKeranio	9%	10%	9%	9%	6%	10%	6%	6%
Lideta	10%	10%	10%	10%	8%	10%	8%	8%
Nefas 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%

Table 5-2) Trip shares of Sub-cities

From figure 5.1 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.

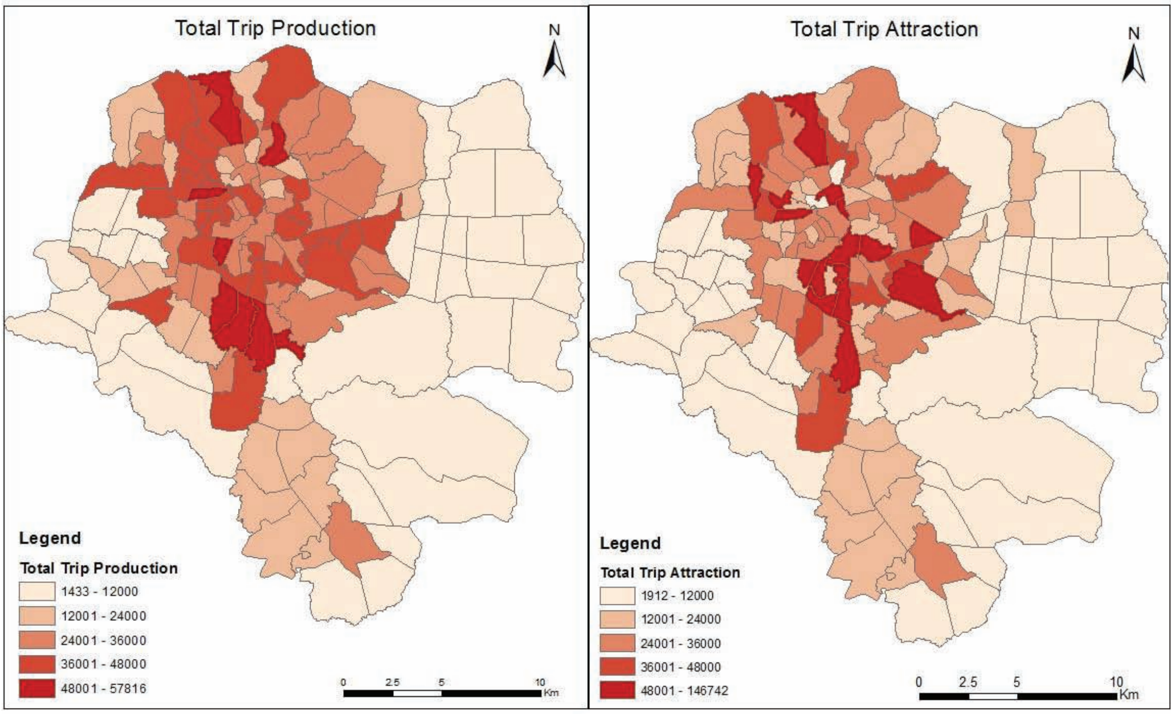

Figure 5-1) Total trip generation

5.1.2. Trip Distribution

In this phase of transport modelling, 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 will be destined to and the proportion of trips that will 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.

The desire lines that connect the OD pairs are shown in figure 5.2. 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, we 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, we 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 kilometres while network distance is 16.6 kilometres, which is 10 times longer in absolute terms. This will be 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. We 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.

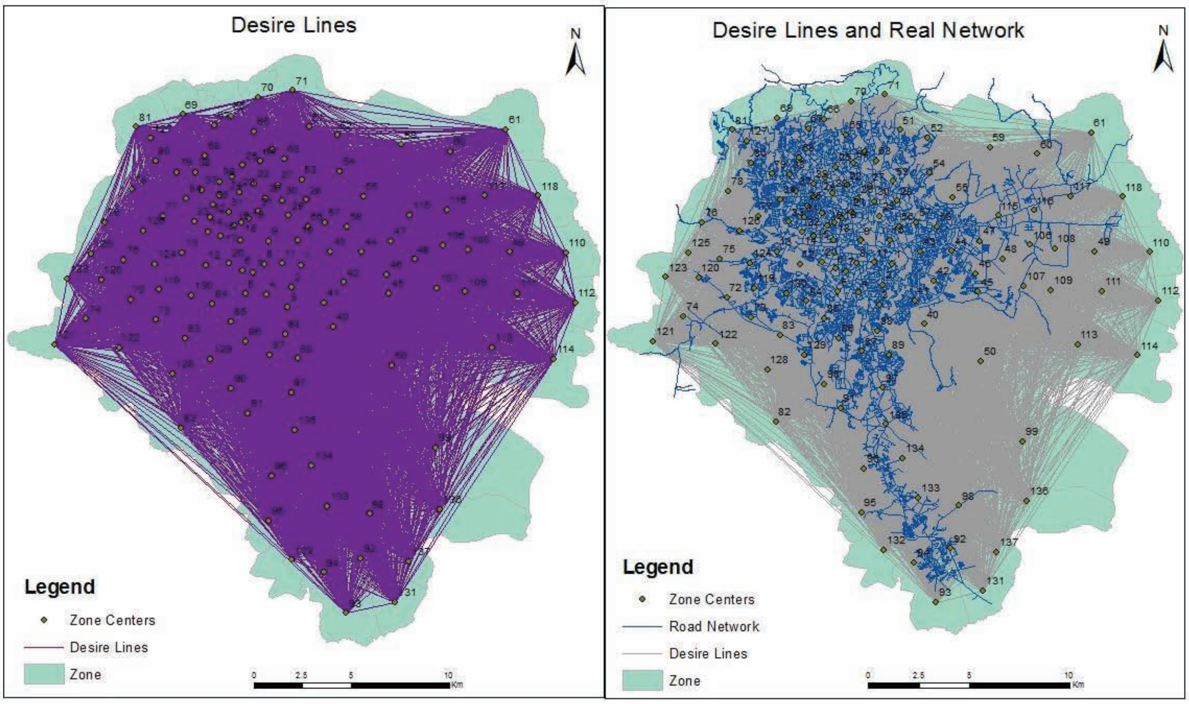

Figure 5-2) Desire lines and Real network

5.1.3. 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 5.4 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.

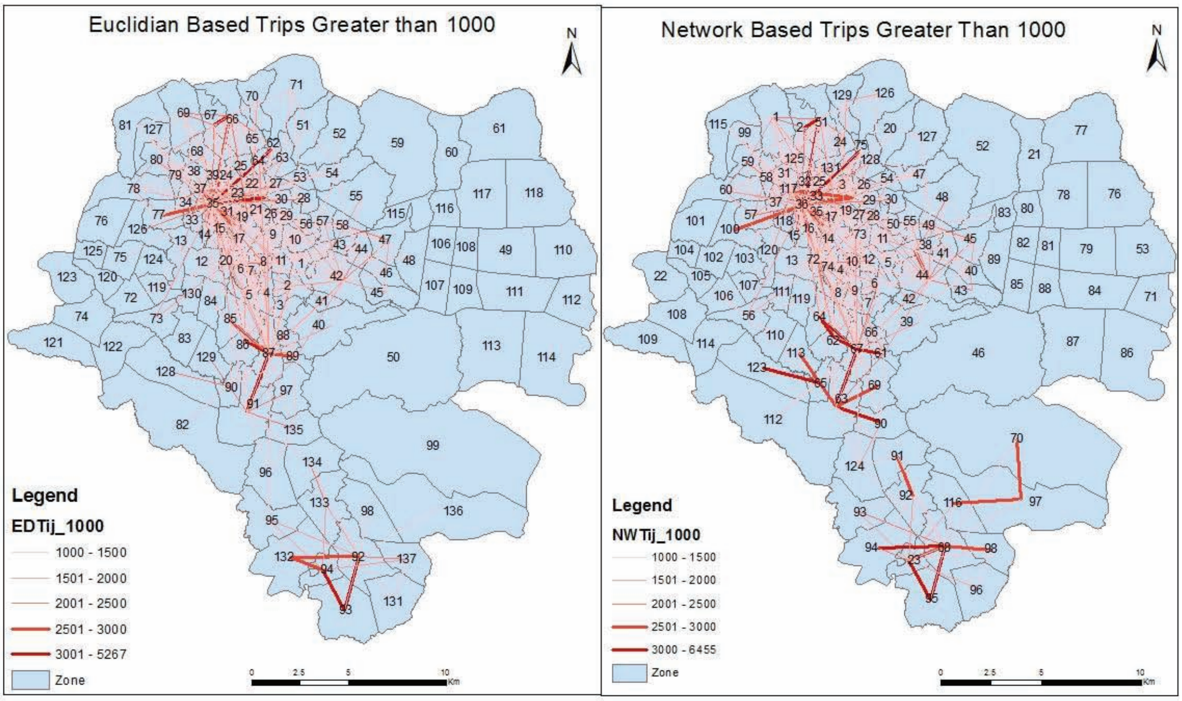

Figure 5-3) Links with trip greater than 1000 trips/ hour

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 we have used a detailed network where all type of roads are included in the model whereas the zonal aggregation in spatial sizes are 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.

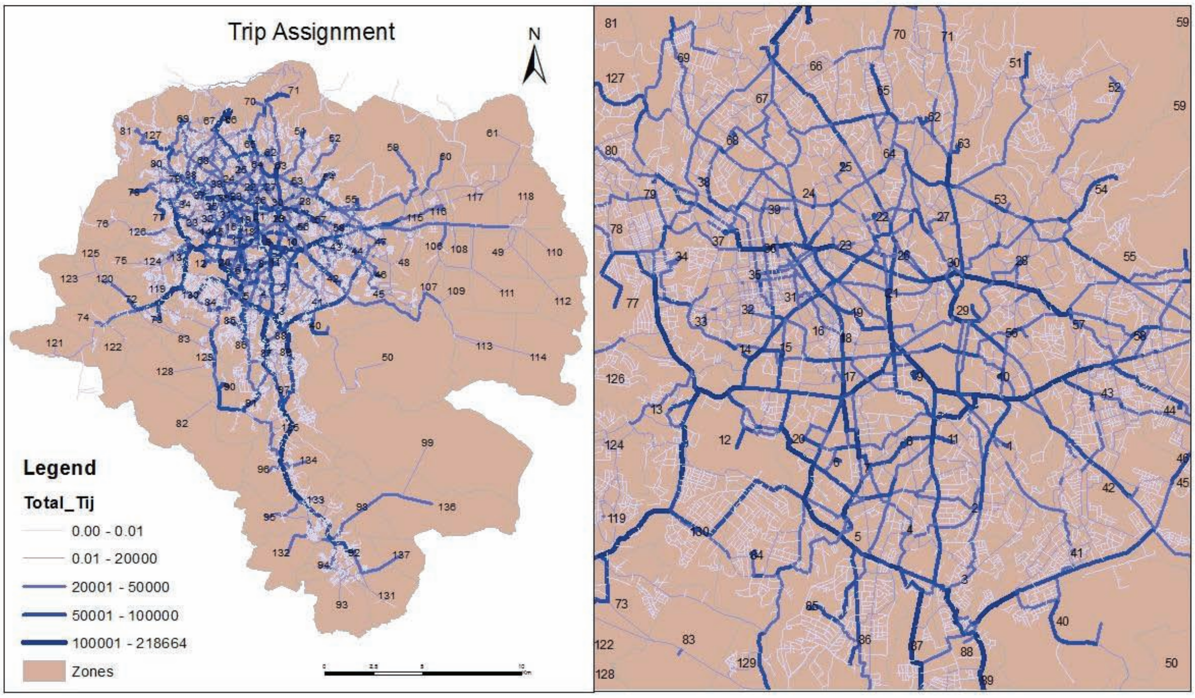

Figure 5-4) Trip assignment on the real network using all modes (trips per hour)

In figure 5.4 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 table 5.3)The roads in the central areas have lower hierarchy than ring road and have capacities less than this value. Even if we 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.

Road type	Capacity
Local	680
Collector	1440
Sub Arterial	2100
Arterial	3700

Table 5-3) Road Types and Capacity

5.2. 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). For the purpose of this research the MI described in chapter two is modified into equation 5.1 below. 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 corrospond with a situation where within zone distance is zero.

For an ideal network, the MI value should be one, but since this can not be achieved we need to have some tolerable value. From Nework Study for Ethiopia (2000/2001), MI values less than 1.41 are within the torelable range where values greater than 1.41 show links that need improvment. According to this analysis, 74% (table 5.4) of the total OD pairs have an MI value of less than 1.41. Figure 5.5 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 inefficent network, passengers have to travel longer distances to reach thier destination as a result of the cross shaped structure of the network.

$$Mobility\ Index\ (MI) \quad = \frac{Travel\ distance\ by\ the\ physical\ route\ between\ origin\ and\ destination}{Travel\ distance\ by\ the\ airline\ distance} \qquad (5.1$$

MI Range	Frequency	Cumulative	Percentage	Cumulative percentage
0	131	131	0.76%	0.76%
1.41	12606	12737	73.46%	74.22%
2.82	4240	16977	24.71%	98.93%
4.23	158	17135	0.92%	99.85%
5.64	16	17151	0.09%	99.94%
8.21	10	17161	0.06%	100.00%

Table 5-4) Mobility Index

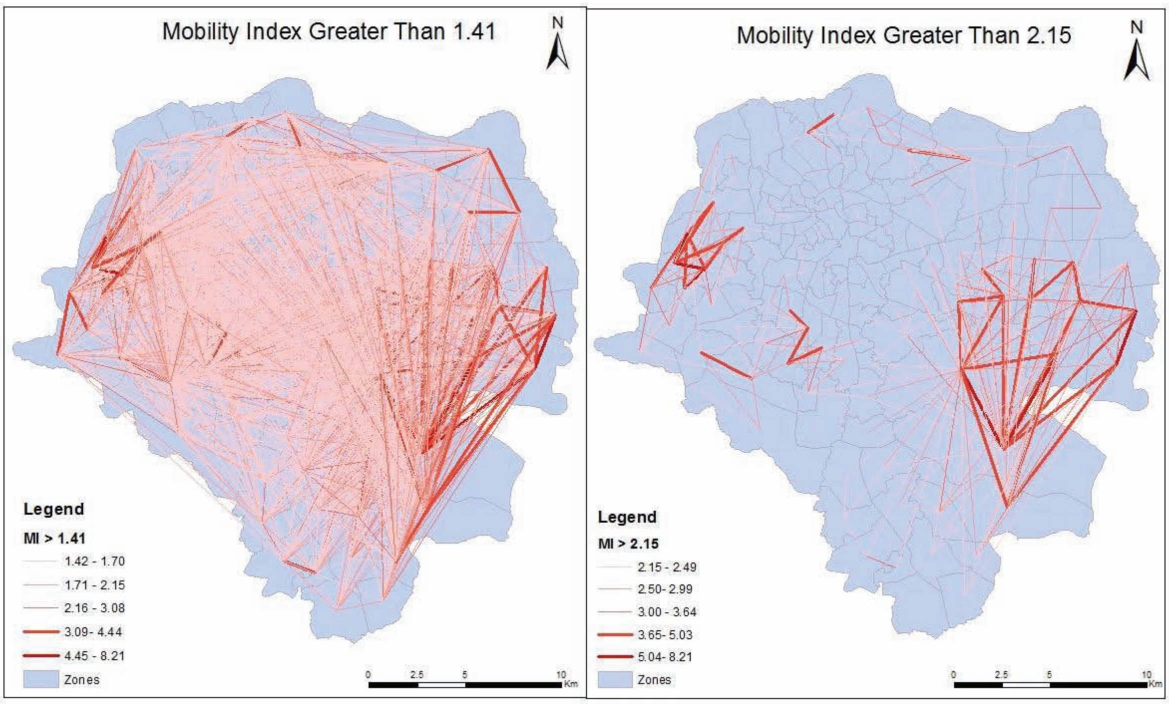

Figure 5-5) Links with Mobility Index greater than 1.41

5.3. 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 will imply higher directedness and connectivity levels within the network. The road density will evaluate the network structure only considering the supply side Whereas the road density per unit of population measures the availablilty of network distance per person.

Figure 5.6 maps 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, road infrastructe exist in more quantities 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 whioch is a suburb under development

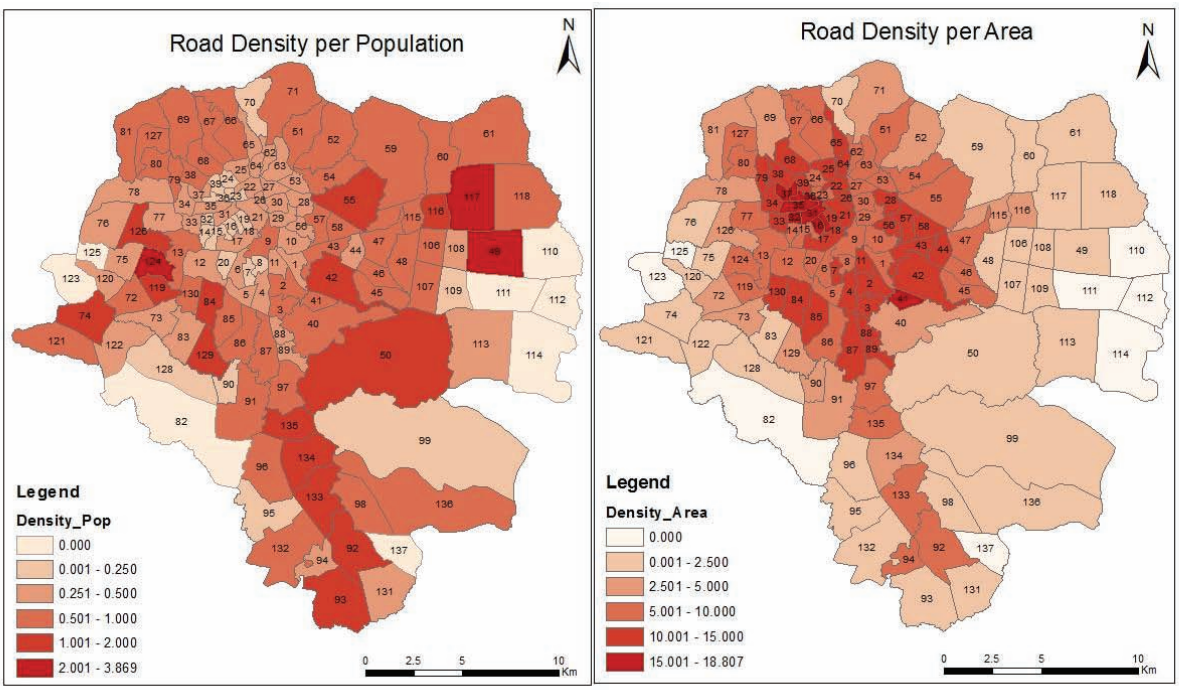

Figure 5-6) Road density, Road length per population in the left (km/1000person) and Road length per area in the right (km/km^2)

From this we can conclude that the zone 82, 110, 111, 112,114, 123 and 125 have low road infrastructure availability both with respect to road density per population and per area. Most of the peripherial 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 amount. The same is true when considering equity by share of road density per person.

5.4. Proximity to the Road Network

One of the parameters that show the availability of transport infrastructure is it's 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 population are within a distance of 250m to any type of road infrastructure and 73% of the population can access paved roads within 250m only; refer to figure 5.7. 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 above, 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 of 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 Thiriez (1968) suggested that the walking distance to these facilities should not be greater than 500m. From this, we 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 5.7) 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.

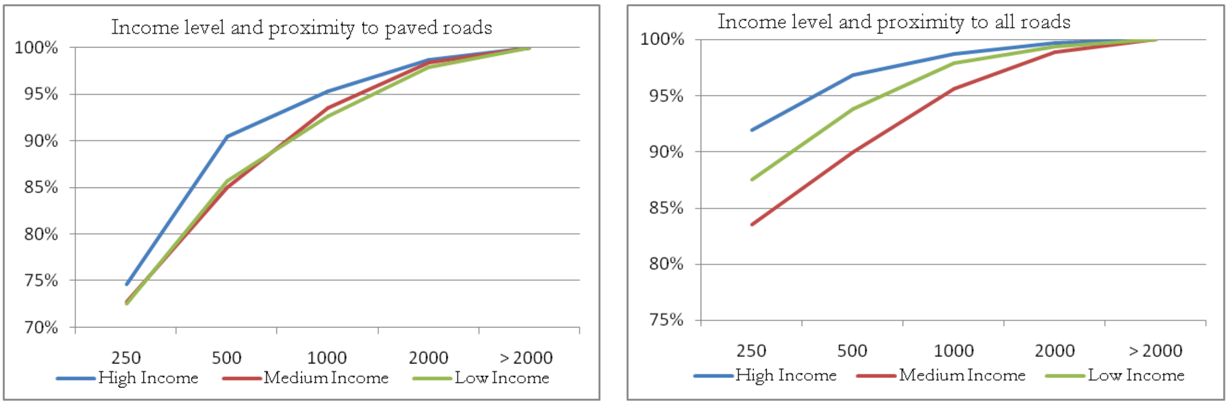

Figure 5-7) Income level and proximity to roads

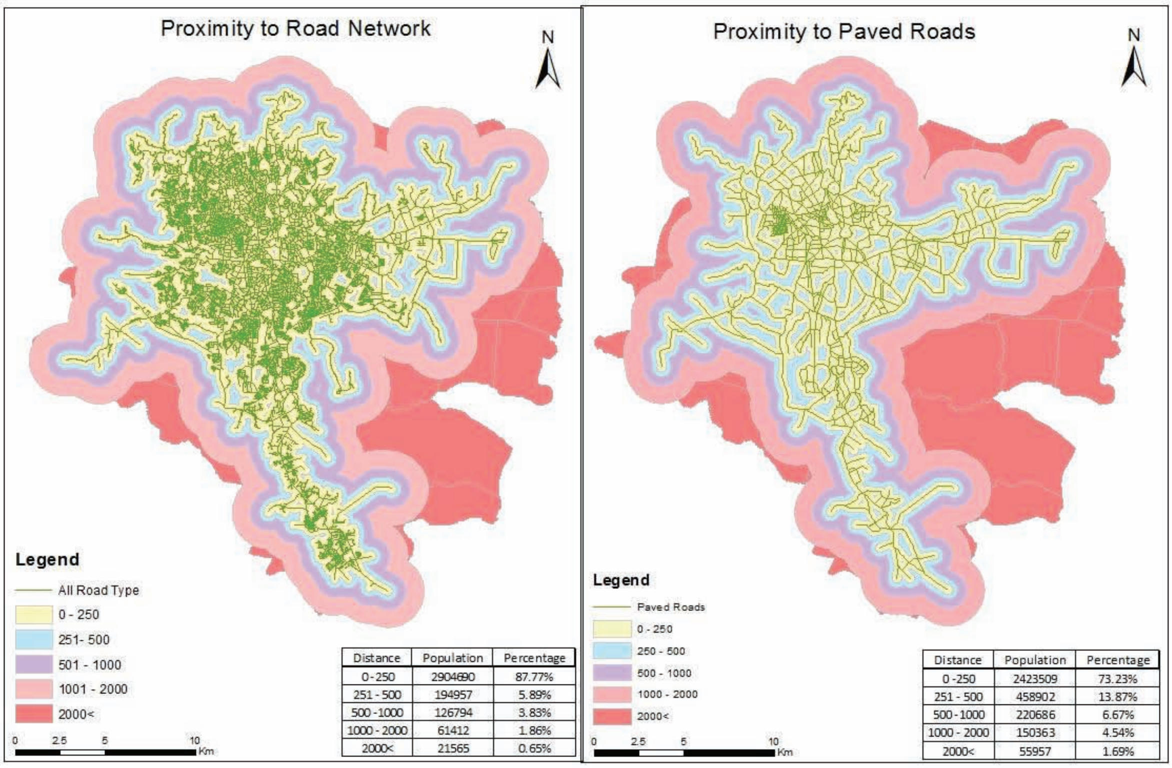

Figure 5-8) Proximity to road infrastructures

5.5. Spatial Mismatch

5.5.1. 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 though each zone are plotted as can be seen in figure (5.9). 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 the same 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 in both cases.

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. SMI 1, 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 5.10 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 has 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 5.10 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.

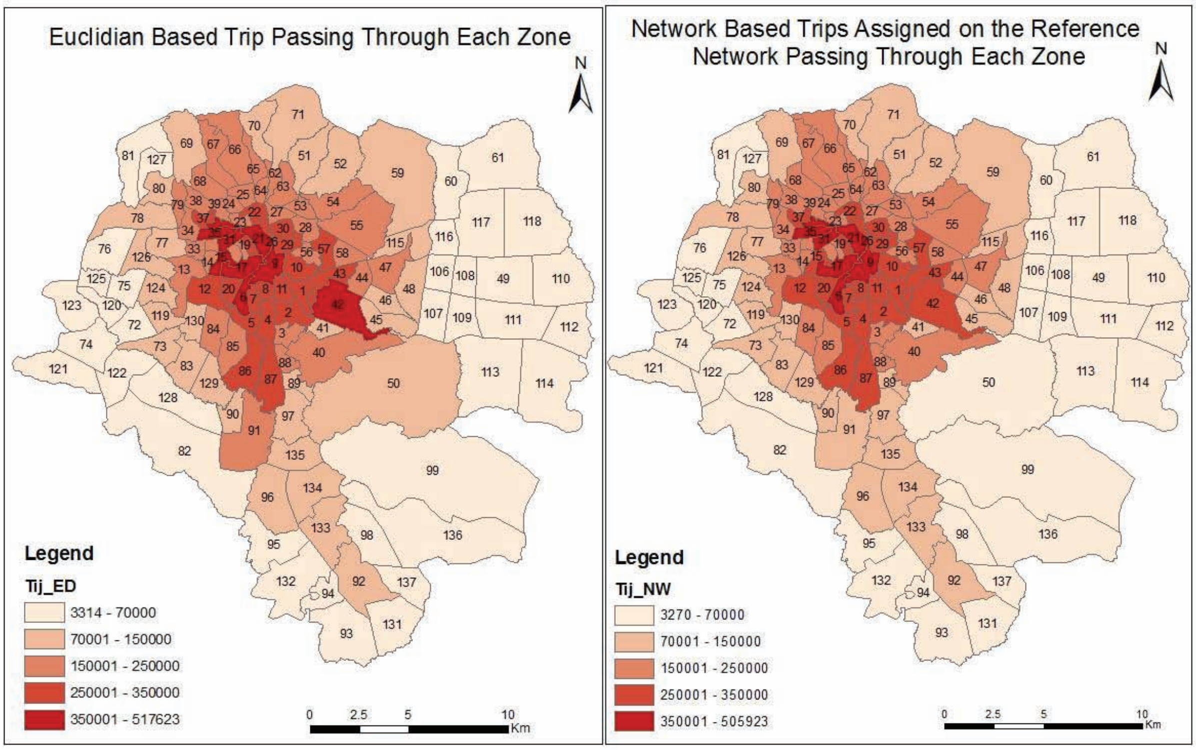

Figure 5-9) Trips passing through each zone by assigning trips on the reference network

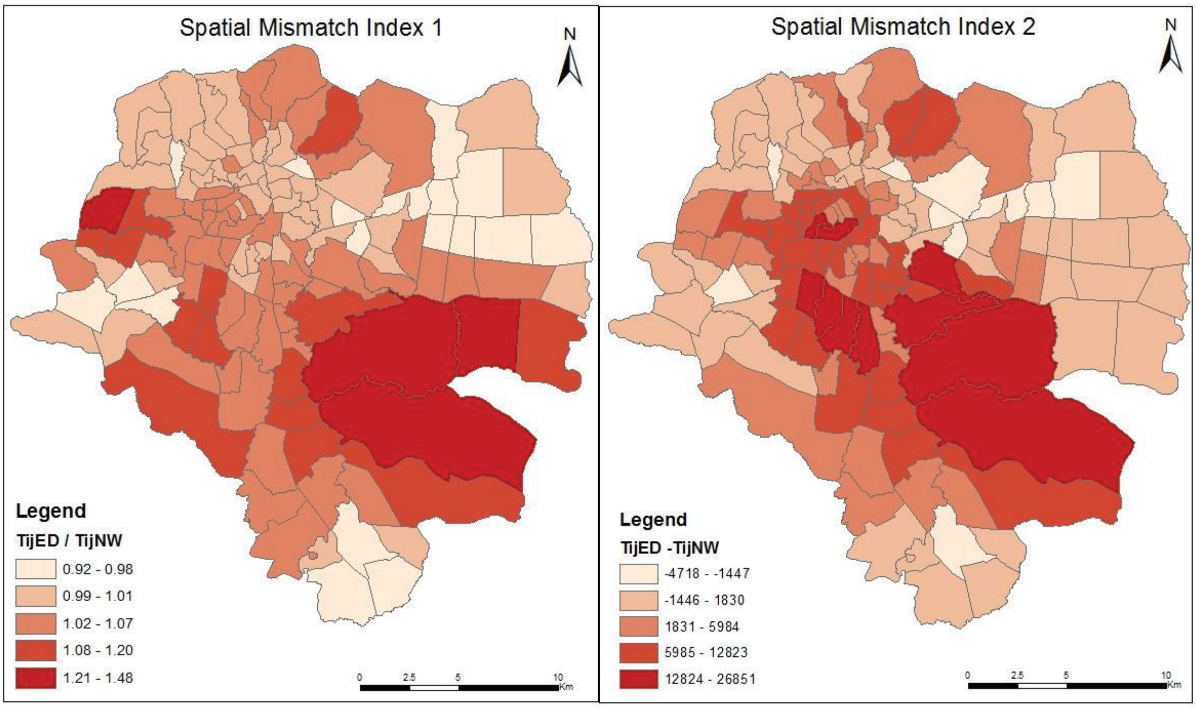

Figure 5-10) Spatial Mismatch Indices using original method

From these indicators we 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.

5.5.2. 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 5.11, 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 5.11 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, we 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, we note that both the maximum and the minimum values of these indicators actually correspond to a scenario where infrastructure inadequacy is exhibited.

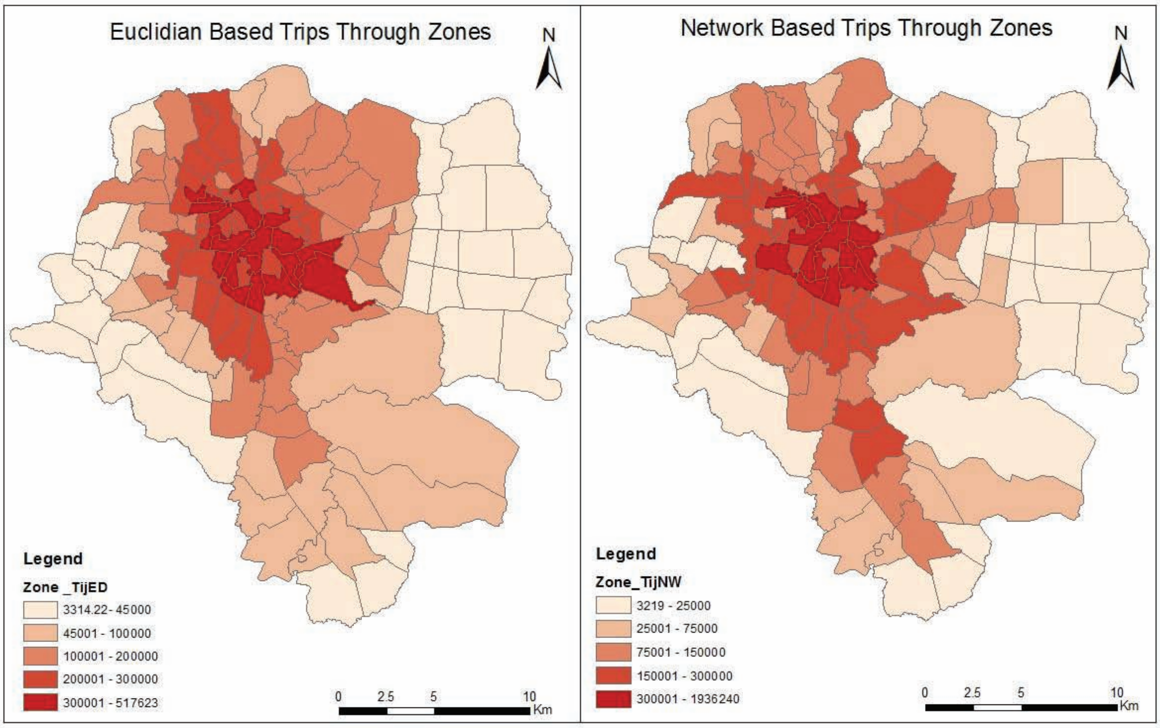

Figure 5-11) Trips passing through each zone by assigning Euclidian based trips on the reference network (left) network based trips on real network (right).

1. Areas with very low values show that the networks in these areas carry more demand than its 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 doesn't 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 oblivious 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 5.12. 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 peripheral zones, and some central area.

Looking at the results of SMI 2, the mismatch levels are also presented in figure 5.8. 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.

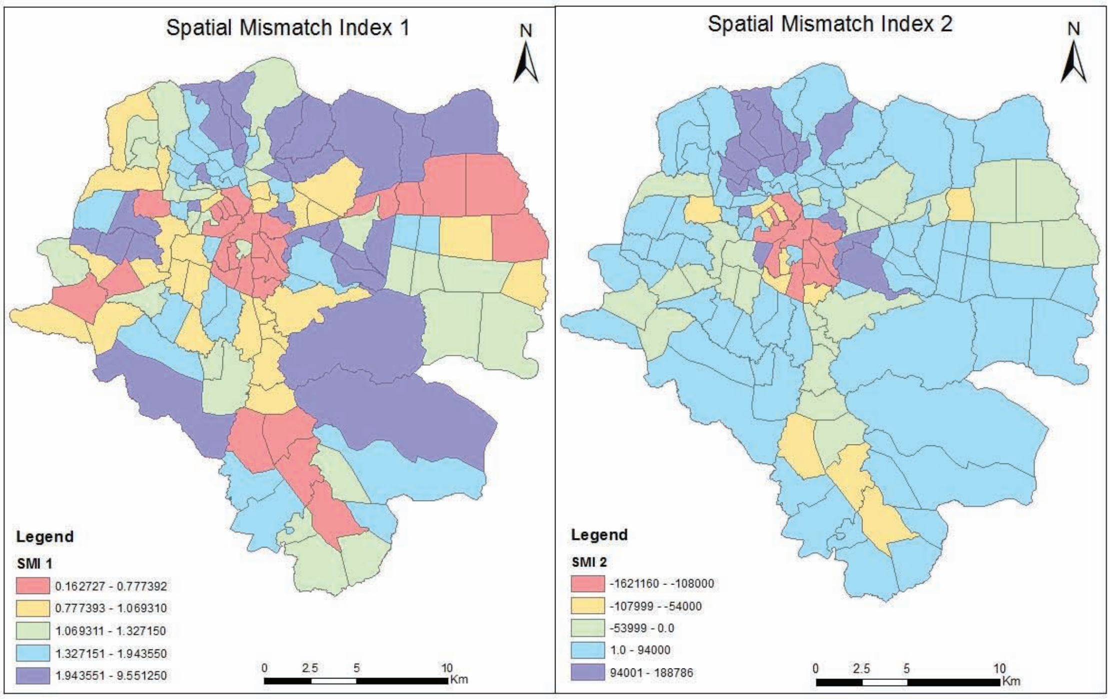

Figure 5-12) Spatial mismatch indices using the improved method

In this method, since the size of these zones is large and unequal, we are 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. The method is discussed below.

5.5.3. Real Network Based Assignment with Disaggregated Zones

The original sizes of the zones are reduced to smaller units ranging 0.3km² to 1.7 km². 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 4.4). Some green areas and reserved areas have zero population. After modelling transport demand, the trips are assigning 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 (refer to appendix D.2). The output of SMIs is discussed below.

The SMIs are shown in figure 5.13. SMI 1 values ranges 0.127 to 181,907, low values (red colour) 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; most, near to North-South corridor. In the Google Image in appendix D.4 and D.5 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.

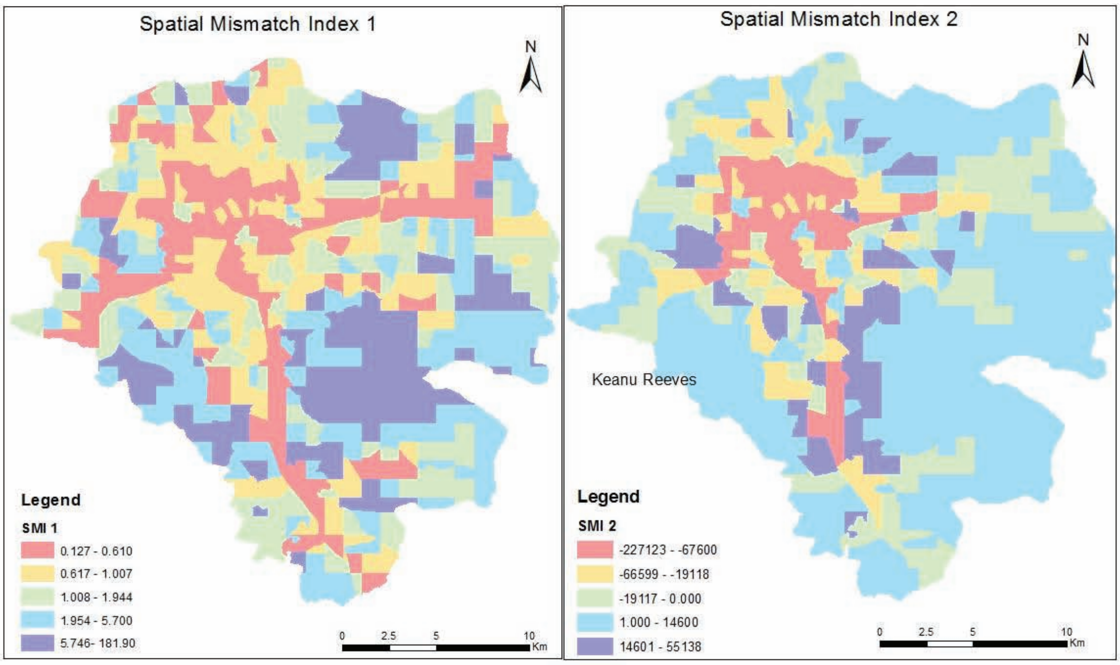

Figure 5-13) Spatial mismatch indices for disaggregated zones

6. QUANTIFICATION OF INADEQUACY WITHIN THE NETWORK

In this chapter based on the results obtain from the Spatial Mismatch Indices in chapter 5 inadequate infrastructure will be identified. How to set the threshold for inadequacy will be discussed and the two types of inadequacies; Infrastructure with Capacity limitation and Missing Infrastructure will be identified and discussed. By adding new roads to the road network, the improvement of the network structure will be assessed. For fanatical purposes based on the construction cost, population they serve and connectivity they create in the network, the identified missing infrastructures will be prioritized.

6.1. Identification of Inadequate Transport Infrastructure

The effort to set a criterion that identifies a particular zone as inadequate actually depends on the level of economy, available resources for implementation of projects and specific objectives of the city government for transport, all pertinent to the study area. As such, a particular network structure in a zone can be deemed adequate in one study area given a particular instance of socio-economy where the same network is deemed inadequate in another one. However, it is still felt important to have forwarded, as part of this research, a particular method of setting acceptable range of thresholds to effectively identify observed inadequacy in the network that can be of help to decision makers for the identification of zones with inadequate network structure.

The thresholds set here are calculated from the histogram of calculated SMIs. For SMI 1, since the optimum value that signifies most desired situation is 1, values both above and below 1 are treated and interpreted separately. Essentially lower values indicate a capacity limitation due to higher demand even though there is an existing network whereas the higher values indicate that the zone suffers from lack of network even though there is a demand. The approach adopted here pre-supposes that for the decision makers, the existing situation is the starting point for making future investment. Hence, the weighted average number of zones by the index is calculated for both sides, i.e. lower side SMI1 = $(-\infty, 1)$ and higher side SMI1 = $[1, \infty)$ and are shown in the plotted histogram. Hence, for the particular range of SMI1 that can be considered as adequate, it can safely be argued that the range SMI1 = [0.61, 5.7] is appropriate. As such, the planner should more focus on the zones that have exhibited SMI1 value outside of this range.

Similarly, for SMI 2 when zero is the optimum value that minimizes inadequacy in a particular zone, the weighted average number of zones by the index is computed and set as threshold. Hence, the decision maker results with an acceptable inadequacy level limited to the range SMI2 = [-67,600, 14,600]. As can be seen from the graphs in figure 6.1 and 6.2, the definition of network inadequacy is sensitive to the value selected as a threshold. This threshold should be set by a realistic decision making system that does consider the existing socio-economic setting of the study area among other possible objectives. Obviously, moving the lower threshold values to the left on the histogram will end up with fewer identified zones with inadequate infrastructure and moving the higher threshold value to the left will end up with more identified zones with inadequate infrastructure. The reverse effect will, of course, have the reverse effect.

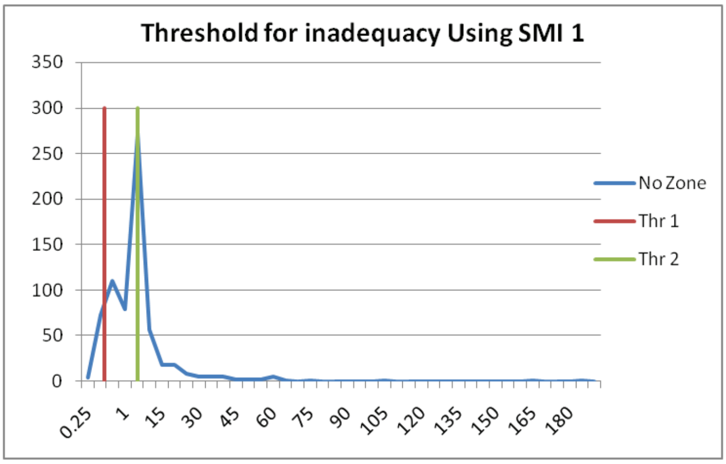

Figure 6-1) SMI 1 threshold values

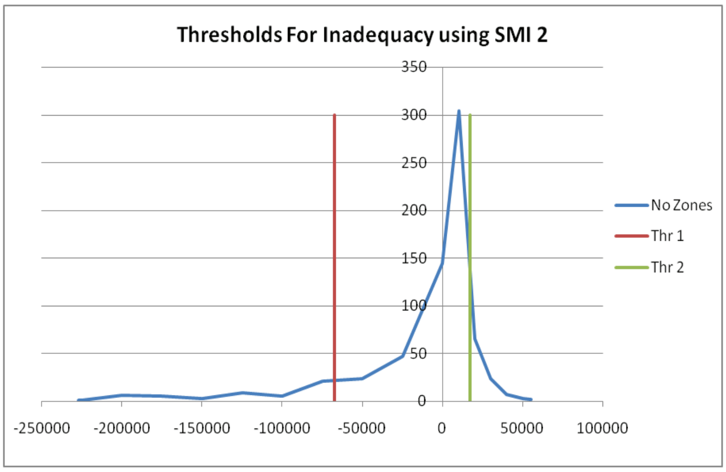

Figure 6-2) SMI 2 threshold values

In the UTS (2004/2006) and Addis Ababa Traffic Managment Final Inception Report (2011), there are six corridors mentioned that need immediate attention. These are;

1. Ayat – CMC – Megenagna – Laghar – Mexico – TorHailoch(the East-West corridor)
2. Urael – Grand Palace – ShiroMeda
3. Kaliti – MeskelSquare– Laghar – Piassa (using DebreZeit and Churchill roads, North-South corridor)
4. Menelik Square – Kolfe
5. Wingate – AbunePetros
6. Mexico Square – Mekanissa

In fact, the UTS(2004/2006) recommended that Light Rapid Transit (LRT) be developed in the East-West and North-South corridors and Bus rapid transit (BRT) in the remaining corridors identified above. However, the latest Traffic Management Study (2011), intimated that the traffic volume for these corridors does not merit LRT and hence, the study recommends development of BRT for all the six corridors and upgrading the road hierarchy to a higher level. These corridors overlaid with SMIs is shown figure 6.3 As it can be visualized from the map, the 6 corridors line up with the lower values of both SMI 1 and SMI 2 except in some marginal areas.

From the figure 6.3, we can see that the already identified corridors for improvement are well captured by the SMIs. However, SMI 1 has additionally identified more corridors for future development. SMI 1 is able to identify 12 more corridors; these include extension of the North-South and East corridors. SMI 2 additionally identified 5 corridors within the central area that are recommended for improvement.

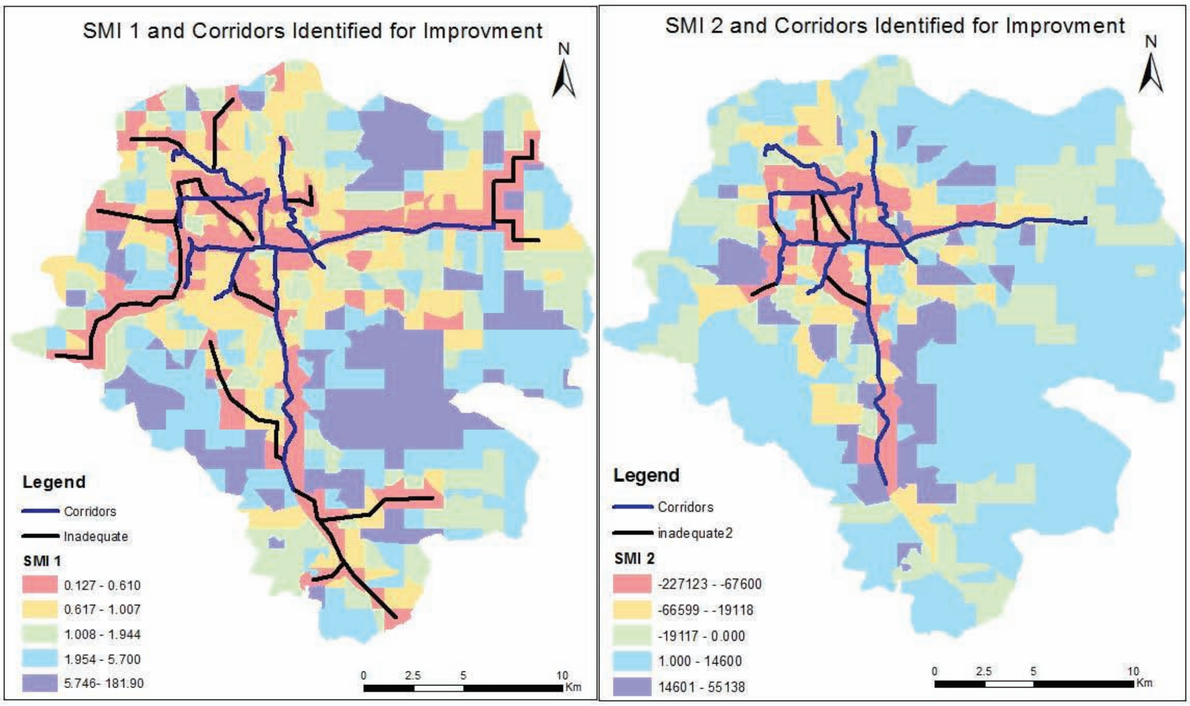

Figure 6-3) SMIs and Corridors Identified for Improvement

6.2. Identification of Missing Infrastructure

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

1. Areas with roads carrying more traffic loads than capacity
2. Areas with roads that 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 only be observed only by scrutinizing SMI 2, observed 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 infrastructure. However, it is still unclear 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 6.4.

Using from the figure 6.4 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 6.5.

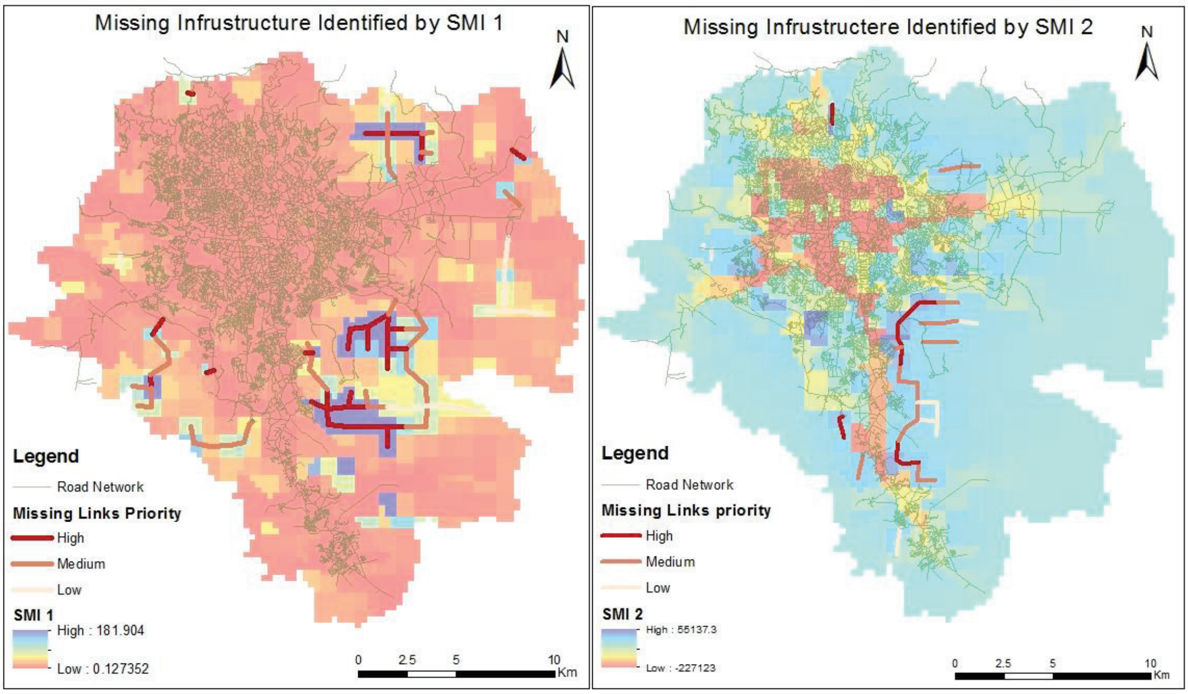

Figure 6-4) Identified Missing Links

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).The Sufficiency Index (SI) is calculated as;

$$\mathrm{SI} = \left(\frac{\text{Population Served By The link}}{\text{Construction cost}}\right) \text{x Connectivity Factor} \tag{5.2}$$

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.

Here this index is adapted to;

$$SI = \left(\frac{\text{Trip on the link}}{\text{Construction cost}}\right) \text{x Connectivity Factor} \tag{5.3}$$

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 6.5.

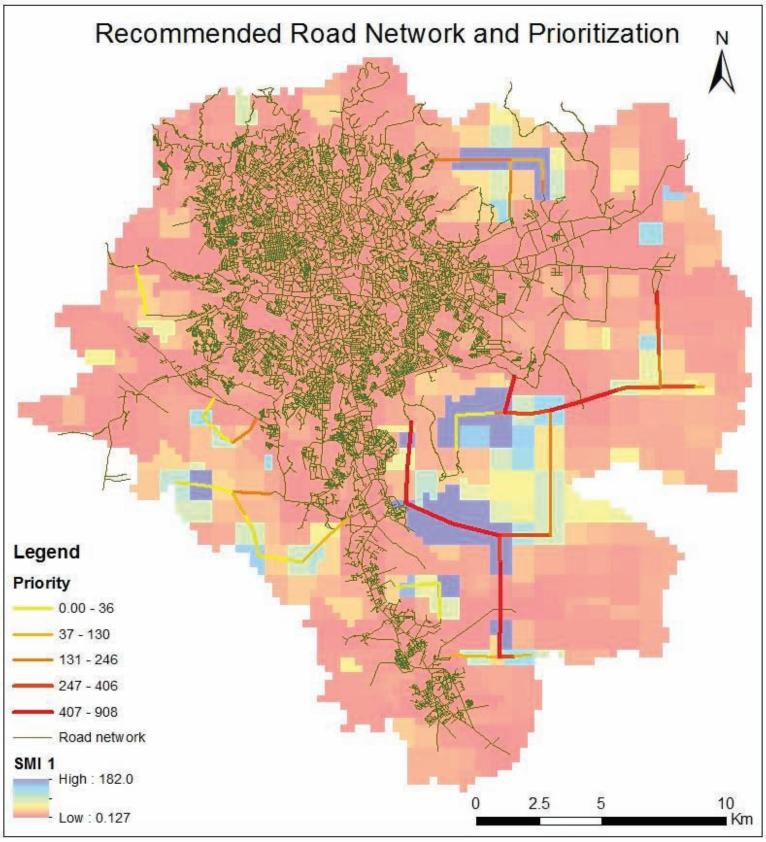

Figure 6-5) Recommended Road Network

6.3. Comparison of Current Network Structure with the Recommended Network Using Network Structure Indicators

As mobility of people is affected by the network structure, several measures and indices can be used to analyse 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 this 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 6.1. The current road network has 13718 links and 9976 nodes and the recommended one has13796 links and 10011 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 have increase by less than 1 present. 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.

Detour Index: measures the efficiency of transport network in terms of how well it overcomes distance. Its value rages from 0 to 1, values closer to one values show more spatially efficient network. The detour indices of the current and recommended network are 0.784 and 0.790 respectively. This show it has improved by 5.6% for the recommended network as compared to it's original version implying the recommended network is more spatially efficient than the current network.

Index	Current Road Network	Recommended Road Network	% increase
Alpha	0.136	0.137	0.57%
Gamma	0.458	0.459	0.22%
Detour	0.748	0.790	5.6%

Table 6-1) Network structure indices

7. DISCUSSION AND CONCLUSIONS

7.1. Discussion

One of the objectives of modelling transport demand in a city is to identify the existing pattern of travel that can provide information on prevailing mobility & travel patterns of goods and individuals in the city. In this particular research, we have modelled 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 an effort to develop a comprehensive transport plan for the city. By synthesising various geographic, socio-economic, infrastructure and land use planning aspects with current travel patterns as observed in the city, key mobility axes 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 have 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 the mono-centric 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 1,000m to access the existing road infrastructure, indicating the inadequacy of the system.

The network structure of the city is composed of two major corridors that intersect at the CBD, which gives it a cross-shaped structure. The prevailing network structure coupled with the absence of the road network will decrease the mobility of people requiring individuals to travel long distances to reach their destination. The Mobility Index measures the ratio of the network distance to the Euclidian distance between a pair of centroids. This is observed to have high values in the South-East and Western parts of the city. In these areas, even though the zones are located close to each other, people still have to go through the CBD to reach their destination.

Based on the method developed for this study, it is possible to assess the existence and level of spatial mismatch in the current road network of Addis Ababa. The results show that there is indeed spatial mismatch in the current transport network; given the outskirt area lacks existing road infrastructure and the road infrastructure in the central areas carry more loads than their capacity.

Comparing the three methods used for spatial mismatch assessment in the current network; Euclidian Network Based Assignment, Real Network Based Assignment and Real Network Based Assignment with Disaggregated zones methods were employed for the purpose, resulting in high mismatch values observed in the South-Eastern part of the city in all the tested cases.

Euclidian Network Based Assignment: In this method the two indicators (SMI 1 and SMI 2) show there is a high spatial mismatch in the peripheral areas. SMI 2 indicates some mismatch in the central part in addition to some of the peripheral areas. However, in this method trips made using the real network are assigned to the reference/Euclidean network which, obviously, deviates from the actual spatial travel pattern.

Real Network Based Assignment: In order to capture the actual travel pattern, the trips made are assigned to the existing links. The two indices developed to measure spatial mismatch have effectively captured and displayed the level of network inadequacy observed in several parts of the city. Higher values are observed in the central areas where there is a high demand for travel and low values at the periphery where availability of road infrastructure is relatively low. But since the spatial aggregation of the traffic analysis zones used here are large and unequal, identification of possible corridors for development is not possible, which required further refinement of the developed method.

Real Network Based Assignment with Disaggregated zones: To overcome the said problems, and to obtain more accurate values of mismatch level and identify potential corridors that can be developed, the size of the zones was disaggregated into smaller zones. As in the two methods described above, the spatial mismatch is observed and the same can be efficiently displayed with greater precision of identification of inadequate zones In this case, the higher and lower values of the SMIs computed indicate different types of inadequacy exhibited in the network. The lower values identify areas that have existing road network but the roads carry more traffic load than their capacity. The higher values identify areas with low road network.

From the three methods developed, using disaggregated zones was shown to most effectively identify corridors where either the available capacity is less than the desired level or corridors that need to be considered for future development. We conclude that by reducing the size of TAZ into a proper spatial disaggregation and assigning the trips on the real network, we can, more efficiently and accurately identify corridors that can increase the efficiency of the existing transport network.

Scrutiny of the obtained results acquired from the two spatial mismatch indices, using the last of the methods described above, shows that there is some difference:

SMI 1: represents the quantitative level of mismatch which increases with the ratio difference between the reference and real networks available in the region. Considering 1 as the optimum value and thresholds for tolerance, values greater than one and less than one can be interpreted differently. The higher values of this index point out regions where there is lack of transport infrastructure. And the values less than one point out regions that tend to have capacity mismatch. This can be explained by the fact that in areas where there are high values there is less road infrastructure so the desired situation is much higher than the existing one. For areas with very low values of the Index, the existing situation is much greater than the desired value which shows that the network is in actual scenario carrying more traffic than the available capacity allows.

SMI 2: represents the quantitative level of mismatch which shows the difference between trips passing through a region in the exiting and Euclidian network scenario. Since we carry out the subtraction of assigned trips in the two cases, the optimum value is taken as 0 and the two extreme values have different meanings. Very high negative values point out areas with capacity mismatch and high positive values point out areas with low infrastructure availability. This index also shows these areas are close to each other which can be interpreted as due to lack of road infrastructure the traffic is diverted.

All in all, both SMIs can help us identify inadequate corridors and SMI 1 can capture network inadequacy better than SMI2. The other thing we have to keep in mind is the thresholds set for inadequacy. We note that as the threshold value varies the number of zones considered as inadequate and hence the level of corridors required for development varies. Hence, while setting these thresholds, decision makers and stakeholders should be involved and it should be made depending on the vision 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. Even though the master plan for the city produced in 2004/2006 recommended some roads in peripheral regions of the city, from this roads only some of them are considered for implementation (refer to appendix 5). The capacity limitation problem in the central areas is also recognized from the studies and actually the master plan recommends LRT 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 one present 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 we can conclude that the recommended network will create suitable situation.

Last but not least, the traffic assignment model used in this research can be readily used for developing countries like Ethiopia where versatile packages for traffic modelling 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:

1. All trip makers are aware of the shortest route before making the trip
2. 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.
3. 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 modelling exercise adopted in this research since they can be used for long term planning purposes without introducing substantial errors in forecasting.

7.2. Limitations of the study

The main limitation of this study is the availability of data, which is mostly at a zonal level while disaggregating these zones into smaller units 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.

7.3. Conclusion

Travel demand modelling can help in understanding the spatial pattern of travel within society and analyse the land use transport interaction. The widely applicable modelling technique for real transport system is the Four Stage Transport Modelling package. The trip generation model for Addis Ababa city pointed out that most of the socio-economic activities responsible for trip making are situated at the central area signifying that the city is mono-centric. The trip distribution model adopted, the doubly constrained Gravity model and can be used to distribute generated trips to the different destinations. The only impedance factor considered in the model is the distance between the TAZs. Later, we split the trips into different modes using results from previous studies and assigned the traffic on the network using the All-Or-Nothing assignment (applying the shortest distance algorithm)

The overall results of the traffic distribution show that the peripheral areas of the city are prohibited from enjoying an acceptable level of connectivity. These areas have a low density of road network and, as expected, even though these zones are physically close to each other, people still have to travel longer distances to their destination. We have noted that people have to travel more than 500 m to reach any type of road infrastructure. Since most of the population living in these areas have low income level, the distribution of network is unequal both in socio-economic status and specially does not support the disadvantaged.

Even though the above conclusions help us to find out areas and societies that are neglected, they are not able to identify inadequate infrastructures in a quantified manner. In order to quantify the level of inadequacy quantitatively, Spatial Mismatch Indicators were used. These indicators consider the structure of the network and spatial pattern of travel. The results of these indicators show that there is indeed mismatch within the current road network of the city. Two types of mismatch were detected in the city, showing that the peripheral areas lack road infrastructure and roads in the central areas carry more than their capacity. This implies that the current road network and transport planning and management within the city need to be improved in order to meet its objectives.

The spatial mismatches were reckoned using three different methods, Euclidian Network Based Assignment, Real Network Based Assignment and Real Network Based Assignment with Disaggregated Zones. From these methods, Real Network Based Assignment with Disaggregated Zones was able to identify inadequacy efficiently. By using smaller and spatially equal zones and assigning the trips to their corresponding networks i.e. Euclidian based trips on the reference network and network based trips on the real network, infrastructure with capacity limitation and that need to be developed can be identified more efficiently.

The SMIs can be used to identify inadequacy in the network both in terms of limitation in existing capacity or complete absence when desired. From the two indices used, SMI 1, the division based index, can identify inadequate infrastructure more efficiently. The extreme low values and high values of the SMI Indices correspond to different ‘kinds of inadequacies’. Extremely lower values correspond to areas with road infrastructure but with capacity limitation whereas extremely higher values of the Indices correspond to areas which do require additional road infrastructure.

Addis Ababa has a cross-shaped network structure built from two major corridors which intersect at the CBD. Connectivity levels and efficiency (in respect to travel distance) of the network are very low. This can be improved by adding infrastructure to areas having low road network density. We suppose that accessibility and mobility level of these areas can be improved if appropriate measures are taken.

Even though the identified missing infrastructure need to be in place, due to the constraint of fund, the ones that serve more people and those that improve the connectivity of the network should be prioritized. This can be done by using, what we call the Sufficiency Index. This index considers the number of trips served by the link, the construction cost and connectivity. Based on the level of the SI, priorities should be given to the links that are more important for better network structure in the city. We have found that the links located in the South-Eastern part of the city are vital for consideration.

All in all the current transport network of the city suffers from different infrastructure inadequacies. The absence of road network in peripheral areas contributes to unequal spatial accessibility, limits mobility and has negative impact on the development strategies of the city. Cost of travel, both in terms of money and time, is considerably high in the peripheral. The absence of road infrastructure also cause people travel unnecessary distances to reach their destination. This restricts the level of mobility of people and goods within certain regions. There is high travel demand on the central area road network, but there roads are characterised to have low capacity. These road need to be upgrade or mass transport system should be considered.

7.4. Recommendations Future Area of Reasearch

In this research based on the data available, the current transport network of Addis Ababa city is evaluated and we have identified inadequate infrastructures in the network which cause unbalanced spatial accessibility to all groups. We have 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 comprehensive and robust results can be obtained by considering the temporal characteristics. 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.

During the master plan development for Addis Ababa 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 will create obstacle on the economic development of the city. 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 different 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 will ease the traffic load in the central areas but since the ring road has longer distance, the network will not be efficient in respect to cost (considering distance as cost). The ring road also does not offer suitable provision for pedestrians. As such, we recommend 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 we have set.

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APPENDIX A: CODES USED

Appendix A.1) Assignment Using Excel File

```
# import module as nx and defining graphs
Import networkx as nx
G = nx.Graph()
H = nx.Graph()

## Initializing variables to be used
n = ""
m = ""

## import excel reading module and reading the sheets
Import xlwt
from xlrd import open_workbook
## the file containing nodes and link attribute
book = open_workbook(r'C:\Users\User\Desktop\Assignment\ForallZone.xls') ## Input file location
## read the sheet containing the data The index count start from 0
sheet = book.sheet_by_index(1)                    ## Contains origins and destinations
sheet2 = book.sheet_by_index(2)                  ## Contains Link number, nodes and link length
sheet3 = book.sheet_by_index(0)                   ## Contains OD matrix
## Reading the network and form Graph
forrow_index in range(1,sheet.nrows):
    G.add_edge(int(sheet.cell(row_index,1).value),int(sheet.cell(row_index,2).value),
weight = sheet.cell(row_index,4).value, linkNo = sheet.cell(row_index,0).value)

## Reading the O-D pairs and find the shortest path
N=[]
forrow_index in range(1,sheet3.nrows):
    n = int(sheet3.cell(row_index,1).value) ## Origin
    m = int(sheet3.cell(row_index,2).value) ## Destination
    i = (sheet3.cell(row_index,0).value)
    j = (sheet3.cell(row_index,3).value)
    L=(nx.astar_path(G, n , m))             ## Shortest Path algorithm
    w=sheet2.cell(int(i),int(j)).value      ## Trip between the OD pairs(Tji)
    M=[]
for i in range(len(L)-1):
        e=[]
e.append(row_index)
e.append(L[i])
e.append(L[i+1])
e.append(w)
M.append(e)
N.append(M)

Import csv
```

```
with open('C:\Users\User\Desktop\Assignment\Assignment.csv', 'wb') as f:      ## Output file location
for i in range(len(N)):
writer=csv.writer(f)
writer.writerows(N[i])

print " writing complete"
```

Appendix A.2) Find the Link ID

```
importnetworkx as nx
G = nx.Graph()
H = nx.Graph()
K = nx.Graph()
n = ""
m = ""

fromxlwt import Workbook
book3 = Workbook()
sheet1 = book3.add_sheet('Sheet 1')

f = open(r'F:\NewInputlinkID\Links1200_\12977_13000.csv', 'w')

import xlwt
fromxlrd import open_workbook
book = open_workbook(r'F:\NewInputlinkID\ForallZone.xls')
#Opensthe whole node and link
book2 = open_workbook(r'F:\NewInputlinkID\Links1200_\12977_13000.xls')
#opens the selected links
sheet = book.sheet_by_index(1)
sheet2 = book2.sheet_by_index(0)
forrow_index in range(1,sheet.nrows):
G.add_edge(sheet.cell(row_index,1).value,
sheet.cell(row_index,2).value,
                w = sheet.cell(row_index,4).value,
                l = sheet.cell(row_index,0).value)
forrow_index in range(sheet2.nrows):
    n = (sheet2.cell(row_index,1).value)
    m = (sheet2.cell(row_index,2).value)
    SP= G.get_edge_data(n ,m)
f.writelines("%s\n" % SP)

f.close()

print "complete"
```

Appendix A.3) Trip Assignment for Large Data Using Text File

```
importnetworkx as nx                          ## import the network module
importcsv                                     ## import the csv module
G = nx.Graph()                                ## define graph

data=open('Recom_Node_link.txt','r')## input file with nodes, link that connect the nodes and link length.
## reading the lines and assigning  edged data to the graph
for line in data:
line_s=line.split()
G.add_edge(int(line_s[1]),int(line_s[2]),
weight = float(line_s[3]),linkno = int(line_s[0]))
## input file containing OD matrix in array form
data2=open('Recom_ODTij.txt','r')

n = ""
m = ""
p = ""
N = []                                  ## initialise
for OD in data2:
   OD_s = OD.split()
   n = int(OD_s[0])                     ## origin
   m = int(OD_s[1])                     ## destination
   w = float(OD_s[2])                   ## Tij
   p = int(OD_s[3])                     ## OD- id
   l = nx.astar_path(G, n , m)          ## shortest path algorithm
   M =[]
for i in range(len(l)-1):               ## organizing the output in to list
      e=[]                              ## initialise list e
e.append(G[l[i]][l[i+1]]['linkno'])
e.append(G[l[i]][l[i+1]]['weight'])
e.append(w)
e.append(p)
M.append(e)
N.append(M)
with open('Recom_131.csv', 'wb') as f:  ## location of output file
for i in range(len(N)):
writer=csv.writer(f)
writer.writerows(N[i])

print " writig complete"

data.close()
data2.close()
f.close()
```

APPENDIX B: SOCIO-ECONOMIC DATA

Appendix B.1 This data is obtained from The Urban Study 2004/2005.

Zone ID	Basic Data				
	Population	Resident Students	Vehicles	Resident Workers	Employees
1	29556	8757	1368	4379	6,765
2	38281	15035	1066	8744	7,672
3	24273	8395	5840	5658	1,973
4	37820	12685	117	10923	12,061
5	33057	11991	324	8750	15,219
6	23415	7057	0	4972	18,374
7	36896	10666	288	6198	2,432
8	37969	11940	119	9433	23,756
9	23022	7276	760	5430	22,873
10	39232	8805	777	9970	17,454
11	30368	8358	836	10216	4,860
12	38533	10261	218	9934	1,643
13	29776	7152	933	6608	6,900
14	35588	11443	210	9028	1,038
15	38255	12303	0	9408	4,951
16	39115	11421	373	12019	306
17	35769	8504	270	6479	5,461
18	21731	7322	78	7088	5,837
19	27162	7461	699	5829	5,268
20	46541	13885	257	12599	30,934
21	37199	11541	1121	10869	6,150
22	37438	4265	158	11216	27,423
23	34255	1865	1187	6953	1,398
24	20503	6609	0	5592	1,455
25	39924	8206	473	8837	4,881
26	21846	7773	670	5093	25,020
27	32200	5691	599	8088	4,072
28	41189	10266	495	9277	3,958
29	34259	10575	0	6830	1,983
30	21812	2819	297	5787	11,747
31	44116	11329	267	11862	2,349
32	34138	9448	178	8913	446
33	30386	8446	0	5660	1,674
34	39188	12943	360	8988	9,255
35	48035	12799	249	13131	50,214
36	35037	10199	120	9719	1,433
37	38105	12898	689	8074	26,936

Zone ID	Basic Data				
	Population	Resident Students	Vehicles	Resident Workers	Employees
38	32082	14002	680	7613	2,209
39	37033	10344	0	9516	2,854
40	26384	1377	4589	11013	8,853
41	26384	2932	1099	8428	3,744
42	37289	6132	5138	12098	27,803
43	37770	12590	323	11137	6,504
44	36937	7221	1111	12497	2,239
45	26384	6957	525	7876	1,257
46	26384	3873	2179	9198	10,678
47	36937	7027	1441	13694	1,613
48	37607	9678	236	7947	9,740
49	6833	932	0	3727	3,970
50	7322	2371	0	1738	474
51	27109	8652	433	6201	3,351
52	27958	6926	0	4617	2,000
53	19219	6443	0	4666	1,693
54	32892	8689	207	7654	11,251
55	29397	8183	455	7273	5,897
56	37398	9285	1161	9801	3,300
57	30495	8713	1005	8713	5,462
58	32440	8196	462	8312	19,509
59	40700	11035	237	9018	2,045
60	20052	5529	165	4786	7,733
61	17941	5741	0	4844	2,155
62	32018	9364	0	6947	9,597
63	41581	15762	150	8856	2,078
64	20115	3468	0	6705	574
65	33125	10717	0	9603	8,058
66	42420	14696	152	11817	16,767
67	35289	11450	751	10605	6,850
68	35776	11798	1149	7814	4,036
69	36937	12182	130	6480	10,624
70	23627	3731	311	7772	4,887
71	35249	9479	296	9923	5,060
72	40755	10631	403	12484	7,446
73	37992	11462	129	7470	1,019
74	15031	5963	248	3354	6,212
75	10686	3130	153	2824	1,577
76	18604	4370	80	2445	1,166
77	36313	13068	377	7288	1,719
78	39573	12281	152	11372	6,355

Zone ID	Basic Data				
	Population	Resident Students	Vehicles	Resident Workers	Employees
79	16937	4759	350	3080	17,408
80	25405	10343	502	6628	1,707
81	34395	11685	0	8599	2,354
82	6332	2111	0	2111	467
83	24484	10202	360	6601	1,238
84	47269	19444	582	10944	15,915
85	48018	16567	1685	9126	4,555
86	44216	14691	2282	11696	3,379
87	44367	15153	2867	9692	28,652
88	26384	7682	334	4843	1,169
89	48546	18393	3317	10855	1,529
90	26384	8795	0	5363	5,439
91	32716	14590	0	6484	6,164
92	32529	10648	0	6553	3,150
93	16259	3495	0	3799	1,674
94	25587	6727	0	4445	4,060
95	37176	12218	483	6057	17,710
96	42986	15370	0	7248	13,889
97	31718	10092	123	6554	3,930
98	7102	2367	0	2367	1,994
99	8557	3775	0	1888	0

Appendix B.2 Results of Regression Equations for Trip Production

Eqn.	Regression Equation	R^2	't' statistic
1	TTP = 1.0584 'X' Pop	0.93	Pop – 36.77
2	WTP = 1.48 'X' W	0.94	W – 38.53
3	WTP (V) = 0.937 'X' W	0.84	W – 22.46
4	WTP (V) = 0.537 'X' W + 22.19 'X' PCI	0.88	W – 6.65 PCI – 5.55
5	ETP = 1.684 'X' ST	0.90	ST – 30.33
6	ETP (V) = 0.30 'X' ST	0.76	ST – 17.42
7	ETP (V) = 0.232 'X' ST + 4.798 'X' PCI	0.78	ST – 8.51 PCI – 2.96
8	OTP = 0.199 'X' Pop	0.73	Pop – 16.38
9	OTP (V) = 0.089 'X' Pop	0.68	Pop – 14.27
10	OTP (V) = 0.065 'X' Pop + 5.534 'X' PCI	0.69	Pop – 5.17 PCI – 2.24
11	NHBTP = 0.023 'X' Pop	0.45	Pop – 8.91
12	NHBTP (V) = 0.0133 'X' Pop	0.34	Pop – 7.25
12	ATTP = 2.56 'X' WHH + 1.454 'X' SHH	0.94	WHH – 8.13 SHH – 5.66
13	ATTP = 2.52 'X' WHH + 1.43 'X' SHH + 0.039 'X'NWHH	0.94	WHH – 6.97 SHH – 5.12 NWHH – 0.22
14	ATTP (V) = 1.32 'X' WHH + 0.19 'X' SHH	0.85	WHH – 7.09 SHH – 1.24
15	ATTP (V) = 0.492 'X' WHH + 0.33 'X' SHH + 0.006 'X' PCI	0.90	WHH – 2.48 SHH – 2.55 PCI – 6.71
16	ATTP (V) = 0.60 'X' WHH + 0.15 'X' SHH + 0.0014 'X' HHI	0.90	WHH – 3.09 SHH – 1.16 PCI – 6.37
17	AWTP (V) = 0.89 'X' WHH	0.84	WHH – 22.87
18	AWTP (V) = 0.51 'X' WHH + 0.003341 'X' PCI	0.89	WHH – 7.43 PCI – 6.32
19	AETP (V) = 0.29 'X' SHH	0.67	SHH – 14.05
20	AETP (V) = 0.23 'X' SHH + 0.0008 'X' PCI	0.69	SHH – 6.76 PCI – 2.50

TTP – Total trip productions	WTP – Work Trip Productions
WTP (V) – Work Trip Productions by Vehicular Modes	ETP – Education Trip Productions
ETP (V) Education Trip Productions by Vehicular Modes	OTP (V) – Other Purpose Trip Productions by Vehicular Modes
OTP – Other Purpose Trip Productions	NHBTP – Non Home Based Trip Productions
NHBTP (V) – Non Home Based Trip Productions by Vehicular Modes	ATTP (V) – Total Trip Production per Household by Vehicular Modes
ATTP – Total Trip Production per Household	Pop – Population
AWTP (V) – Work Trip Production per Household by Vehicular Modes	AETP (V) – Education Trip Production per Household by Vehicular Modes
W – No. of Workers	PCI – Monthly Per Capita Income (ETB)
ST – No. of Students	WHH – No of Workers per Household
SHH – No. of Students per Household	NWHH – No of non-working per Household

Appendix B.3 Regression Equations for Trip Attraction

Eqn.	Regression Equation	R^2	't' statistic
1	TTA = 5796.9 + 3.584 'X' E	0.79	CO – 2.77, E – 19.61
2	TTA = 3.919 'X' E	0.89	E – 27.73
3	TWTA = 1.57 'X' E	0.88	E – 27.10
4	TSTA = 1.61 'X' ST	0.50	ST – 9.78
5	TOTA = -472.11 + 0.89 'X' E	0.59	CO – -0.54, E – 11.72
6	TOTA = 0.86 'X' E	0.70	E – 15.23
7	NHBTA = 0.0695 'X' E	0.60	E – 12.17
8	NHBTA = 331.8 + 0.050 'X' E	0.34	CO – 4.09, E – 7.10
TTA – Total trip Attractions TWTA – Total Work Trip Attractions ST – No. of Student Enrolment NHBTA – Total Non-Home Based Trip Attractions		E - Employment TSTA – Total Education Trip Attractions TOTA – Total Other Purpose Trip Attractions CO - Constant	

APPENDIX C: INTERVIEW QUESTIONS

Evaluating Transport Network Structure;
Case Study in Addis Ababa
By: Yetnayet Ayalneh Bogale
(MSc. in Geo-Informatics, Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, The Netherlands)

The research is mainly concerned about developing new method to identify inadequate infrastructure in current road network using network based indicators and travel for demand. It is hoped that this research will contribute to realize the vision of the city 'affordable transport, enhanced access and mobility'

Interview Questions

1. Are there studies conducted to evaluate the transport network structure of Addis Ababa? What are the pertinent criterions used?

2. What factors are considered for generation of travel demand? How do you take into account the spatial nature of demand?

3. Is the land use-transport integration well considered in the transport planning and forecasting of future demand?

4. How do you decide to construct new road or upgrade the existing road? What are the criterion (such as accessibility, connectivity, connectedness, directedness, etc) used for selection of the projects for intervention. Is there a quantitative threshold?

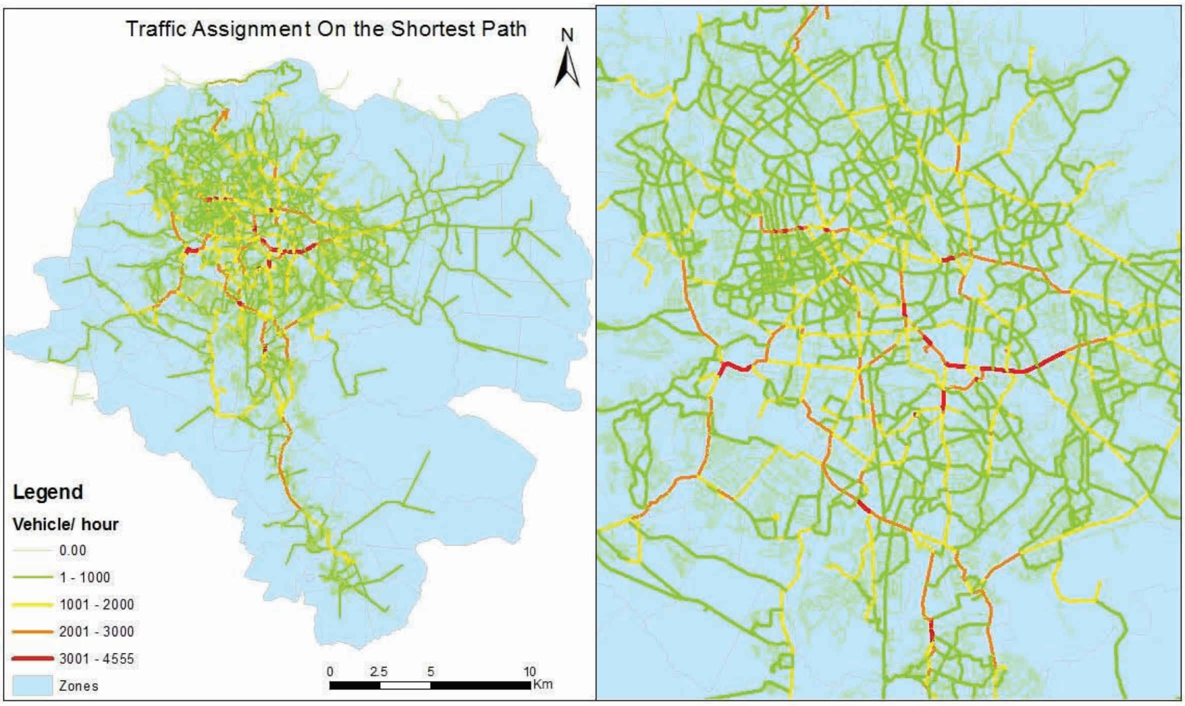
5. How do you prioritize infrastructure for improvement?

6. Which part of Addis Ababa city is not well served by the network? Are there already identified areas suffering from inadequate infrastructure?

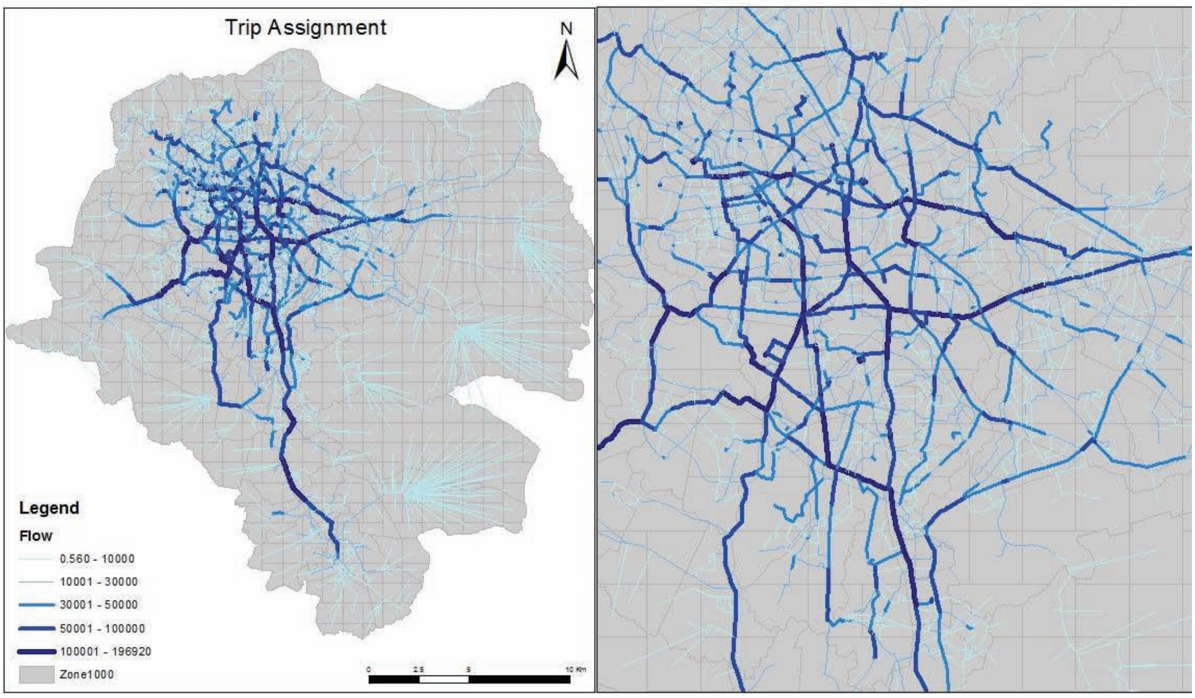
7. How do you define inadequacy in network?

APPENDIX D: MAPS

Appendix D.1) Real Network Based Traffic Assignment in Vehicles per Hour

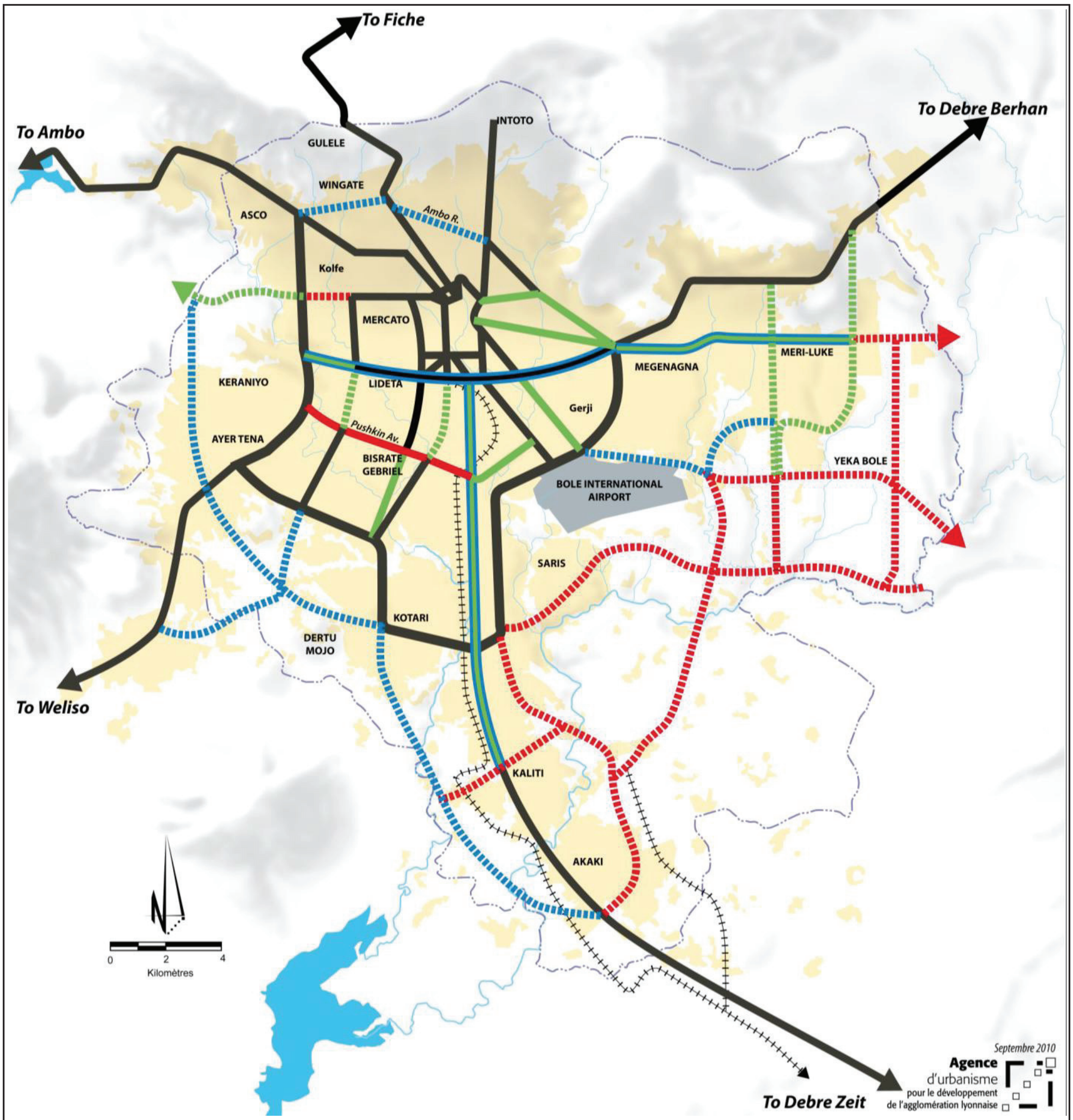


Appendix D.2) Real Network Based Assignment with Disaggregated Zones in Trips per Hour



Appendix D.3) Proposed Infrastructures and Implementations

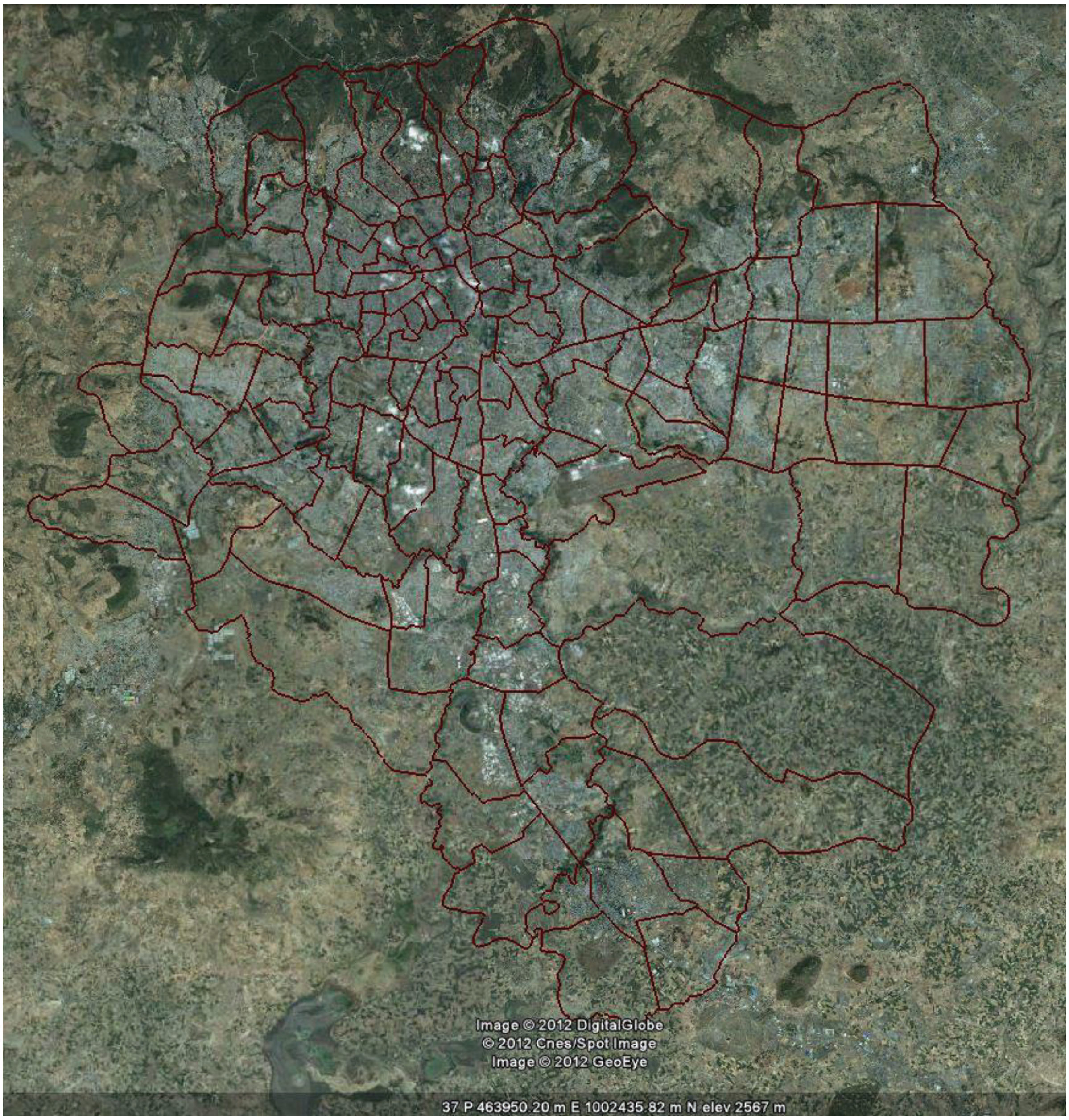
Evaluation of Road Network and Transport System Proposal of City Master Plan



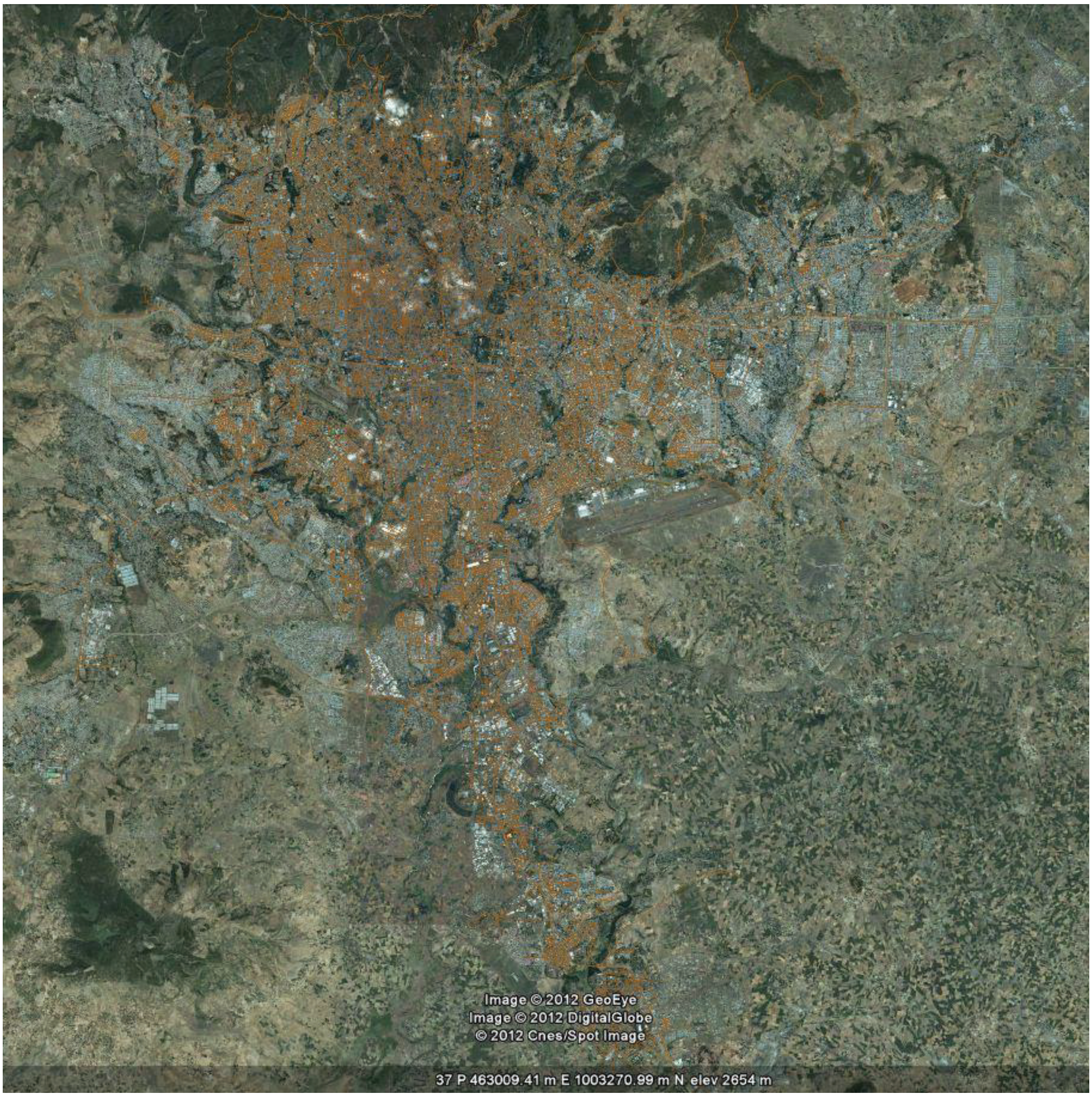
Road rehabilitation	Road construction	Mass transport	Transport Infrastructure Project
Implemented	Implemented	Right of way served	Implemented
Partly implemented	Partly implemented		Partly implemented
Not Implemented	Not Implemented		Not Implemented

Source: Evaluation of the Master Plan (2001-2010)

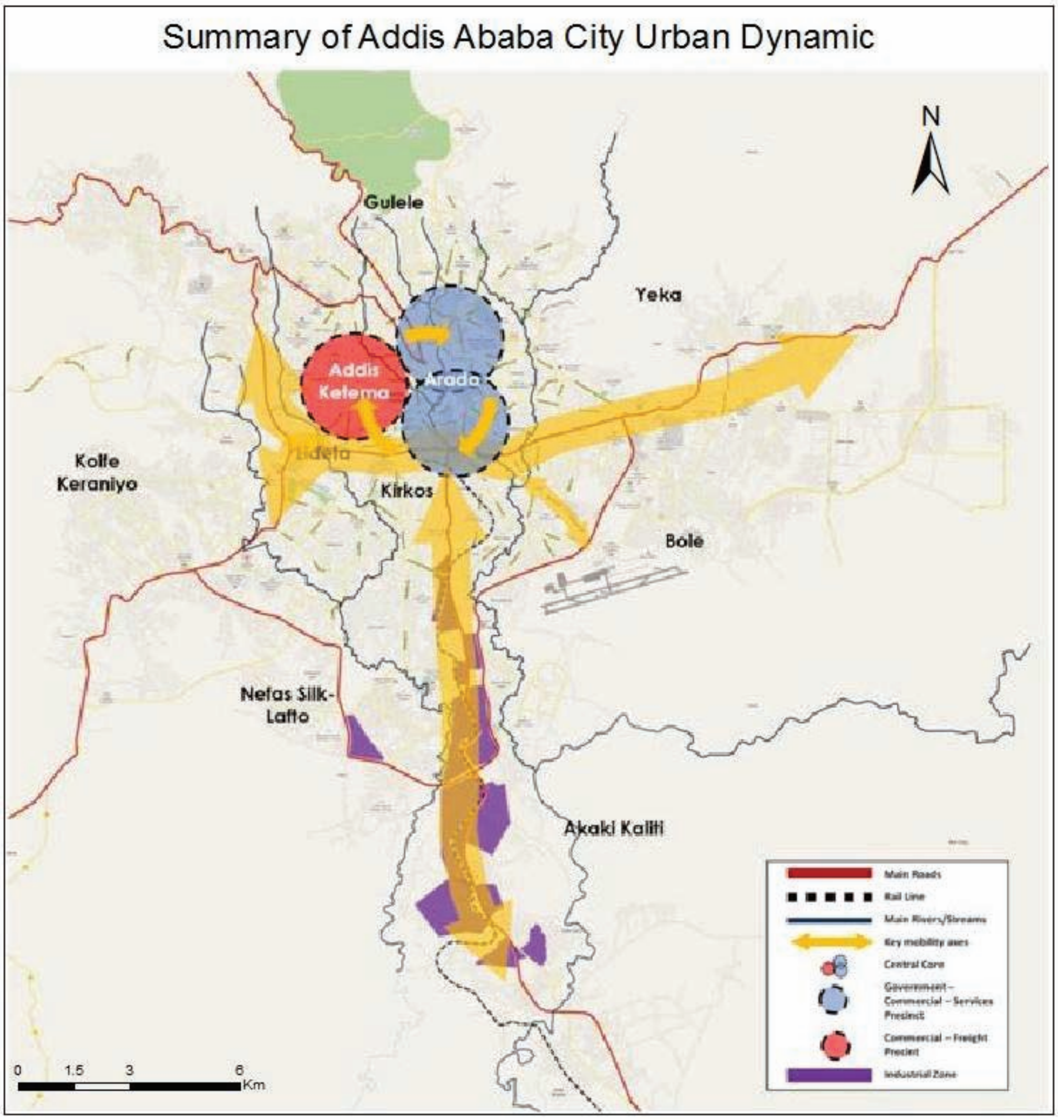
Appendix D.4) Google Image of Addis Ababa City and TAZs



Appendix D.5) Google Image of Addis Ababa City and Road Network



Appendix D.6) Urban Dynamics of Addis Ababa City



Source: ICT Consultants based on Map from Ethiopian Mapping Agency

APPENDIX E: INPUT STRUCTURE

Appendix E.1) Sample inputs for Python script

Input samples for Python script in appendix A.1

Origin / Destination

Node 1	Node 2
7072	7072
7072	6520
7072	6287
7072	5140
7072	4054
7072	3899
7072	4452
7072	5003
7072	5257
7072	6920
7072	5961
7072	2313
7072	1375
7072	2415
7072	2973
7072	3521
7072	3815
7072	3890
7072	4210
7072	3281

Links , node and link length

Link_No	Node1	Node 2	Length
1	5446	5286	276.8027
2	5513	5427	103.3977
3	5641	5594	66.04277
4	5692	5649	88.10201
5	5766	5692	103.255
6	5692	5669	182.9922
7	5965	5805	180.8066
8	5681	5672	143.8238
9	5681	5672	74.21779
10	5744	5681	64.0209
11	5717	5672	186.6732
12	5858	5717	112.4182
13	5717	5611	148.92
14	5717	5644	155.2458
15	5644	5546	142.5612
16	5986	5921	131.289
17	5986	5884	107.9999
18	6137	5983	136.2661
19	6337	6324	183.8283
20	5676	5651	143.7508

O/D	7072	6520	6287	5140	4054	3899	4452	5003	5257
7072	0	1009.919	365.1511	675.8826	563.0334	508.4352	329.1922	971.2185	807.2252
6520	1089.098	0	1010.064	1726.633	1282.289	1005.927	739.3002	1849.048	1140.046
6287	481.5529	1152.851	0	1027.666	822.5213	588.8252	383.4263	1002.462	612.6704
5140	685.4336	1555.504	745.7584	0	1585.556	1282.874	849.5567	2087.495	1171.822
4054	468.0382	959.2839	486.7023	1294.903	0	1290.135	839.2284	1654.069	866.8248
3899	276.5531	491.6549	211.0986	667.77	859.1528	0	476.7832	969.5779	578.2119
4452	451.6213	890.0778	396.5951	1180.355	1317.315	1096.849	0	1715.237	843.3666
5003	676.3886	1156.078	468.066	1380.036	1353.674	1214.846	907.8382	0	1302.174
5257	418.4237	500.2283	188.7512	523.2018	488.8676	517.7405	287.8418	930.1864	0
6920	779.0726	895.4969	294.9242	711.1403	671.9306	717.2523	313.8095	1292.01	1239.934

To execute the program, link and node data should be organized as shown in the table, the zone centers are selected from the nodes and saved in a sheet. The OD matrix developed considering network distance was also saved in different sheet. The three data are saved in the same work book and the program can be executed.

Input samples for Python script in appendix A.3

Linkid	Node1	Node2	link length	Origin	Destination	Tij	OD-number
1	5446	5286	276.8027047	7072	7072	0	1
2	5513	5427	103.39768	7072	6520	1009.919012	2
3	5641	5594	66.04277303	7072	6287	365.1511299	3
4	5692	5649	88.10201342	7072	5140	675.8826329	4
5	5766	5692	103.2550426	7072	4054	563.0334419	5
6	5692	5669	182.9922489	7072	3899	508.4351585	6
7	5965	5805	180.8066109	7072	4452	329.192248	7
8	5681	5672	143.8238088	7072	5003	971.218534	8
9	5681	5672	74.21778594	7072	5257	807.2252487	9
10	5744	5681	64.02090459	7072	6920	916.0099308	10
11	5717	5672	186.6732042	7072	5961	540.7322601	11
12	5858	5717	112.4181873	7072	2313	173.8118151	12
13	5717	5611	148.919997	7072	1375	181.6095008	13
14	5717	5644	155.2457918	7072	2415	163.6839182	14
15	5644	5546	142.5611641	7072	2973	259.8471776	15
16	5986	5921	131.2889627	7072	3521	204.6101408	16
17	5986	5884	107.9998944	7072	3815	279.4188486	17
18	6137	5983	136.2660675	7072	3890	238.0590339	18
19	6337	6324	183.8283204	7072	4210	239.0061073	19
20	5676	5651	143.7508018	7072	3281	875.2604707	20
21	5651	5631	133.4323859	7072	4717	358.8466693	21
22	5775	5651	135.9187925	7072	4515	476.8513615	22
23	5623	5609	298.3890062	7072	3754	44.73878708	23

Since the second scrip is written to read text files the two inputs should be saved in text file separately.

Appendix E.2) Link-Zone table in the left and Link-OD table in the right

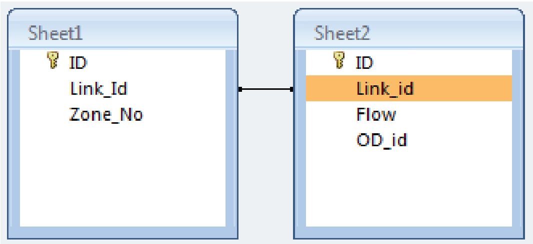
Output_1... | Sheet1 | Sheet2 | Relatic

ID	Link_Id	Zone_No
27	23	29
28	24	29
29	25	29
30	26	29
31	26	9
32	27	29
33	27	9
34	28	29
35	29	29
36	30	29
37	31	29
38	31	9
39	32	29

Output_1... | Sheet1 | Sheet2 | Relationsh...

ID	Link_id	Flow	OD_id
1	14071	1009.919012	2
2	14074	1009.919012	2
3	591	1009.919012	2
4	9089	1009.919012	2
5	1037	1009.919012	2
6	9314	1009.919012	2
7	9313	1009.919012	2
8	9312	1009.919012	2
9	9311	1009.919012	2
10	9310	1009.919012	2
11	9309	1009.919012	2
12	9308	1009.919012	2
13	9307	1009.919012	2
14	9306	1009.919012	2

Appendix E.3) Relation between the Link-Zone and Link-OD tables



Appendix E.4) Spatial join of link and zones to the left, OD array to the right.

Get External Data | Connections

D2 | =LOOKUP(C$2:C$659922,OD!A$2:A$45

	A	B	C	D	E	F	G
1	TARGET_FI	JOIN_FID	ObjectID	Tij_Eucl	Tij_Nw		
2	0	1	1	0	0		
3	1	1	2	104.5551	123.124		
4	1	118	2	104.5551	123.124		
5	2	1	3	54.92243	61.98722		
6	2	44	3	54.92243	61.98722		
7	3	1	4	121.7957	134.3166		
8	3	627	4	121.7957	134.3166		
9	4	1	5	207.3356	228.6511		
10	4	118	5	207.3356	228.6511		
11	4	229	5	207.3356	228.6511		
12	5	1	6	180.1034	185.6538		

Sheet2 | 0_56_SpatialJoin | OD

Ready

F1

	A	B	C	D	E	F
1	ObjectID	Origin	Destinatic	Tij_Eucl	Tij_NW	
2	1	1	1	0	0	
3	2	1	118	104.5551	123.124	
4	3	1	44	54.92243	61.98722	
5	4	1	627	121.7957	134.3166	
6	5	1	229	207.3356	228.6511	
7	6	1	113	180.1034	185.6538	
8	7	1	628	49.01142	55.89838	
9	8	1	108	71.47007	74.03143	
10	9	1	28	153.498	157.7663	
11	10	1	21	101.2132	97.25865	
12	11	1	230	49.04867	52.66799	

Sheet2 | 0_56_SpatialJoin | OD

Ready

Join_fid is the zone number, objectID is id of reference network, Tij_Eucl and Tij_NW are desired trips using the Euclidian and Network distance respectively. To find these trips, the objectID columns in the left sheet are looked up objectID of the right sheet and the corresponding Tij_Eucl and Tij_NW values are found. Using pivot table this values are summed for each zone. The total zone trips are exported to ArcGIS and joined with new zone layer