ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

SEGMENTAL ASSESSMENT OF LEVEL OF TRAFFIC CONGESTION ON KALITY RING ROAD TO DUKEM BRIDGE

A Thesis submitted to School of Civil and Environmental Engineering

In partial fulfillment of the requirements for degree of

Masters of Science in Civil Engineering (Road & Transport Engineering)

By: Solomon Shanko

Advisor: Bikila Teklu (Dr.)

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MSc Thesis on

SEGMENTAL ASSESSMENT OF LEVEL OF TRAFFIC CONGESTION ON KALITY RING ROAD TO DUKEM BRIDGE

By

Solomon Shanko Sebero

Approved by Board of Examiners:

Bikila Teklu (Dr.) Thesis Advisor	………………………. Signature	…………………… Date
HabtamuM.Zelelew (Dr.) External Examiner	………………………. Signature	…………………… Date
Abel Kebede (Ato) Internal Examiner	………………………. Signature	…………………… Date
Agizew Nigussie (Dr.) Chairman	………………………. Signature	…………………… Date

DECLARATION

I certify that this research work titled "(***Segmental Assessment of Level of Traffic Congestion on Kality Ring Road to Dukem Bridge***)" is my own work. The work has not been presented elsewhere for assessment and award of any degree or diploma. Where material has been used from other sources it has been properly acknowledged/ referred.

Solomon Shanko Sebero	……………………….	……………………
Candidate	Signature	Date

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LIST OF ACRONYMS

AACRA	Addis Ababa City Roads Authority
AADMTC	Addis Ababa Drivers' and Mechanics Training Center
AATPO	Addis Ababa Traffic Police Office
ABSs	Accident Black Spots
ERA	Ethiopian Roads Authority
ERTA	Ethiopian Road Transport Authority
CBD	Central Business District
CMS	Congestion Management System
GFM	Global Finance Magazine
GDP	Gross Domestic Product
HCM 2000	Highway Capacity Manual 2000
HDM	Highway Development and Management Model
HOV	High Occupancy Vehicles
IMF	International Monetary Fund
ITS	Intelligent Transportation System
LOS	Level of Service
PCU/E	Passenger Car Unit / Equivalent
RR	Ring Road
RSDP	Road Sector Development Program
RTABSs	Road Traffic Accident Black-Spots
TDM	Transportation Demand Management
TOC	Traffic Operation Center
TSM	Transportation Supply Management
TTI	Texas Transport Institute
WEO	World Economic Outlook

ABSTRACT

Transport plays an important role in economic growth and development, though most types cause air pollution, traffic congestion and utilize large amount of land. While it is heavily subsidized by government, efficient planning of transport is essential to traffic flow and restrains urban sprawl. Now a days traffic congestion is increasing and becoming a challenge in the transportation sector. Larger cities and major trunk roads along the most business activity corridors are facing the traffic congestion problem due to increased population and in turn travel demand. Traffic congestion directly affects commuters with an excessive delay in a queue, increased fuel cost, and delay for loss in productive hours. It also affects the living standard of cities and the environment. Therefore, traffic congestion causes upon road users and cities as well as heavy occupancy roads to incur a significant amount of money for both economic and social costs. Assessing the level of the traffic congestion and understanding how much time effect and cost are being incurred due to traffic congestion and the probable cause of the same; hence, it will be important to make appropriate decisions and seek possible implementable mitigation measures.

Following the economic and population growth and the high demand for import-export trade activities in Ethiopia, traffic congestion challenges has emerged and the challenge is even growing faster in the nation's eastern active major trunk road corridor of Addis – Dukem –Debre Zait - Modjo road segment. This road segment is part of the country's one of the most congested road corridor. In this study, the level of traffic congestion in part of this road segment is assessed and quantified based on the concepts of Capacity and Level of Service (LOS) on the existing road.

Moreover, the study evaluated the relation between traffic congestion and occurrence of traffic accident as one of the negative consequences. In addition, the study has identified the locations of accident black spots and their relations with delay and travel time for different categories of vehicle groups. It also evaluated the aggravating factors such as proportions of heavy trucks with the performance measures in the route. The study segments in general exhibited Level of Service, LOS E. Traffic accidents and accident black spots in both city and inter-city sections of the selected segments are clearly aggravating the effects of traffic congestion and proportions of heavy and long vehicles. The terrain conditions of the route as well as the location of bottleneck relative to upgrades or downgrades have also significant effect on the occurrence of road traffic congestions in the selected corridor.

The study proposed High, Medium and Low cost engineering countermeasures which are recommended to reduce the level of Road Traffic Congestion and its associated impacts either through traffic management procedures or building better infrastructure development along the segment.

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1. 0. INTRODUCTION

1.1. Background of Study

Transportation mobility is a basic human need throughout their life. From the times immemorial, everyone travels either for necessity or leisure. A closely associated need is the transport of raw materials to a manufacturing unit or finished goods for consumption purposes. Transportation fulfills these basic needs of humanity. Transportation plays a major role in the development of the human civilization. For instance, one could easily observe the strong correlation between the evolution of human settlement and the proximity of transport facilities. Also, there is a strong correlation between the quality of transport facilities and standard of living, because of which society places a great expectation from transportation facilities. In other words, the solution to transportation problems must be analytically based, economically sound, socially credible, environmentally sensitive, practically acceptable and sustainable. Alternatively, the transportation solution should be safe, rapid, comfortable, convenient, economical, and eco-friendly for both men and material [36].

In the last couple of decades transportation systems analysis has emerged as a recognized profession. Several government organizations, universities, researchers, consultants, and private industrial groups around the world are becoming truly multi-modal in their orientation and are determining a systematic approach to transportation problems.

The availability of highway transportation has provided several advantages that contribute to a high standard of living. However, several problems related to the highway mode of transportation exist. These problems include highway-related accidents, parking difficulties, congestion, environmental hazards (carbon emissions, noise pollution, etc.) and delay. Not surprisingly, there are a wide range of suggested solutions to these problems: from building new roads to banning cars, and from improving public transport services to the use of technologies such as telecommunications and internet as alternatives to reduce the need for travel. Many of these 'solutions' are expensive, and may not be very effective depending on the type of the economical stand of a country/city; moreover they may introduce new problems; for instance: - new roads, for example, consume precious land; ban on cars may result in a loss of trade. It is the task of politicians, and of skilled professionals who advise them, to identify the most appropriate solutions for today's, problem taking tomorrows need and safety on transport systems. These solutions from the basis of transport policy can be designed for a nation, an individual city or town or rural areas.

To reduce the traffic congestion and delay including their associated effects of Addis – Dukem road section in this case, it is necessary to adequately collect information that describes the extent of the problems and identifies their locations. Such information is usually collected by organizing and conducting traffic surveys and studies. Systematic traffic studies involve the collection of data under operational conditions and include studies of speed, traffic volume, travel time and delay, parking, and accidents, etc. Such studies shall be carried out due time in the course of this research work which will be conducted to evaluate current conditions and develop the most reliable solutions for the existing as well as the probable problems in the future due to the expected economic development bound with the specified scope of the work .

Normally, transportation projects are justified for the improvements in traffic flow and safety, savings in energy consumption and travel time, economic growth, reduction of environmental hazards, increased accessibility and mobility, and the likes. Having these general facts and realities, the existing travel time and delay of Addis - Dukem road section will be studied through the research that is going to be conducted based on the parameters of the Capacity and Level of Service (LOS) of the existing infrastructure and the traffic management aspect in the same section will be assessed accordingly. The scope of the problem will be defined and the analysis and discussion parts will be followed. Then, the most probable improvement measures or engineering solutions in this regard will be amended as recommendation.

1.2. Problem Statement

There are many reasons to mitigate traffic congestion. Congestion delays time and wastes money, and it increases the risks of accidents and localized pollutants like emissions. But, potentially the most seriousconsequence of traffic congestion is increased emissions of greenhouse gases. Despite all these facts, there are still no significant countermeasures to reduce the traffic congestion, delay and its negative impacts on community as well as mobility of human and materials.
According to the Ethiopian Roads Authority (ERA) traffic count for the last five consecutive years 2010 to 2014;

Table 1: AADT for randomly selected 5 successive years [3]

Segments/ Sections	**Annual Traffic Count, AADT for randomly selected 5 successive years**				
	2010	**2011**	**2012**	**2013**	**2014**
Segment I	40591	29431	23134	23169	14984
Segment II	19458	28800	21913	25274	14199

Here, the significant indication of decline of the traffic volume in both sections can be expected by the study due to the construction of dry ports and certain industrial zones in the vicinity of the route especially in the inter – city section of the study area. But, the problem is still there in a provoked manner. The responsible road authorities attempt to lessen the current situation by conducting long-term policies and strategies such as designing and constructing a separate six lane express ways from Addis Ababa to Adama town. In addition, secondary bus stations are being provided by concerning bodies in certain peripheries of Addis Ababa in all the five gates or directions. One of these stations is the Kality Bus Station which is located at Akaki –Kality Sub – City for medium and small vehicles moving along the corridor. However, these all efforts are not still the immediate corrective measures for the prevailing adverse conditions on the route even if they have their own contributions in this case. The present study is intended to assess and investigate the information gap to bridge the same, and subsequently deduce countermeasures so as to improve the existing condition either through adequate and sufficient infrastructure development scarifying the precious land and existing valuable properties in the vicinity of the road section, or apply traffic management principles that will be related to the study of existing and future traffic pattern along the road segment.

In general, the traffic conditions across this corridor are in a grim situation caused by daily congestion and daily accidents. The current highway systems are used for daily commuting, transportation of goods and interstate travels. It is then essential that the study provides solutions to these problems or at least ways to alleviate the magnitude of their occurrences.

Moreover, the road segment is also part of the Eastern Corridor which is currently the nation's major **ex**port - **im**port route accounting for more than half of all the other gates to and from the capital Addis. It has an estimated traffic flow that was 10,092 AADT exceeding the rest four major entry/exits' summing up only 5,646 [*2*)]. On this route, as actually observed in the same year, heavy vehicles and high containerized trucks are the dominating vehicles with the proportion of more than 37 and 13 percents respectively by the same year *[2]***.** Also there are considerable business centers and town sections along the route. It is obvious how the road side villages on that route has developed viciously since the last 15 years and that sooner or later that Addis and Debre Zait will not have an unpopulated road stretch.

1.3. Research Questions and Objectives

The objectives of this study are to answer the following questions: Can we apply Capacity Analysis, Operational Characteristics and Performance Quality or Level of Service (LOS) in the selected segment to evaluate road infrastructure facilities? How can we mitigate such a traffic jam situations? Can we identify/ investigate the influence factors for the condition and relate to the performance indicators such as Capacity and LOS? Can an understanding of these factors that contribute to traffic congestion provide some clue on possible remedies? Hence, these questions are the basic requirements of the research work.

1.3.1. General Objective

The general objective of this study is to assess road traffic congestion and investigate the possible causes and effects on the existing conditions along the selected road segment and propose possible countermeasures to minimize the current as well as expected traffic jam. From the perspectives of the study, it will also reduce the cost of traffic congestion in the specified road segment by creating appropriate time utilization in this regard.

1.3.2. Specific Objectives

The research has the following three main specific objectives:

i. To assess the Capacity and Level of Services (LOS) on the road segment so as to evaluate the existing performance or serviceability of the road;
ii. To investigate possible causes of traffic congestion in both city and inter - city sections of the selected road segment;
iii. To examine the effect of heavy and long vehicles on traffic stream during congestion.

1.4. Scope and Limitations

The scope of this study was limited to the Addis Ababa (Addis Ababa Drivers and Mechanics Training Center, "*Maseltegna"*) to Dukem Bridge segment that is part of the major road of Eastern corridor and other road sections and intersections were not included in this study. Furthermore, the analysis was segment study rather than area wide or regional study. Hence, it focuses mainly on the road segments both in the city and inter-city sections and the relative effect of consecutive intersection was not discussed. Since, the main objectives of the study are assessment and quantifying the congestion level, investigation of possible causes of traffic congestion and examining the effect of heavy vehicles on traffic stream during congestion in the same segment. And hence, the congestion management procedures and measures were not discussed in detail and have been left for further studies in this area.

1.5. Research Organization

The first chapter of this paper gave a brief introduction of transportation needs as well as traffic congestion issues and continued with the objectives and limitations of the research. Then, chapter two undertakes review of relevant literatures. Chapter three discusses the methodology of the research and chapter four gives a detailed description and analysis of the traffic survey and secondary data utilized for study objectives. Chapter five tries to discuss on the results of the detailed descriptions and analysis of that of the previous chapter. Finally, conclusions and recommendations are presented in chapter six of this paper.

2.0. LITRETURE REVIEW

2.1. General Overview

Highway Engineering is an engineering discipline branching from civil engineering that involves the planning, design, construction, operation, and maintenance of roads, bridges, and tunnels to ensure safe and effective transportation of people and goods. [*28] & [17*]. All of these authors agree on the above idea. Highway engineering became prominent towards the latter half of the 20th Century after World War II. Standards of highway engineering are continuously being improved. Highway engineers must take into account future traffic flows, design of highway intersections/interchanges, geometric alignment and design, highway pavement materials and design, structural design of pavement thickness, and pavement maintenance *[17]*.

Similarly, Traffic Congestion is a condition on road networks that occurs as use increases, and is characterized by slower speeds, longer trip times, and increased vehicular queueing [*35*]. The most common example is the physical use of roads by vehicles. When traffic demand is great enough that the interaction between vehicles slows the speed of the traffic stream, this results in some congestion. As demand approaches the capacity of a road (or of the intersections along the road), extreme traffic congestion sets in. When vehicles are fully stopped for periods of time, this is colloquially known as a traffic jam or traffic snarl-up [*28]*.

Summary document of European Joint Transport Research Center states that Congestion has No Single Definition [*35*]. Congestion is a situation in which demand for road space exceeds supply. Congestion is the impedance vehicles impose on each other, due to the speed-flow relationship, in conditions where the use of a transport system approaches capacity. Congestion is essentially a relative phenomenon that is linked to the difference between the roadway system performance that users expect and how the system actually performs.

Having the above know how of the discipline, traffic flow theories and models are already developed by some scholars during late 19^{th} century involving the development of mathematical relationships among the primary elements of a traffic stream: flow, density, and speed. These relationships help the current traffic engineers in planning, designing, and evaluating the effectiveness of implementing traffic engineering measures on the highway transportation system. But the theories and models need to be further studied since traffic flow is a complex human or driver behavior related system unlike the normal fluid flow. Starting from these basics further researches should be conducted.

Congestion takes on many faces, occurs in many different contexts and is caused by many different processes. Because of this, there is no single best approach to manage congestion – and this study is therefore not prescriptive about specific congestion management measures. However, there are many things that congestion management policies should take into account if they are to achieve the goals they set themselves.

2.1.1. Ethiopian Trend

The need and importance of reliable information on traffic volume of roads for transport planning and management has been strongly realized by Ethiopia through Ethiopian Roads Authority since the very beginning of its establishment. In order to avail information on volume and composition of road vehicular traffic for various purposes of analysis, ERA, since 1952, has been carrying-out traffic count survey three times a year on all roads under its responsibility. From all types of Trucks on paved roads in the reporting year, the highest traffic volume was registered on Addis Ababa – Kality road section (AADT 34,372) and the dominant vehicles type on this road section is the same accounting for 35% of the total vehicles counted. AADT on Kality – D/Zeit and D/Zeit - Nazert is 18,304 and 13,528 respectively *[2]*. The corresponding AADTs recorded for A.A to Kality and Kality to D/Zeit were increased to 23,134 and 21,913 respectively from AADT of 2012.

Road Network of ERA 16 years assessment report indicates that since the inception of the Road Sector Development Program (RSDP) in 1997, it has focused on rehabilitation and expansion of the main paved and unpaved roads and important regional roads. The total road network has expanded from about 26,550 km at the beginning of the RSDP (in 1997) to 48,793 km(in 2010), increasing the road density from 24.1 to 44.4 km per 1000 sq. km and 0.46 to 0.58 km per 1000 population.

By far, the country‘s road network has increased from 26,550 km in 1997 to 85,966 km in 2013 (an increase of 224 percent). As result, the road density per 1000 sq. km has increased from 24 km in 1997 to 78 km in 2013. The condition of the road network also reveals substantial improvement as has been registered in the condition of the country’s road network. The proportion of road network in good condition increased from 22% in 1997 to 70% in 2013 [*34]*.

Even though the corridor in question might not be expected to have exact analogy with the requirements of the Highway Capacity Manual (HCM) due to the nature of the infrastructure, the study tries an operational analysis of the road segment to determine the level of service for an existing or proposed facility operating under existing or projected traffic demand and propose the required countermeasures. Operational analysis may also be used to determine the capacity of a two-lane highway segment, or the service flow rate which can be accommodated at any given level of service.

2.1.2. Physical and Financial Performance of RSDP

The Government of Ethiopia has placed increased emphasis on improvement of the quality and size of road infrastructure in the country. To address constraints in the road sector, mainly low road coverage and poor condition of the road network, the Government formulated the Road Sector Development Program (RSDP) in 1997.

The RSDP has already been implemented over a period of seventeen years and in four successive phases, as follows:

- RSDP I - Period from July 1997 to June 2002 (5 year plan)
- RSDP II - Period July from 2002 to June 2007 (5 year plan)
- RSDP III - Period July from 2007 to June 2010 (3 year plan)
- RSDP IV - Period July from 2010 to June 2015 (5 year plan, 4 years elapsed)

Over the Seventeen years of the RSDP, physical works have been undertaken on a total of ***110,163 km*** of roads excluding routine maintenance work. The total budget for the planned works during this period amounted to ***ETB 160.3 billion (USD 11.1 billion).*** The total amount disbursed in the same period, is ***ETB 180.9 billion (USD 12.2 billion).*** Physical and financial performance over the past 17 years against plan is ***86%*** and ***113 %*** respectively. Table 1 shows summary of 17 years assessment of physical and financial performance of RSDP.

Table 2: Summary of 17 Years Performance of RSDP [34]

Program	***Physical Plan Vs. Accomplishment, km***			***Finical Plan Vs. Disbursement, in million ETB***		
	Plan	***Actual***	***% age***	***Budget***	***Disb.***	***% age***
Total RSDP I	8908	8709	98	9812.9	7285.0	74
Total RSDP II	8486	12006	141	15985.9	18112.9	113
Total RSDP III	20686	19251	93	34643.9	34957.8	101
RSDP IV (Four years)	***90386***	***70196***	***78***	***99871.2***	***120501.2***	***121***
Total RSDP (17 yrs)	***128,466***	***110,163***	***86***	***160,313.9***	***180,856.9***	***113***

Fig. 1 :Physical Plan Vs. Accomplishment (in km)

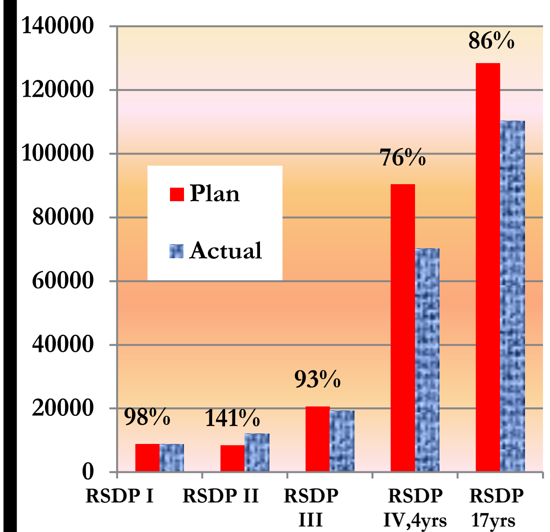
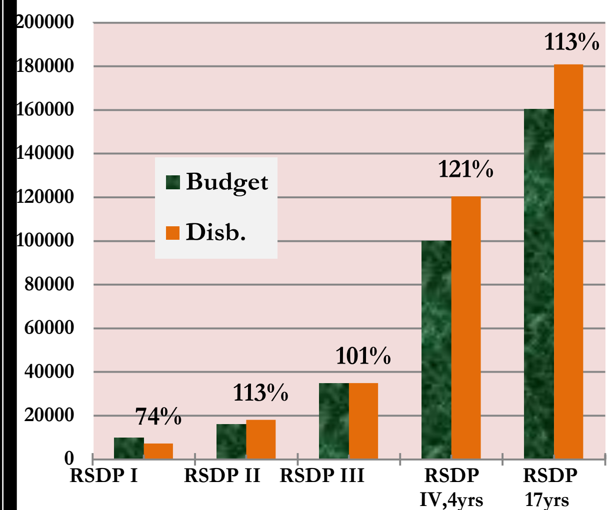


Fig. 2: Financial Plan Vs. Disbursement (cost in million)



The Fourth Phase of RSDP which is part of GTP has been implemented since 2010/11. During the past four years of RSDP IV, a total of ***69,421 km*** physical work has been carried out, of which ***10,970 km*** by Federal roads, ***19,355 km*** by regional roads and ***39,096 km*** woreda roads.

Fig. 3: Newly Built Addis – Adama Expressway Section (Semi-Manual System) [34]

The completed Addis – Adama Expressway with a total length of 78km has a six lane divided that is three lanes in each direction with 3.75m lane width and 3.5m tree planting median separation in the middle. The total roadway width is 31m, including 2.5m Asphalt shoulder in each side. The Expressway's maximum design speeds are 120km/hr for the flat section 51% and 100km/hr for the remaining 49% rolling terrain type. All the design and construction standards are based on the Chinese Design Standards. The design life of the project is expected to be 20years. Currently, the expressway is accommodating about 5000ADT with three different toll tariffs based on the size of the entrance vehicles.

2.2. Defining Traffic Congestion

As a general term, congestion is a phenomenon that occurs almost in all walks of life which demand competition for certain service or supply. For instance, at banking desk, fuel stations, theater gates, e.t.c. Similarly, the Hand Book of Transportation explain road traffic congestion as a phenomenon resulted when vehicles compete or demand for the available road space and the demand reaches or exceeds the capacity.

Definitions of Critical Parameters [*15*]:

2.2.1. Capacity

The capacity of a facility is defined as the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions. Capacity analysis is conducted for segments or points (such as signalized intersections) of a facility having uniform traffic, roadway, and control conditions. Because capacity depends on these factors, segments with different prevailing conditions will have different capacities.

2.2.2. Demand

The demand is the principal measure of the amount of traffic using a given facility. The term ***demand*** relates to vehicles arriving, while the term ***volume*** relates to vehicles discharging. If there is no queue, demand is equivalent to traffic volume at a given point on the roadway. Throughout HCM manual, the term volume is generally used when operating conditions are below the threshold of capacity.

2.2.3. Quality and Levels of Service

The concept of ***quality*** of service uses quantitative measures that characterize operational conditions within a traffic stream. ***Level of service*** is defined as a term which denotes a range of operating conditions which occur on a transportation facility when it is accommodating a range of traffic volumes. The descriptions of individual levels of service characterize these conditions in terms of such factors as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.

Six levels of service are defined for each type of facility for which analysis procedures are available. The levels are given letter designations, from A to F, with level of service (LOS) A representing the best operating conditions and LOS F the worst a simple concept analogous to school letter grades and comprehensible by most non-technical audiences. Each level of service represents a range of operating conditions and the driver's perception of those conditions. Safety is not included in the measures which are used to establish service levels.

2.2.4. Service Flow Rates

The service flow rate is the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform segment of a lane or roadway during a given period under prevailing roadway, traffic, and control conditions while maintaining a designated level of service. The service flow rates are generally based on a 15-min period. Typically, the hourly service flow rate is defined as four times the peak 15-min volume.

2.2.5. Performance Measures

Performance measures can be calculated for each facility type with a defined method for assessing capacity and level of service. Travel speed and density on freeways, delay at signalized intersections, and walking speed for pedestrians are examples of performance measures which characterize flow conditions on a facility.

Many scholars agreed that, despite the fact that engineers and other transport professionals had studied traffic congestion for long time, there is no still consensus even within academia on the single and precise definition of traffic congestion [31].

This is mainly due to the fact that traffic congestion is:

1. A ***physical phenomena*** relating to the manner how vehicles impede each other's progression as demand for limited road space approach to capacity [7];
2. A ***relative phenomena*** to users' expectation versus road system performance [21];
3. It can't be fully described using one dimensional parameter [33].

Hence, there are many definitions given for traffic congestion based on different parameters. If we summarize them they all lie in at least one of the following definition. These are:

- *Traffic Congestion is travel time or delay in excess of that normally incurred under light or free flow travel condition*.
- *Traffic Congestion is a situation where the traffic demand for the road space exceeds the capacity*.
- *Traffic Congestion is an excess of vehicle on the portion of the road way at a particular time resulting in slower speed from normal or free flow speed and mostly characterized by stop or stop*-go traffic.

As it can be seen from the above definitions and the diagram below, definitions of traffic congestion generally fall in to two major categories. These are definitions which base on the cause and which base on the impact of traffic congestion. However, in order to quantify or measure traffic congestions definitions which are based on the impacts are more appropriate due to the fact that the impact of traffic congestion can be felt by many road users and easy to understand. Lomax (1997) argued that traffic congestion is dependent on the perception of the road user's and gives two definitions for "Congestion" and "Unacceptable Congestion". Accordingly; "Congestion" was defined as a travel time or delay in excess of what normally incurred under light or free flow travel condition and "unacceptable congestion" as travel time or delay in excess of an agreed upon norm. However, the later definition involves a subjective aspect and difficult to demark in between. Hence, many researches and reports use the first definition in quantifying traffic congestion.

In traffic engineering, flow is an important parameter that shows the state of the traffic movement. In terms of traffic flow, congestion is usually considered as the state where the speed-flow graph is reverted or sloped positive. Hence, congestion can be defined as a state in the traffic flow pattern which represents the condition at which ***demand exceeds capacity*** or the speed is below acceptable value.

Depending on its occurrence congestion can be classified as ***recurring and non-recurring*** congestion. Recurring congestion includes congestion due to bottlenecks, traffic signal, and persistent higher demand etc and they are predictable. Whereas non-recurring congestion includes those congestion caused by mainly accidents and unprecedented events.

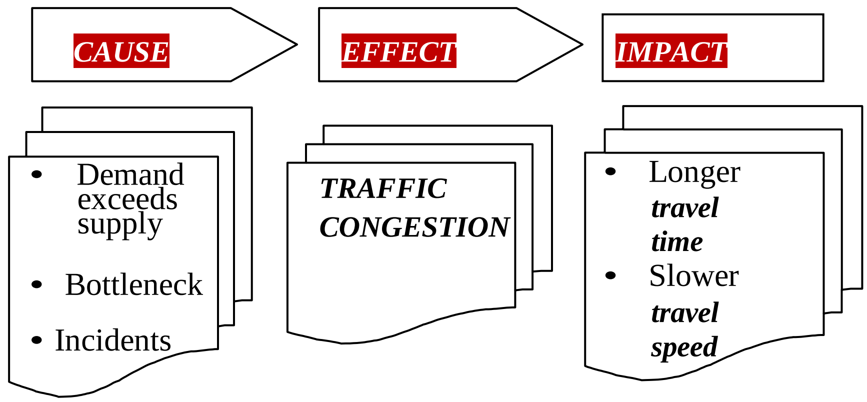


Figure 4: Conceptual frame work of Congestion Cause and Impact [23]

2.3. Causes of Traffic Congestion

Different researches and reports identified many interrelated factors that cause traffic congestion in developed and developing countries where the road network and road users behavior are different [7] & [4]. For instance, Cambridge Systematics (2005) in its "Traffic Congestion and reliablity" report showed the main causes of traffic congestion in United States of America and the research by Aworemi, et.al;(2009) identified the major traffic congestion causes in Lagos Metropolitan. Accordingly, the results showed that in the United States of America the cause and their percentage share are; *bottleneck* (40%), *traffic incidents* (25%), *work zone* (10%), *bad weather* (15%), *poor signal timing* (5%) and *special events* contribute 5% of the traffic congestion.

Adedimila [4] classifies the major causes of traffic congestion in Lagos metropolitan in to five and the summary of his discussion is shown in the Table 3 below.

The major causes of traffic congestion in Addis Ababa city might be suggested as limited road capacity, road side parking, un-integrated urban planning, and lack of mass transit, accident, poor vehicle condition, and road side illegal trade. Therefore, the common feature in the causes of traffic congestion in developing countries shows that the root causes emanate from the lack of proper planning and improper use of limited road network.

Table 3: Major causes of traffic congestion in Lagos Metropolitan

Item No.	Factors	Causes Described
1	Social & Economic factors	• Rising population number together with the rural-urban migration • Unplanned land use which result unidirectional traffic flow especially at pick hours • Increased car ownership in line with the improved living standard
2	Road factors	• Smaller number of lane & Narrow road with • Lack of side walk which result occupation of traffic lanes by pedestrians • Distressed pavement which result in a reduced travel speed • Uncontrolled traffic Intersections
3	Vehicle factors	• Size of vehicle • Age of vehicles
4	Human factors	• Perception of drivers • Perception of pedestrians
5	Accident	• The severity, number and location of accident

2.4. Quantification of Traffic Congestion

According to Cottrell (2001) and other studies, during the early 1990's the ever growing traffic congestion became the concern of transport agencies of major metropolitans .Then different legislations and acts were drawn in the United States of America which demands transport agencies to establish Congestion Management Systems (CMSs). In response, some state Agencies funded researches on measure, threshold, and method of assessing congestion. Further studies and researches then conducted to develop parameters and indexes to quantify traffic congestion. And also developing empirical models that help to predict recurrent and non-recurrent traffic congestion become a concern [33].

The survey made by Lomax (1997) in 1992 to investigate the existing practice of different agencies for measuring traffic congestion showed that there were a range of empirical measures being used by different agencies and out of these about 90% used the Level of Service (LoS) as congestion measure as defined in Highway Capacity Manual (HCM). However, the same research assesses the suggestion of agencies to on the most appropriate measure for congestion. Accordingly, Travel delay and Travel time/ speed were frequently proposed as the best congestion measure [21].

The Highway Capacity Manual 2000 defines six states of traffic flow or operations with clear boundaries of traffic flow parameters. The six states of traffic flow are named with the English alphabet from A to F where A represents a free flow condition while F represents a blocked or a stop and go traffic flow. However, the HCM do not specify a boundary as to which LoS is considered as congested state. Hence, different agencies define their own boundary for congestion and the survey result showed that LoS C, D, E and the worse were used by agencies. Furthermore, as the HCM uses the volume to capacity ratio or saturation index (v/c) as a base for LoS criteria, some agencies were using the v/c ration for measuring congestion and the values ranging from 0.8-1.25 were used as a boundary for defining congested state [21 & 30].

However, all the above congestion approaches both LoS and v/c ratio cannot be a comprehensive measure for congestion due to the fact that congestion is a multidimensional phenomenon. Meyer (1994) indicates that there is no consistent congestion measure used by transport engineers and planners to monitor system congestion. Meyer also states "*A good set of congestion measures has the potential to improve not only the quality and consistency of public transportation policy but also pubic understanding of the congestion phenomenon, leading to political support for policy improvements and more rational behavior by individual travelers*". Accordingly, most literatures agree that travel time approach for quantifying congestion gives a better opportunity for public and policy makers to understand the level of congestion.

agencies funded researches on measure, threshold, and method of assessing congestion. Further studies and researches then conducted to develop parameters and indexes to quantify traffic congestion. And also developing empirical models that help to predict recurrent and non-recurrent traffic congestion become a concern [33].

2.5. Components of Traffic Congestion

Almost all researches done so far agreed that in order to fully express traffic congestion, it is necessary to understand its four components or dimensions; namely, duration, extent, intensity and reliability [18] & [33]. ***Duration*** express the amount of time that the congestion affects the transportation system or lasts with daily recurrences possible. ***Extent*** concerns the number of persons or vehicles affected by travel delay. ***Intensity*** describes how much the congestion is severe and affects the travel and ***Reliability/Variation*** describes the changes in the above three other parameters and their predictability.

According to Jenks et.al (2008), the four dimensions are actually are very important and can help to define the magnitude of congestion. He explained the relationship of the four components with a three dimensional box as shown in the Figure 3 below and the volume of the box is related with the magnitude of congestion and the variation in the volume of the box with time is an indication of reliability.

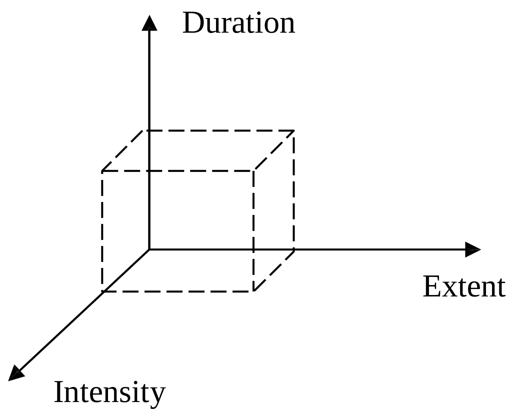


Figure 5: Components of Congestion [18]

2.6. Traffic Congestion Indicators

As congestion is a relative measure unlike the other traffic flow parameters and it is defined on the road user's feedback on how the transport system is operating at a given period of time; it is essential to define or have indicators of the presence of congestion in the system. According to Cottrell (2001) many other researchers LoS is the best empirical indicator of congestion in transport system. Moreover, according to Lomax (1997) the road user's perception as a measure for "acceptable" or "Unacceptable" congestion can be taken as an indicator or a demarcation for classifying a road section or an intersection as Congested or not.

2.6.1. Level of Services (LOS) as Traffic Congestion Indicator

The objective of Highway Capacity Manual (HCM) is to provide a consistent system and techniques for the evaluation of the quality of service on highways and street facilities. The HCM does not set policies regarding a desirable or appropriate quality of service for various facilities, systems, regions, or circumstances. Its objectives include providing a logical set of methods for assessing transportation facilities, assuring that practitioners have access to the latest research results, and presenting sample problems. HCM presents LoS as an easy-to-understand methodology of analysis and performance measure for single homogenous road segments. LoS is featured for describing conditions in road links and there is no direct methodology for aggregation. LoS has been criticized by analysts and experts in the area, but it is still in use for the easy-to-communicate properties.

As it is stated earlier, HCM doesn't specify the boundary LoS for congestion state but clearly states that the LoS F is defined as the worst state of flow and represents congested flow. Though there are some reports using other level of service (D and E) as congested flow, LoS F is generally accepted as a state of traffic flow and hence LoS is the most appropriate congestion indicator. The LoS criteria on the HCM are given in the form of min speed, flow or density for road way sections and as a max delay in sec for signalized and un-signalized intersection.

The LOS criteria of HCM are summarized in Tables 4 and 5 below:

Table 4: Typical Highway Level of Service (LoS) rating (HCM 2000)

LOS	Description	Speed (mile/hr)	Flow (Veh/hr/l	Density (Veh/mile)
A	Traffic flows at or above posted speed limit. Motorists have complete mobility between lanes.	Over 60	Under 700	Under 12
B	Slightly congested, with some impingement of maneuverability. Two motorists might be forced to drive side by side, limiting lane changes	57-60	700-1100	12-20
C	Ability to pass or change lanes is not assured. Most experienced drivers are comfortable and posted speed maintained but roads are close to capacity. This is the target LOS for most urban highways	54-57	1100-1550	20-30
D	Speeds are somewhat reduced, motorists are hemmed in by other vehicles. Typical urban peak-period highway conditions.	46-54	1550-1850	30-42
E	Flow becomes irregular; speeds vary and rarely reach the posted limit. This is considered a system failure.	30-46	1850-2000	42-67
F	Flow is forced; with frequent drops in speed to nearly zero mph. Travel time is unpredictable.	Under 30	Unstable	67- max

Table 5: Level of Service (LoS) Criteria for Two -Lane Highways in Class I (HCM 2000)

Level of Service (LOS)	Percent Time Following	Average Travel Speed (km/hr)
A	≤	>90
B	>35-50	>80-90
C	>50-65	>70-80
D	>65-80	>60-70
E	>80	≤ 60

*Note: Level of service **F** applies whenever the flow rate exceeds the segment capacity*

2.6.2. Two-Way Segments

A two-lane highway may be defined as an undivided roadway having two lanes, with one lane for use by traffic in each direction of travel. Passing of slower vehicles requires the use of the opposing lane where sight distance and gaps in the opposing traffic stream permit. As volumes and/or geometric restrictions increase, the ability to pass decreases, resulting in the formation of platoons in the traffic stream. Motorists in these platoons are subject to delay because of the inability to pass.

Two-lane highways compose the predominant mileage or kilometers of most national highway systems. They are used for a variety of functions, are located in all geographic areas, and serve a wide range of traffic requirements. Consideration of operating quality must account for these disparate traffic functions.

Fig. 6: Typical two-lane, two-way highway in rural environment [15]

The two-way segment methodology estimates traffic operational measures along a section of highway based on terrain, geometric, and traffic conditions. Terrain is classified as level or rolling, and mountainous terrain is addressed in the operational analysis procedures for specific upgrades and downgrade to highway sections of at least 3.0 km in length. Traffic data needed to apply the extended two-way methodology include the two way hourly volume, a peak-hour factor, and the directional distribution of traffic flow. Traffic data also include the proportion of trucks and recreational vehicles (RVs) in the traffic stream. The operational analysis of extended two-way segments for a two-lane highway involves several steps, as described in the Methodology section as well as Appendix B part of this paper. This includes:

- ✓ Determination of Free-Flow Speed
- ✓ Determination of Demand Flow Rate
- ✓ Determination of Average Travel Speed
- ✓ Determination of Percent Time Spent Following and
- ✓ Determination of Other Performance Measures

Two-lane highways are categorized into two classes. Class I facilities, compromises high speeds major intercity routes, mostly used by daily commuters, long-distance trips whereas Class II facilities exhibit medium to low speeds, access routes to Class I facilities, scenic or recreational routes, rugged terrain, and short trips [15]. Hence, Class I facilities are utilized or simulated for this research paper.

Fig.7: Typical section of the road corridor [on the rural area of the segment]

2.6.3. Multi - Lane Highway Segments

Multilane highways generally have posted speed limits of between 60 and 90 km/h. They usually have four or six lanes, total of both directions, often with physical medians or two-way left-turn lane (TWLTL), although they may also be undivided. Multilane highways are typically located in suburban communities leading to central cities or along high-volume rural corridors that connect two cities or significant activities generating a substantial number of daily trips.

Multilane highways in suburban and rural settings have different operational characteristics than do freeways, urban streets, and two-lane highways. Multilane highways are not completely access controlled. At-grade intersections and, occasionally, traffic signals are found along these highways.

Friction created by opposing vehicles on undivided multilane highways and the impact of access to roadside development contribute to a different operational setting than that found on freeways. Multilane highways span the range between the uninterrupted-flow conditions found on freeways, and the flow conditions on urban streets which are frequently interrupted by signals.

The capacity of a multilane highway is the maximum sustained hourly flow rate at which vehicles can be reasonably expected to traverse a uniform segment of roadway under prevailing roadway and traffic conditions.

Fig. 8: Typical Divided Multilane Highway in a Suburban Environment

Fig. 9: Divided Multilane Highway in Kality; [Crown Hotel area, Addis]

2.6.4. Other Traffic Performance Measures

Other traffic performance measures including v/c ratio, total travel, and total travel time can be determined using the equations in the appendices except that directional volumes, flow rates, and speeds must be used rather than their two-way equivalents.

2.7. Traffic Congestion and Accident

There are only limited researches available on the relationship between traffic accident and congestion as it relates to the performance of the transportation system. However, [*28*] reports that accidents and congestion are two frustrating events, which can be observed very frequently on roads. Accidents, especially on expressways, can trigger heavy traffic congestions imposing huge external costs and reducing the level of service. Therefore, it is obvious that accidents clearly have an impact on congestion. But the opposite, i.e. the effect of congestion on occurrence of accidents, is less studied and still questionable. One can argue that congestion can reduce the high speeds on expressways and as result of that accident rate is reduced. But in a congested road section vehicles are closely packed and as a result of that rear-end collisions, back-up collisions as well as side collisions can occur. However, it should be kept in mind that the probabilities of fatalities/severities are less in congested road sections compared to that of un-congested sections where operating speeds are high. Therefore, it is important to analyze the impact on the accidents by congestion so that the policy makers can implement relevant measures to reduce the external costs of both accidents and congestion [35].

The evidence is mixed on the degree to which congestion reduces the number of traffic accident on a congested road segment. In some cases, traffic accident shows a reduction in less congested road section. The study concludes that shifting vehicle travel from congested to less congested condition tends to reduce traffic accident but increases the accident severity. Other researches for instance [*16*] agreed that traffic congestion causes traffic accident and hence the cost of congestion should include the cost of accident risks.

The traffic accident rate in Ethiopia is reported to be one of the highest accident rates in the world. Though, the vehicle ownership in the country is the lowest among the sub-Saharan countries, the traffic accident is found to be the highest. According to the Ethiopian Road Transport Authority statistics about 1,800 people died, 7000 people injured and over 400 Million Birr was lost only in the year 2003 [29]. Birhanu, G. (2000) in his PhD dissertation disclosed that out of the total traffic accident in Ethiopia, 21 % of the fatalities, 42% of injury accidents and 65% of the total accidents occurred in Addis Ababa. Moreover, he related the traffic volume as a parameter in the traffic accident model and concluded that as the travel volume increase the headway between vehicles decrease and minor nose-tail collision rate increases. Even though there are many research have been conducted on the traffic accident & safety issues in Ethiopia, there was no any research so far studied on the relationship between the traffic accident and the traffic congestion in the context of Ethiopia or Addis Ababa.

2.8. Cost of Traffic Congestion

Many transport engineers and economists have been interested in costing traffic congestion for long period and different studies have been done to estimate the cost of traffic congestion. As all planning and congestion mitigation measures decisions require a quantified cost benefit analysis, costing traffic congestion is a critical task in traffic congestion management process. Traffic congestion costs nations for their transportation activities, negatively impact their national economy, impair the quality of life by costing traveler's time and money, degrading the environment and causing accident [*16*]. According to [16] report the principal economic and social costs of traffic congestion are:

- The costs of reduced economic output and accompanying job losses
- The costs of travel delay or lost time
- Vehicle operating costs (fuel, ideal time)
- Environmental costs and higher frequency of accident risks

Estimating the social and environmental cost is much difficult and different from area to area; but, some literatures try to estimate person hourly cost as a function of considering all trips to work place. However, the Urban Mobility Report 2010 of TTI, determined the cost of congestion in United States of America as a function of delay time and wasted fuel cost of 2009. Accordingly, the result shows that [30]:

- *The congestion cost for extra time and fuel for 439 urban areas were 24 Billion, 58 Billion and 115 Billion for the years 1982, 2000 and 2009 respectively.*
- *3.9 Billion gallon of fuels wasted*
- *4.8 Billion person-hours of extra time wasted*

Similarly, the congestion cost estimated for Toronto and for major Australia's cities estimated to be 3.3 Billion and 9.39 Billion per year respectively [16]. The above results show how the traffic congestion costs individual travelers and a nation in general. However, to the knowledge of the study of this thesis there is no single attempt so far in Ethiopia to evaluate the cost of traffic congestion in major cities and hence the problem of traffic congestion is felt but it is unknown.

2.9. Vehicles Dimensions and Sizes

Whenever vehicles other than passenger cars (which include small trucks and vans) exist in the traffic stream, the number of vehicles that can be served is affected. Heavy vehicles are defined as vehicles having more than four tires touching the pavement. Trucks, buses, and RVs are the three groups of heavy vehicles addressed by the methods presented in HCM. Heavy vehicles adversely impact traffic in two ways:

• They are larger than passenger cars and therefore occupy more roadway space, and

• They have poorer operating capabilities than passenger cars, particularly with respect to acceleration, deceleration, and the ability to maintain speed on upgrades [*15*].

Heavy Vehicles (HVs) are known for their significant effect on traffic due to their larger dimensions (in general) and inferior performance compared with an average automobile. These vehicles include trucks, buses, and recreational vehicles, with each category having a wide variety of size, power, and design concepts. Historically, the Highway Capacity Manual (HCM) procedures have treated heavy vehicles' effect through the use of Passenger Car Equivalent (PCEs). Using those PCEs, a non-homogeneous mix of vehicles in a traffic stream can be expressed in a standardized unit of traffic, i.e. Passenger Car (PC). While the PCE factors provided by the HCM were derived based on free-flow conditions, they have been used (unknowingly) by transportation professionals for all traffic conditions, i.e. congested and non-congested operations. Recent empirical observations suggest that heavy vehicles' effect is significantly greater during congestion and queuing operations (compared with free-flow operations) and that the use of the HCM PCE factors for congested facilities may involve a considerable amount of error [*12*]. Specifically, the acceleration and deceleration cycles, a situation normally experienced during congestion or stop-and-go conditions, is expected to impose an extra limitation on the performance of heavy vehicles, and in particular on their acceleration away from the front end of the queue that had been moving slowly. The literature review found no other study that investigates the heavy vehicles' effect during congestion.

The current research involves an investigation of several important factors on the effect of heavy vehicles during congestion using empirical data and traffic simulation. These factors involve grade, grade length, and percentage of heavy vehicles, lane-use restriction by vehicle type, and the location of bottleneck with respect to grade. This investigation is deemed very important due to the fact that recurrent and non-recurrent bottlenecks have become commonplace on urban highways and many traffic engineers need to deal with congested facilities on a regular basis. Further, no guidance exists in the current practice concerning the treatment of heavy vehicles' effect during congestion.
The objective of the current study is to examine the effect of heavy vehicles on traffic stream during congestion. This investigation is mainly concerned with level and upgrade highway segments where the presence of heavy vehicles typically has serious impacts on traffic operations. Several factors that are thought of as important determinants of this effect are investigated in this study.

As Ethiopia is a land-locked country the import - export activities of several commercial goods and industrial raw materials are transported through trucking on trunk roads even if the contemporary in and out trade proportion is approximately in a level of 3.32:1 ratio that is annual $ 10.68 billion to $ 3.214 billion respectively [16]. Currently, the number of border crossing heavy vehicles in Ethiopia is about 9,000 and which are engsaged from more than 80 companies such as CoMeTA, BEKELCHA, TRANS, etc. almost all sharing the existing trunk road corridor under discussion to the hub dry ports in the main land or the center including Modjo, Gelan and Kality in this case[12].

2.10. National or International Trends on Existing Traffic Jam Images

2.10.1. Ethiopia – Addis Ababa Road Traffic Jam Cases

Fig. 10: National Trends on selected sites in Addis Ababa

Traffic congestion here in Addis is most often observed, where the demand for travel during morning and afternoon peak periods increases sharply, while capacity remains relatively fixed. Besides, limited modes of transport, numbers of sub-arterial roads, pedestrian roads and increase of private cars are the main causes of traffic congestion in the capital.

Zonal taxi transport system is commenced to improve the overall transport situation of the city in addition to certain private and public buses transport services. Even though, the system improves traffic speed as compared to the users demand, taxi situations are established with small parking area. To sum up, the city transport is poor in duality from the perspective of transport congestion.

2.10.2. Nigeria - Lagos Road Traffic Jam Cases

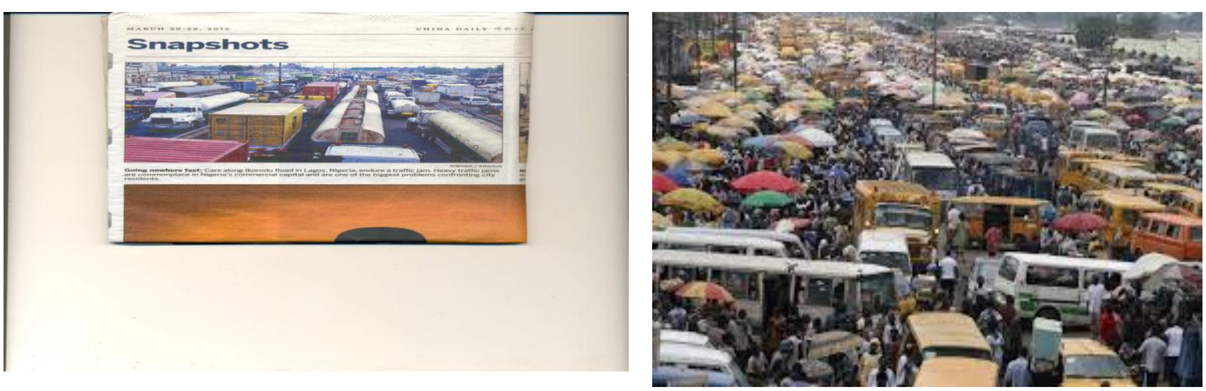


Fig. 11: International Trends/ Replicable Sub-Saharan Corridor Images (Nigeria – Lagos)

Going nowhere fast: Cars along Ikorodu Road in Lagos, Nigeria, endure a traffic jam. Heavy traffic jams are common place in Nigeria's commercial capital and one of the biggest problems confronting city as *China Daily*, *March 2015* states.

2.10.3. Egypt - Cairo Road Traffic Jam Cases

The economic costs of traffic congestion in Cairo could be as high as 4 percent of GDP yearly - what are possible solutions?

Fig. 12: International Trends/ Replicable Maghreb area Africa Corridor Images (Egypt – Cairo – traffic – 650 -41611.jpq)(Retrieved 15/07/15)

Fig. 13: Overcrowded area causing pedestrians to share roads with vehicles

Since Phase I of the Cairo Traffic Congestion Study is an analysis of the causes of Cairo congestion only as well as the preliminary estimation of economic cost, this overview also provides potential solutions, based on the work of the ongoing Phase II of the Cairo Traffic Congestion Study and previous studies, including the World Bank's Proposed Urban Transport Strategy for Greater Cairo.

A study recently released by the World Bank reveals that Cairo's infamous traffic costs Egypt EGP 47 billion (USD 6.5 billion) annually and is expected to reach EGP 105 billion (USD 14.6 billion) by 2030. The study takes place in the Greater Cairo Metropolitan Area (GCMA), which is home to 19.6 million people making it the largest share of population, economy, industry and human resources in Egypt. According to the study, almost four percent of Egypt's GDP is lost due to traffic congestion which takes into account the cost of time wasted (50 percent), delay expenses (31 percent), and health costs (19 percent). The percentage of Egypt's GDP loss due to Cairo's traffic is relatively high compared to that of New York, which makes up 0.7 percent of the US' GDP, and Jakarta, which represents 0.6 percent loss of Indonesia's GDP. The country's crippling traffic problem is not only a result of poor urban and traffic planning, but also due to a lack of order in the country. The study concluded that poor traffic management was the main cause of congestion.
The study mentions "limited parking capacity, few traffic signals, random stops by cars and minivans, no proper pedestrian crossings and U-turns," as the main reasons to Cairo's chaotic

traffic. The lack of appropriate infrastructure and implementation of laws are also to blame. “There are no on-street parking charges, no tolls on most major corridors, and gasoline and diesel are heavily subsidized in Egypt (up to 50%),” mentions the report. The study also mentions the ease of owning and operating a private car burdens the traffic system. Cairo’s passenger cars make up 55 percent of vehicles in Cairo. Furthermore, the study states that there are “no incentives for people to rationalize their travel or carpool.” However, excessive ownership of private cars is not the only reason Cairo’s traffic congestions could last for most of the day. The Greater Cairo Metropolitan Area is under-supplied with public transport. Cairo has 4km of metro line per million inhabitants, while London has 166km and Mexico City has 12km, and only 231 buses per million inhabitants, while London has 753 and Mexico City has 362.

2.10.4. India – New Delhi Road Traffic Jam Cases

Fig. 14: Overcrowded area causing Bajajs to share roads with other vehicles (Delhi – India)

Some myths about urban Indian traffic are; Traffic can’t get worse, more roads and flyovers will ease congestion, Parking is their birthright, Delhi Metro will solve all problems and they don't have anything to learn from the West or East.

2.11. Technology

Emerging transportation technologies under the broad heading of intelligent transportation systems (ITS) are being developed to enhance the safety and efficiency of roadway systems. Depending on the particular application, ITS strategies are intended to increase the safety and performance of roadway facilities. For the purposes of this discussion, ITS is considered to include any technology that allows real-time information to be gathered and used by drivers and traffic control system operators to provide better vehicle navigation, roadway system control, or both.

To date, little research has been conducted to determine the impact of ITS on capacity and level of service. The procedures in this paper are considered how to relate segmental traffic flow pattern to roadway facilities without ITS enhancements.

2.12. Congestion management and electronic road pricing (ERP)

Today, governments face a common problem of worsening traffic congestion in urban areas. Some reasons account for this. In developing countries, vehicle ownership represents growing affluence and social status. In developed countries, people have already grown accustomed to the ease of mobility through private ownership of vehicles, while public transportation is often perceived as unreliable, inefficient or inconvenient. As such, faced with rising transportation demand and growing negative impacts, the urban areas of most countries require new approaches to address their transportation needs. Cities cannot continue to expand their transportation systems forever. Although some expansion is necessary, the economic, social, and environmental costs of doing so are prohibitive. Cities need to re-examine urban transportation demand and devise new strategies which can provide maximum access at minimum total cost. For years, the traditional solution for traffic congestion has been to build more and wider roads, but road building is not a viable long-term solution for dramatically growing cities like Addis Ababa, where land is becoming scarcer.

The Electronic Road Pricing (ERP) system is an electronic toll collection scheme adopted in Singapore to manage traffic by way of road pricing, and as a usage-based taxation mechanism to complement the purchase-based Certificate of Entitlement system. The ERP was implemented by the Land Transport Authority in September 1998 to replace the Singapore Area Licensing Scheme after successfully stress-testing the system with vehicles running at high speed. Singapore was the first city in the world to implement an electronic road toll collection system for purposes of congestion pricing. The system uses open road tolling; vehicles do not stop or slow down to pay tolls.

(a) ERP Implementation (b) ERP & Semi-Manual Implementation

Fig. 15: A comparative approach in utilization of current technologies

3.0. METHODOLOGY OF THE RESEARCH

The methodology employed for a research work was the critical aspect for ensuring the proper result which aligns with the objective or the research question rose. Hence, this part of the thesis discusses the methodology followed and the reason for the selection of the methods in order to address the research problem stated earlier in chapter 1.2.

3.1. Description of Study Area

The study area selected for this research is in south Addis Ababa, Akaki Kality subcity and its peripheral intercity part on the south east main route of the nation. Addis Ababa is a capital city of Ethiopia which is administratively divided in to 10 sub-cities, and each sub-city is in turn divided into lower level administrative units known as 'kebele' (*the lowest administrative unit in Ethiopia including both urban and rural greater than village*). Addis Ababa is not only the capital city of Ethiopia but it is also the seat of African Union head quarter and more than 100 embassies. Due to the fact that Addis Ababa is the political and economic center of the nation, it is the highly populated town in the country. According to the population census report of 2013, the population of Addis Ababa is estimated about 3.27milion.

As it lies in the central part of the country, in addition to serving as a capital, there is a higher concentration of human and vehicle populations leading to road traffic congestions and crashes. Most of the economic and social developments in the country manifested at this capital city and hence all the benefits and aftermath of such economic and population growth affect Addis Ababa. One of the undesirable effects of such growth in the city is traffic congestion. In order to study traffic congestion in Ethiopia, there is no a best place like Addis Ababa due to many factors. The research focuses on the Addis Ababa city and its surrounding along the selected segment. Hence, this section of the research describes briefly the study area and the selected corridors. It also discusses certain descriptive parameters and trends which affect the traffic congestion.

As shown in Figure 9 below Addis Ababa is one of the metropolitans in Africa which is found at the horn of the continent with geographical coordinates ***9^{o}1'48'' North and 38^{o}44'24'' East*** and an average elevation of 2355 above sea level. The city has a total area of about 530.14 Km^2 and a population of 2,738, 248 according to 2007 censes. The city is divided in to 10 administrative sub-cities and the first segment falls totally in Akaki Kality Subcity.

3.1.1. Study Corridor: Akaki – Kality (11.2km) Segment

As per the Addis Ababa City Master Plan its functional classification is PAS-2, which have 50m corridor. Out of the 50m corridor the 11m width at the centre is dedicated for mass transport. Accordingly, the route demands four lanes in each direction for motorized traffic and 5m width for pedestrians in each direction considering the current traffic condition. Then it may be confirmed after the study.

However, currently the existing road does not have the master plan geometry. Rather the existing road geometry is as discussed as follows:

- The Akaki – Kality road has two lanes single carriageway in most of its stretches with some section having two lane dual carriage ways. On the section with two lane single carriageway, the flow is highly unstable and can easily get blocked and form very long queue as shown in the following picture.

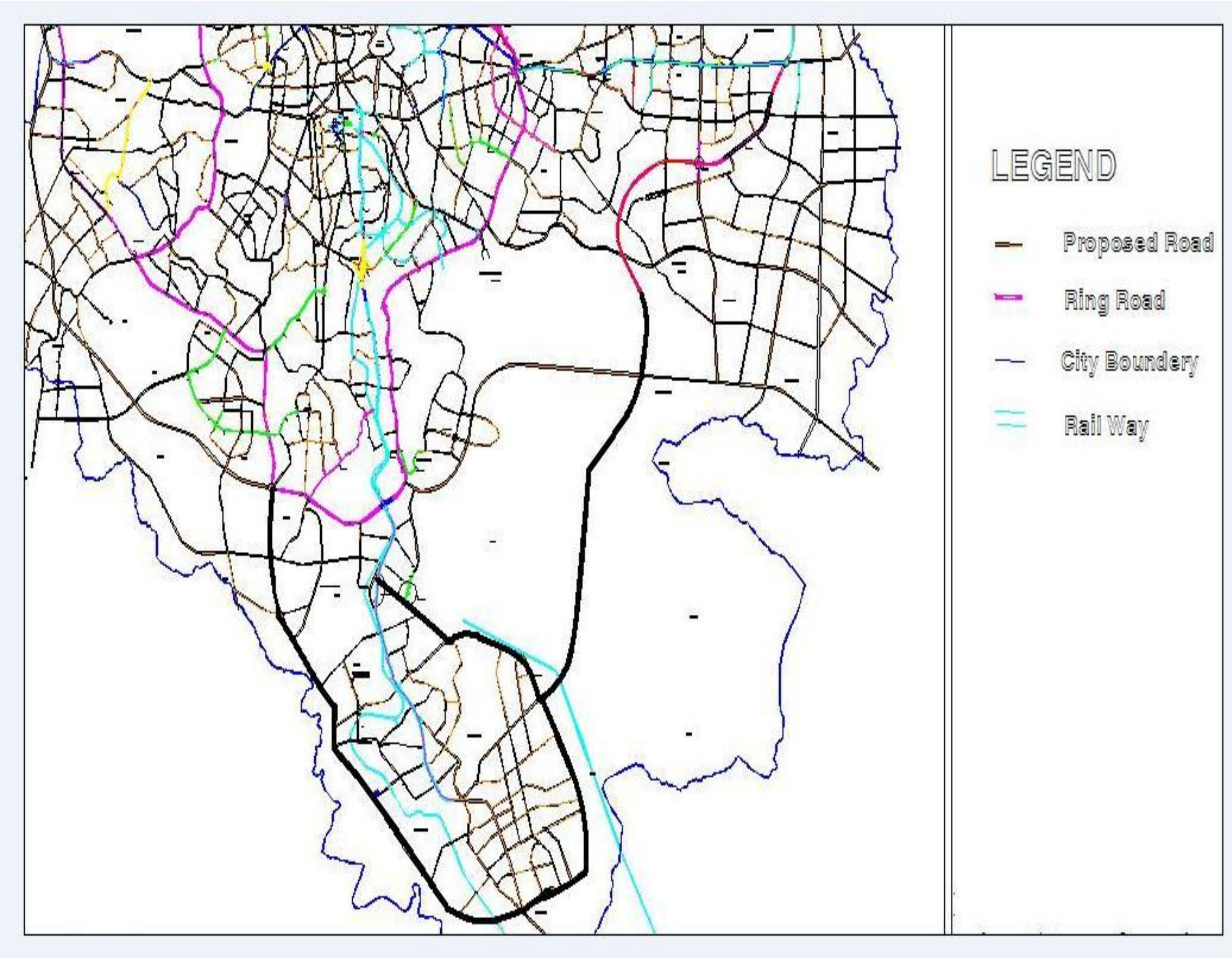


Figure 16: Nortek Map of Addis Ababa and its Administrative Boundaries

Figure 17: Pictures of stacked truck due to mechanical problem blocking the main carriageway and forming very long queue

As shown in the picture above a truck encountered mechanical problem during manoeuvring around Kidanemeheret area and blocked the two lane dual carriageway. The consequence was having long queue which extended up to around Kality Bridge. Fortunately this incident was not during pick hour, otherwise if it was during pick hour the effect could have been more pronounced.

- The existing Akaki –Kality road does not have walkway for pedestrian: due to this reason on areas where the carriageway has two lane in each direction, are functioning as single lane

Figure 18: Existing Akaki –Kality road that does not have walkway for pedestrian and are functioning as single lane

- The existing Akaki – Kality road does not have bus bays, while there is big fleet of public transport and the result is encroaching one of the lanes for loading and unloading passengers which results in long queue formation.

Figure 19: As there are no bus bays along the segment one lane is currently dedicated for loading and unloading passengers which results in long queue formation.

- Have frequent uncontrolled at grade intersection. This scenario creates more frequent jams with worst effect during pick hour
- The outlet and inlet for this section is Kality Round about Overpass at inner ring road. It is the bottleneck for this road segment, which creates very long queue during pick hours. The major cause for congestion at this intersection is the inadequacy of the ramps towards and from the Ring Road, absence of auxiliary lane for taxi/bus stop on all legs, and inadequate number of approach lane from Akaki side. The ramps for outlet are used for parking of buses, where they block sometimes the traffic from the roundabout.

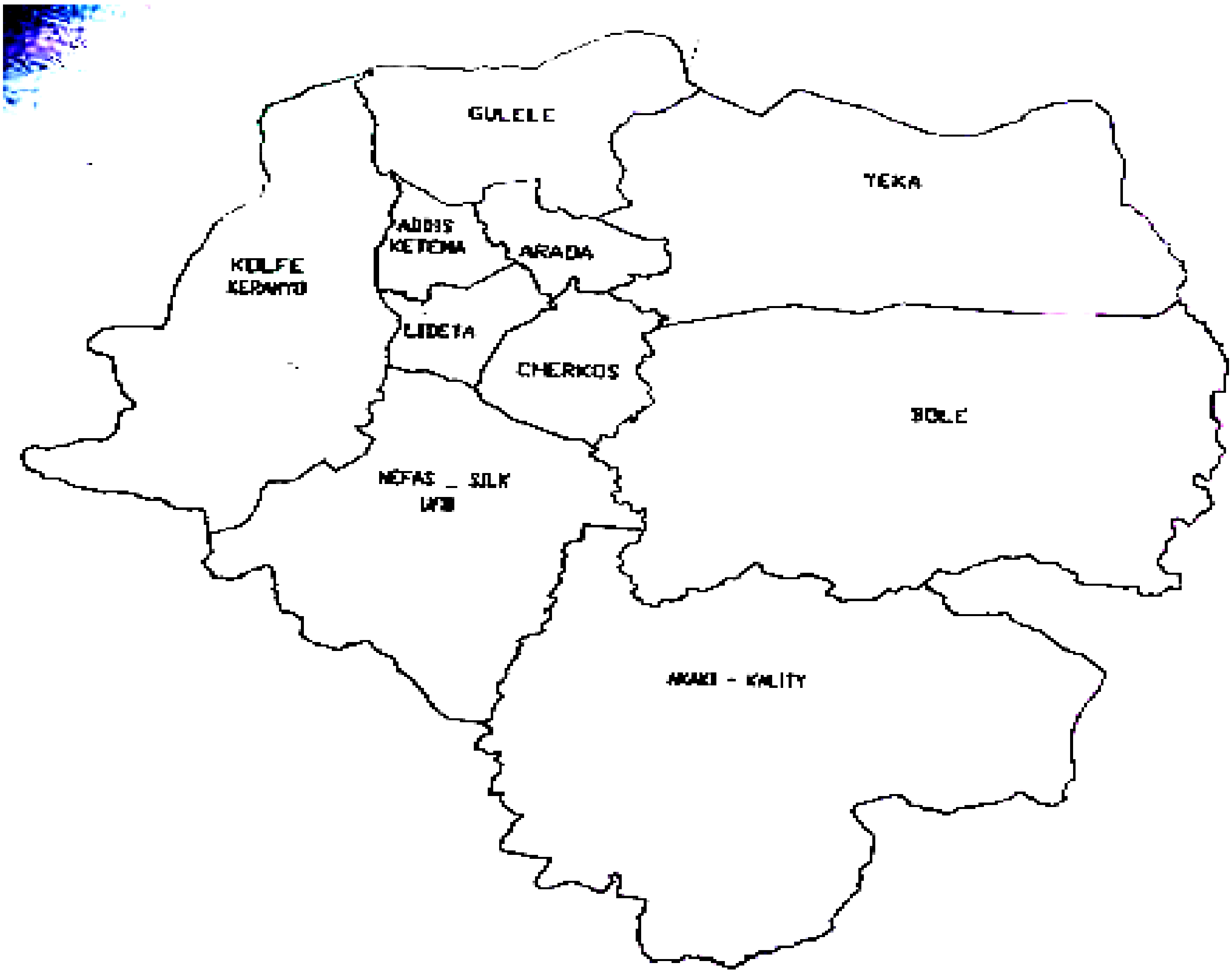


Figure 20: Addis Ababa boundary and the 10 Administrative Sub cities

3.1.2. Study Corridor: Tulu Dimtu – Dukem Bridge (13.7km) Segment

This segment of the road which is regarded as an intercity segment in this research work is totally administered under the Finfine Zuria Oromia Special Zone of the Oromia Regional State. The section is a sub urban as well as a rural type with an urbanization extension of Gelan and Dukem towns and expanding industrialization zones along these town sections. The dry port located at Gelan town is also one of the emanating factors for the commercial heavy traffic activities and hence congestion in the segment.

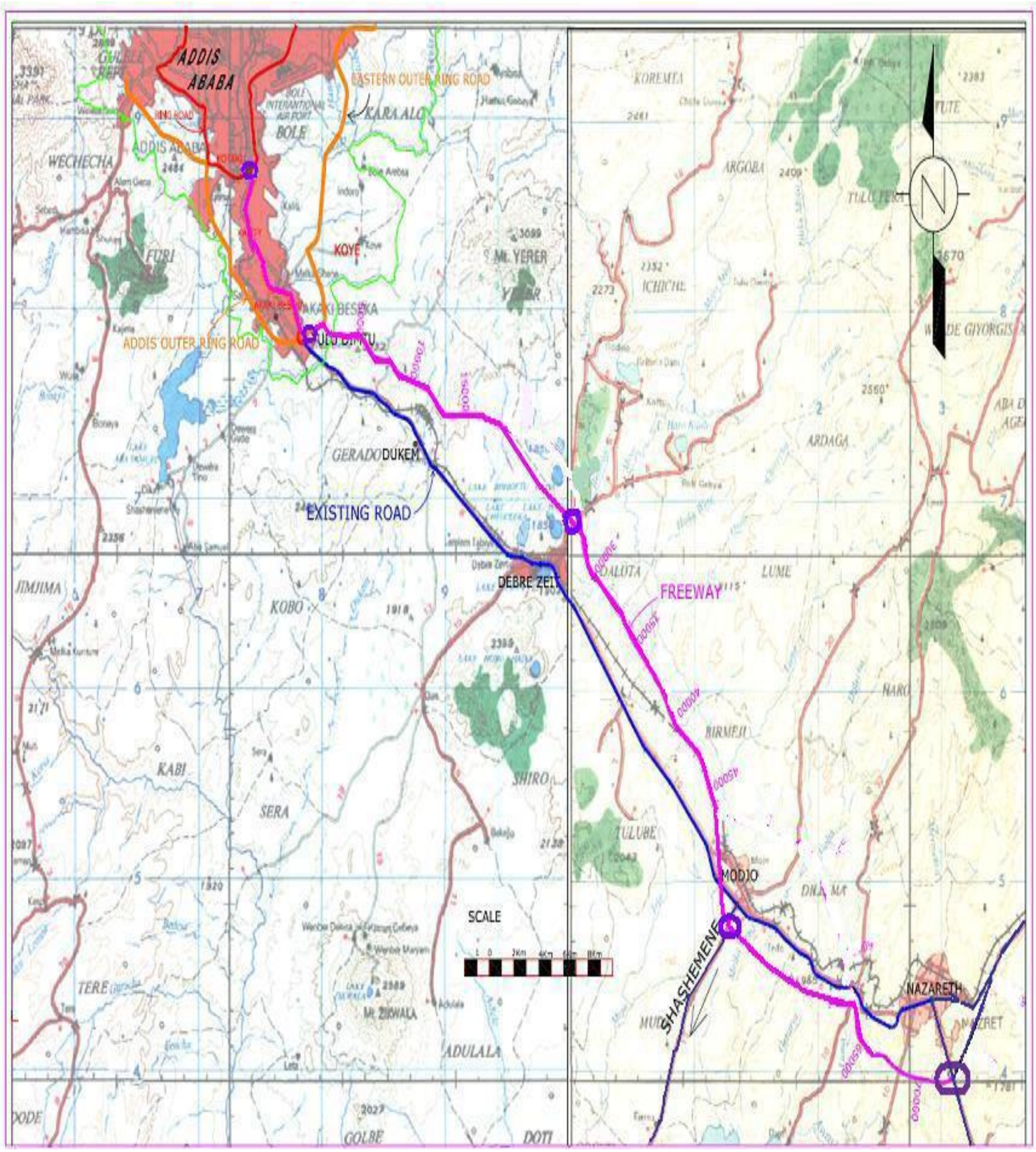


Figure 21: Road Map of the Project Corridor

3.1.3. Population Dynamics

According to the 2007 and previous census report the population of Addis Ababa is increasing at an alarming rate. The annual growth rate for 2007 was 2.1% and according to estimates the population number will be about 5 Million by 2020. Migration from rural area contributes more than half the population growth rate. For instance, in the 1994 censes, out of the 3.8% annual Population growth about 1.98% of the population growth was due to migration from rural areas (*9*).

Figure 22 below shows the population growth trend and population numbers during the last three national censes periods as well as the estimate for the year 2014.

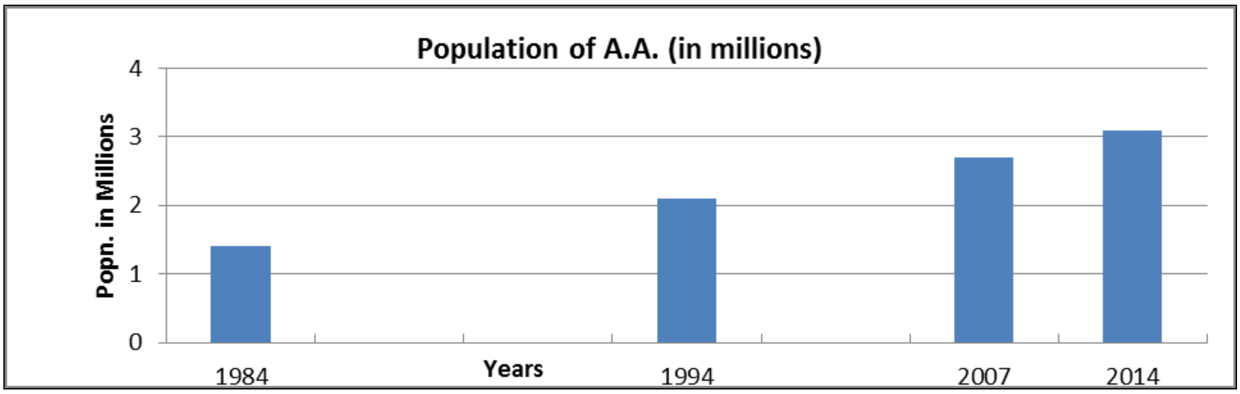


Figure 22: Population of Addis Ababa in millions [14]

3.1.4. Economic Activity and Trends in GDP

According to the International Monetary Fund (IMF)-World Economic outlook report April 2014 data, the real GDP growth of the country is summarized in figures 23 & 24 below. The data shows that the country recorded a double digit economic growth after and including 2004 up to 2011 and kept the pace despite the global economic recession during those periods.

As most of the economic activities in the country centers the capital city Addis Ababa and the periphery, such economic growth of the country obviously reflected in the cities economic activities. Therefore, we can conclude that the economic activity in Addis Ababa is increasing with equal or higher rate than the national economic growth rate.

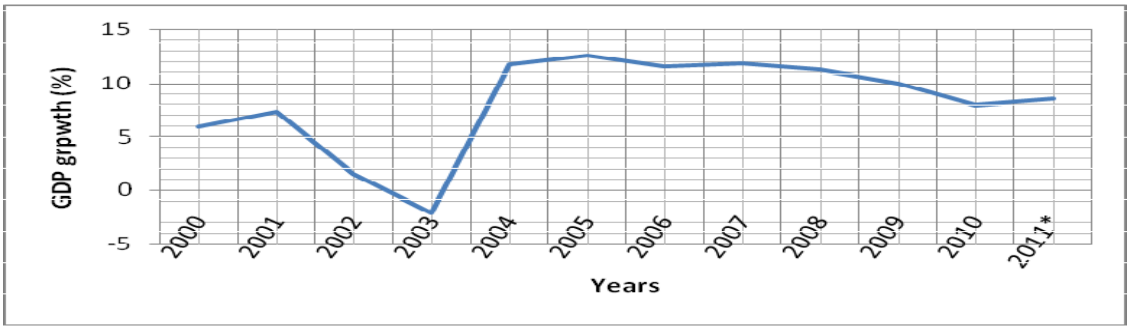


Figure 23: Real GDP Growth Rate of Ethiopia [16]

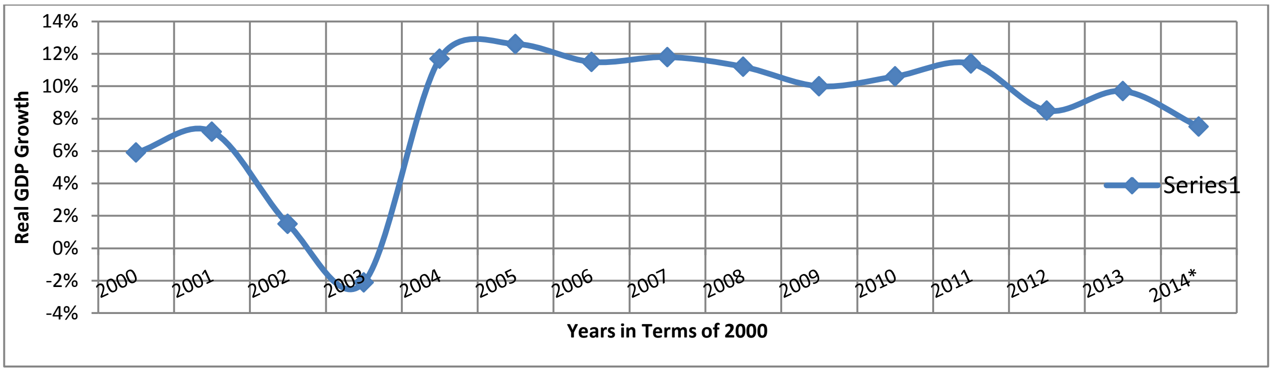


Figure 24: Real GDP Growth Rate of Ethiopia [16]

From the analogy of the referred sources, it is clear that the economic trend of both Addis Ababa and its periphery is expected to follow almost the same real GDP growth rate since the city Addis is serving both economic and administrative or political capital of the nation as well as seat for African Union and foreign diplomatic site.

For predicting the GDP of Ethiopia, an exponential model was developed which in turn gives a constant annual growth rate by considering the time period (year) as the independent variable and GDP as the dependent variable. It is seen that there has been an annual increase of around 8.1 % over a period of 11 years for Ethiopia in general and Addis in specific.

Addis Ababa and the periphery Oromia Special Zone through which the research corridor passes, contribute significantly of the country's industrial output. The observed relative differences in industrialization level have been used to forecast industrial growth rate by region in relation to the country-level industrial growth.

3.1.5. Traffic and Transport Operations in Addis Ababa and the Selected Periphery

Understanding the characteristics of the traffic and transportation system in the city Addis and the periphery helps to correlate and interpret the basic parameters and congestion exacerbating factors. Hence, essential data and resources regarding the vehicle ownership, the growth in vehicles number and the trend in traffic demand for Addis Ababa city can be seen from the view that the vehicle ownership per capita of the nation is the lowest in the world even below from the sub Saharan countries and the capital accommodates the lion share of those (about 80% of the total).

As there is no demarked data for the number of registered vehicles only for the capital Addis, about 80% vehicle population those are registered in the entire nation coded on regional basis are expected to contribute for the city's vehicle density. Most of them are commuter vehicles. Even the rest of them are expected to come and leave for a short time the city Addis for their business purposes.

Table 6: Number of Registered Vehicles in Ethiopia as of 2005 E.C. (2012 G.C)

Year of Registration/GC	Year of Registration/EC	Cum. Number Of Vehicles
Before 2002	Before 1995	116025
2002	1995	132420
2003	1996	147106
2004	1997	161620
2005	1998	176533
2006	1999	195286
2007	2000	287518
2008	2001	323153
2009	2002	361517
2010	2003	400660
2011 and 2012	2004 and 2005	452736

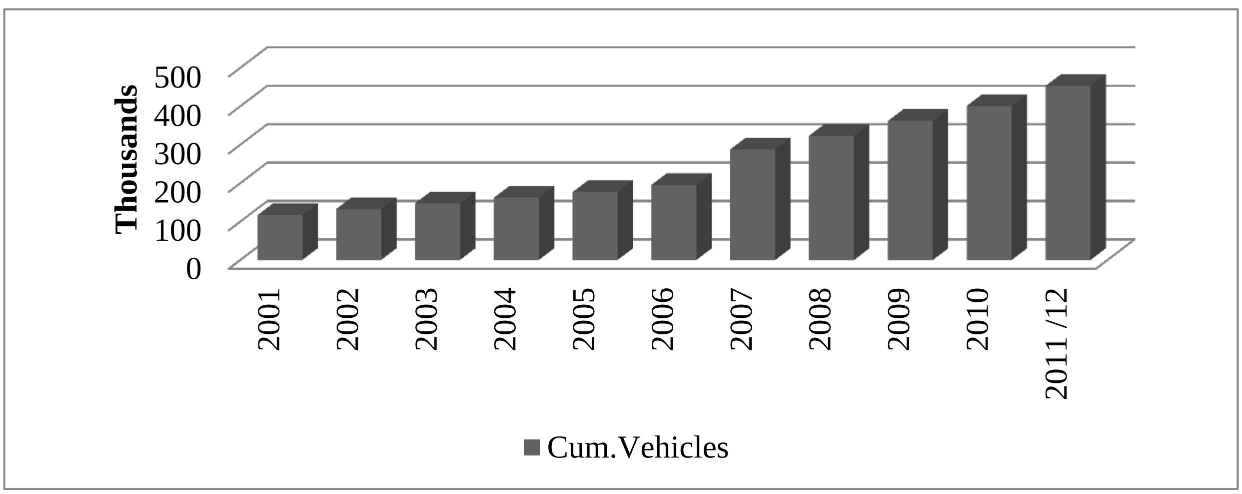


Figure 25: Cumulative Numbers of Registered Vehicles in Ethiopia till 2012 GC. (ERTA)

Despite the fact that the per capital vehicle ownership in the country is so small, data and reports from Transport Authority showed that there were 132,420, 195,286, and 452,736 registered vehicles in 2002, 2006, and 2011 respectively. Out of the total vehicles about 44% are private vehicles and the average vehicle number growth rate is above 5% *[31 & 10]*.

One of the interesting information stated on Urban Transport study final report is that about 80% of the total vehicles in the country are believed to be in Addis Ababa only. According to the estimate on the above document the projected vehicle number will be 231,556. Which means about 90,000 vehicles will join the road netw ork from 2005-2020. However, the absence of adequate public transport and the practices of vehicle assembling activity in the country escalate the vehicle ownership; hence, the estimate could be undermined and the value could reach to the said figure within few years as revealed in the years 2011/2, almost at half way of the estimate year that is the value 452,736 as shown in the following figure above:

3.1.6. Travel Demand Trend and Forecast

According to the result of Urban Transport Study (2005), the 2004 average daily person-trip in Addis Ababa was about 3.63 Million trips per day and out of which 60.5 % is walking and 31.5% of the trip was public transport leaving the private vehicle trip only 8%. However, the projection for year 2020 showed that the travel demand will increase by more than 100% and estimated to be 7.7 Million trips per day.

Table 7: Travel demand for the year 2004 and for projected year (2020) [10]

Mode	Share of Person Trip per Day			
	Base Year 2004		Horizon Year 2020	
	Trip (Million)	%	Trip (Million)	%
Walk	2.03	60.5	3.5	45.45
Public Transport	1.06	31.5	3.5	45.45
Private Vehicles	0.27	8.0	0.7	9.10

Furthermore, as shown in the following Figure 26 the travel demand along the corridor is significantly high showing the fact that this corridor links the industrial zones and highly populated residential areas with the trip attracting institution along the corridor.

In summary, facts and data showed that the transport demand in Addis Ababa is by far higher than the supply and hence, the number of vehicle joining the cities road will increase with considerable rate. Furthermore, some of the parameters discussed above which are related to the traffic congestion shows an increasing trend. The parameters which affect the traffic congestion level discussed above are summarized in the following Table 8.

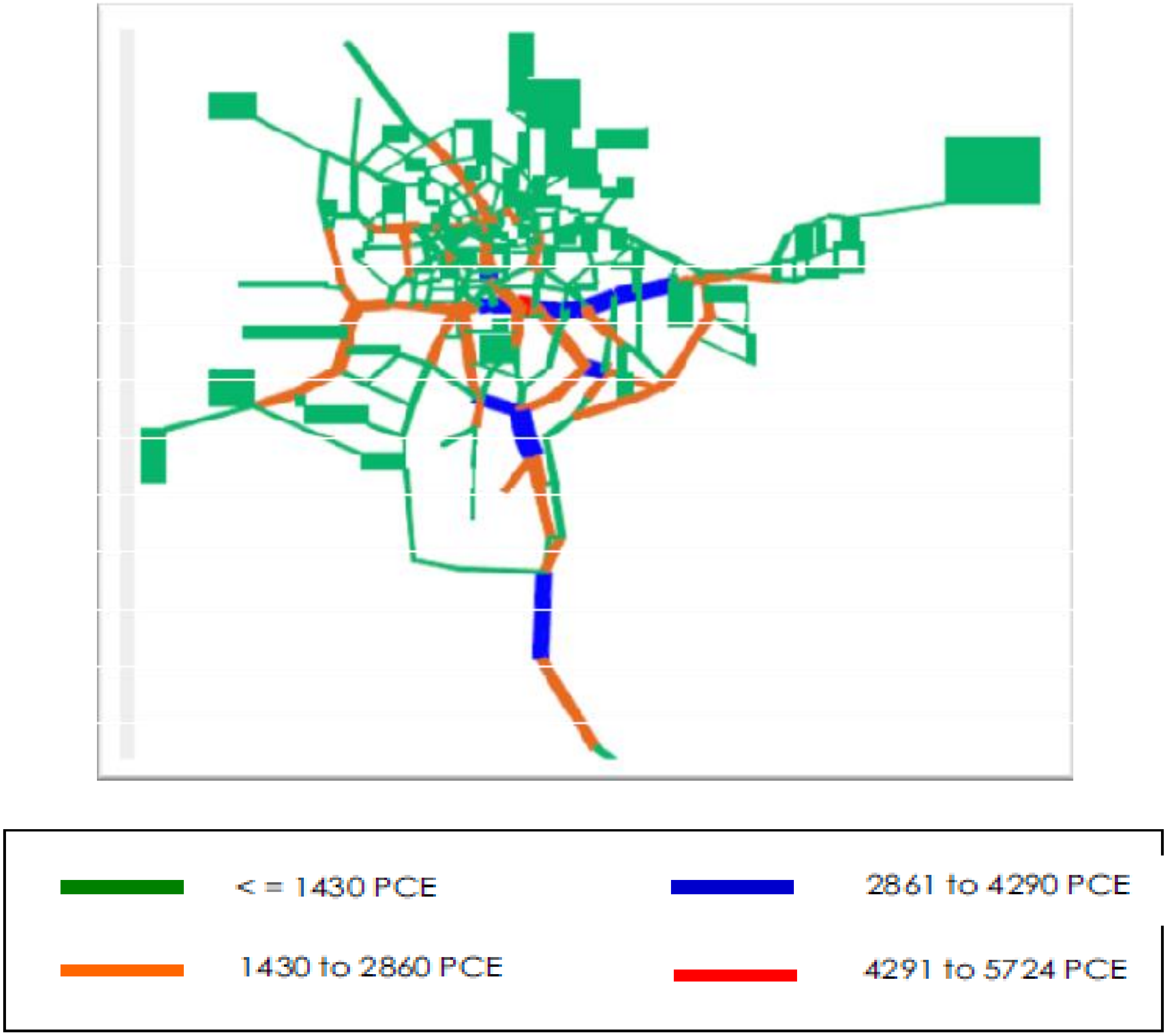


Figure 26: Traffic flow in Passenger car unit – [10]

Table 8: Summary of Trends in Addis Ababa – [10]

Parameter	**Trend**
Population	Increase by average annual rate of 2.1%
GDP	Average yearly GDP of 8.5%
Vehicle Number	Increase 5% yearly
Travel Demand	Will increase by 106% in 2020

3.2. Research Approach

The research approach in this thesis involves both quantitative and qualitative approaches. Quantitative data and analysis were used to determine the level of service of intersections and to measure the congestion levels quantitatively. Observation, direct field measurements and secondary data were the main sources of quantitative data. Furthermore, qualitative data from questionnaire were also used to determine whether the congestion in the segment is considerable or not and to assess other related parameters.

Observations, collecting relevant data and subsequent analysis of the data help to generate inductive conclusions on the level of congestion at the observed or considered road sections. Though it is impossible to assess the traffic congestion at all stretches in the Addis Ababa to Modjo road section, representative segments could be taken along the route to derive a generalized conclusion. However, in this research the segments and road sections considered are both the city section Addis to Tulu Dimtu and the intercity segment Tulu Dimtu to Dukem Bridge; which is connecting towns of highly populated residential ends and inhibits one of the nation's largest Exim corridors.

In this thesis the methods followed were designed in such a way that the key questions of the research be answered properly. As it shown in figure 27 below, in order to assess whether the road sections or segments are congested or not; a key question "*Does traffic congestion exists at this segment*?" was raised and answered first using congestion indicator parameters. The congestion indicator parameters used in this research were Level of Service (LOS) and road users' perception. The LOS criterion are according to HCM-2000 and determined using the parameters on the same manual and the road users' perception was collected using questionnaire by adopting the current condition of the segments under study. The general organization of this thesis is presented in detail on section 1.5.

Flowcharts for the Research Approach

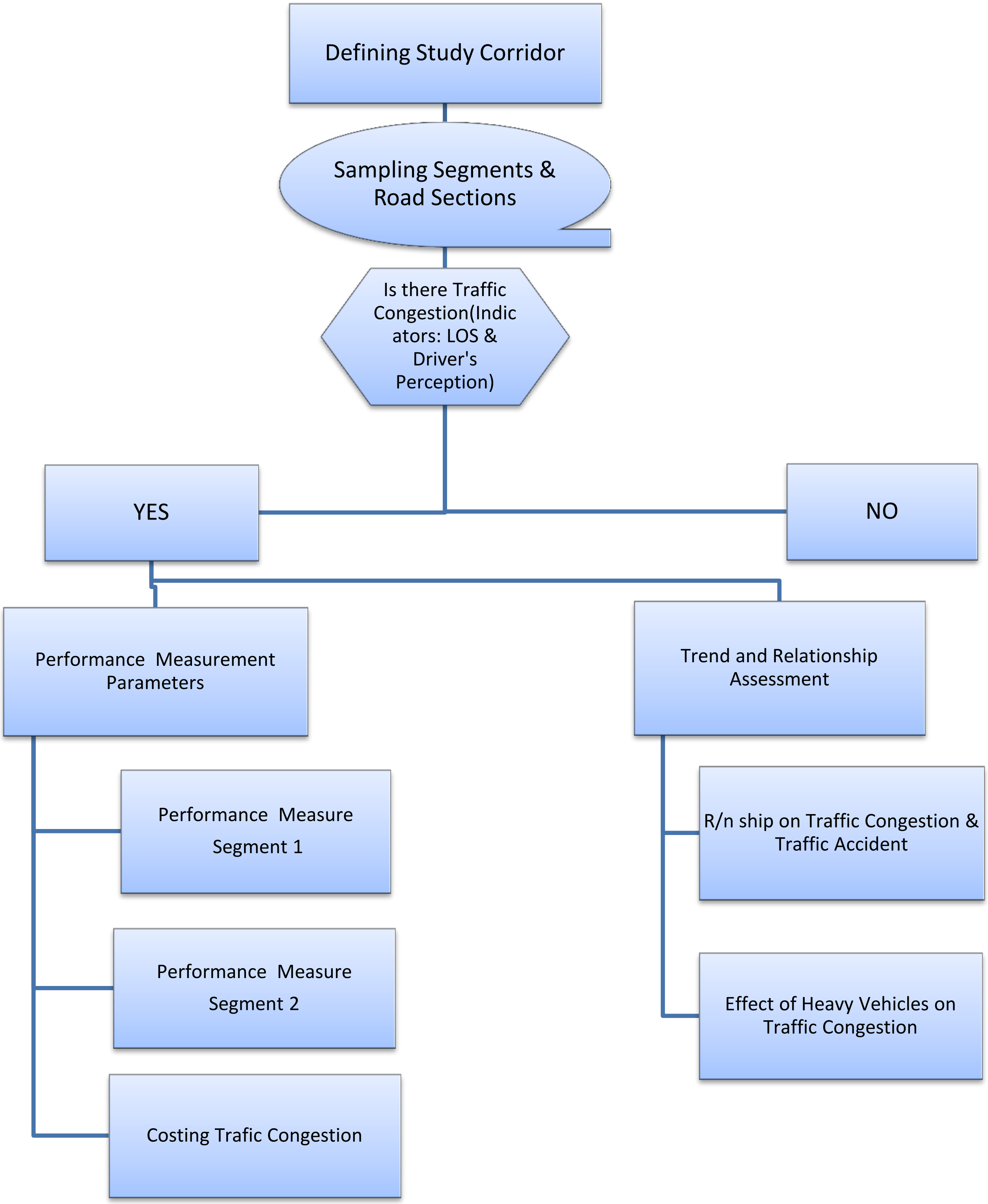


Figure 27: Framework for Level of Congestion & LOS Analysis

Methodology for Two -Lane Highways in Class I Facilities

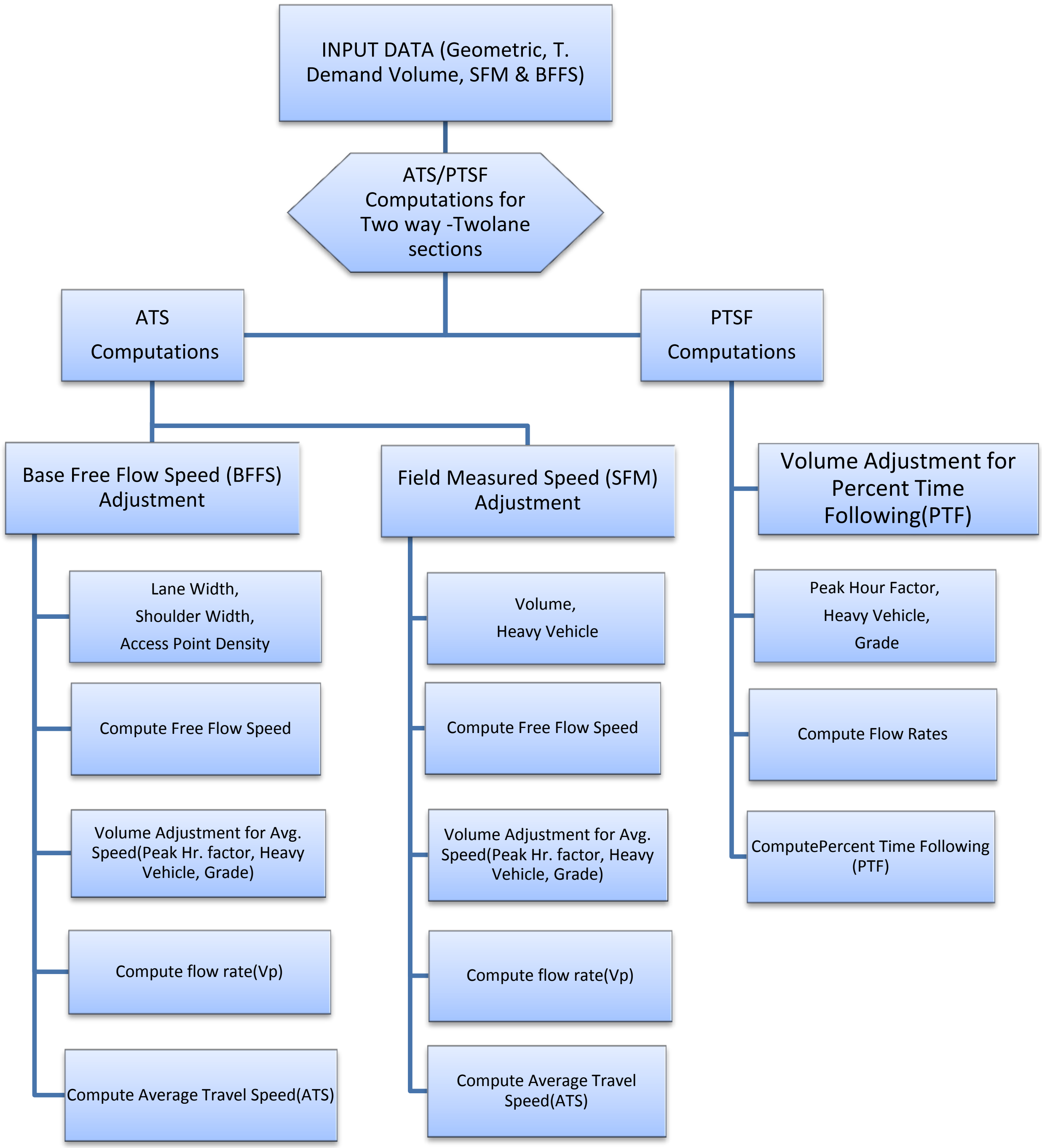


Figure 28: Analysis Approach for Two - Lane Highways

Note: **BFF** Base Free-Flow speed adjustment is used since the measurement procedures for **SFM** Field Measured Speed is not as such practical in this stretch due to the prevailing traffic jam during traffic speed data collection

Analysis Methodology for Multi-Lane Highways

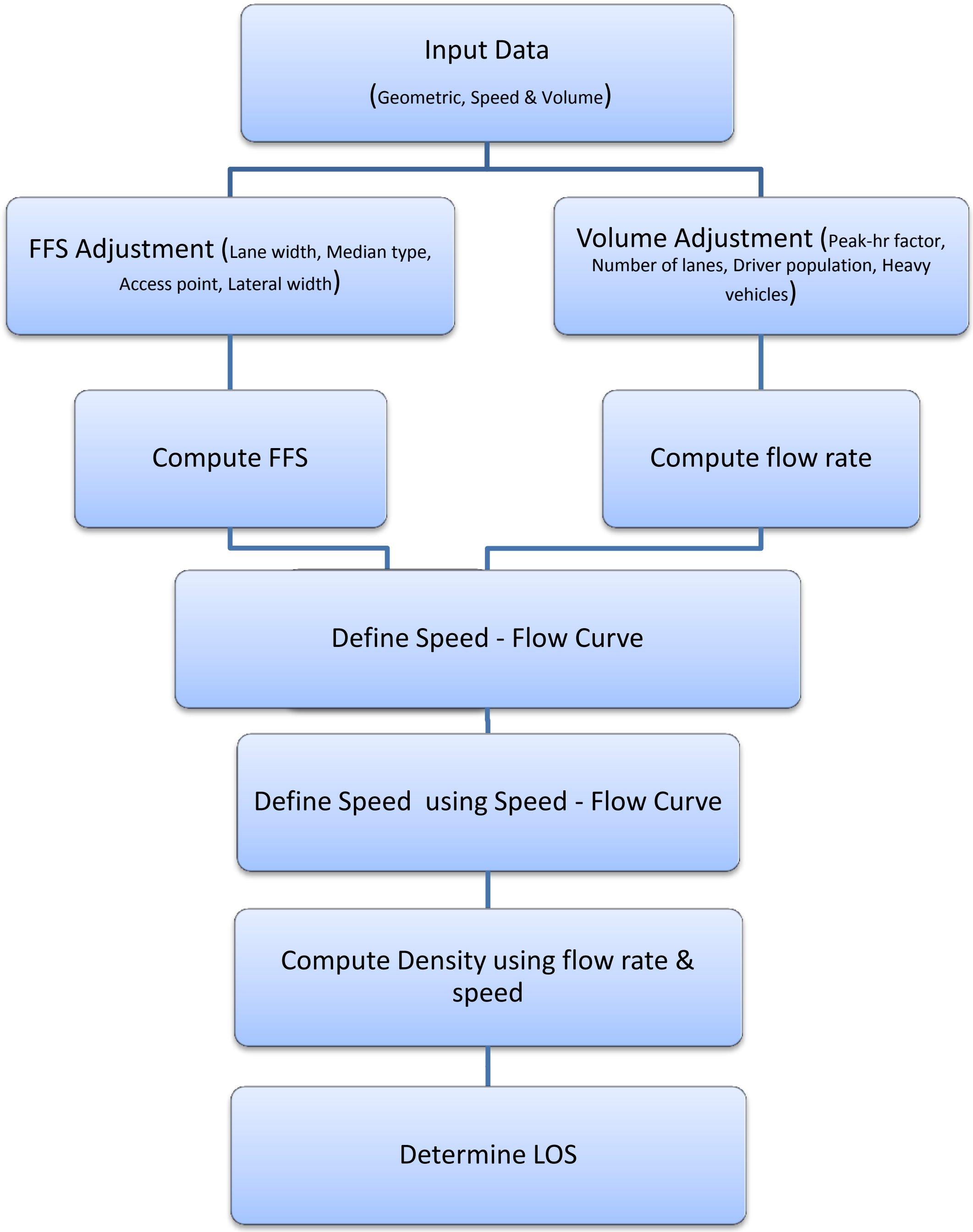


Figure 29: Analysis Approach for Multi-Lane Highways

The procedures in this section are used to analyze the capacity, level of service (LOS), lane requirements, and impacts of traffic and design features of suburban multilane highways.

3.2.1. Base Conditions for Multilane Highways

The procedures in this section determine the reduction in travel speed that occurs for less-than-base onditions. Base conditions under which the full speed and capacity of a multilane highway is achieved are good weather, good visibility, and no incidents or accidents.

3.2.2. Base Conditions for Highway Flow

Studies of the flow characteristics of multilane highways have defined a set of base conditions for developing flow relationships and adjustments to speed. The base conditions for multilane highways are as follows: [17]

- 3.6 m minimum lane widths,

- 3.6 m minimum total lateral clearance in the direction of travel. This total represents the lateral clearances from the edge of the traveled lanes to obstructions along the edge of the road and in the median. Lateral clearances greater than 1.8 m are considered in computations to be equal to 1.8 m,

  - only passenger cars in the traffic stream,
  - no direct access points along the roadway,
  - a divided highway, and
  - free-flow speed higher than 100 km/h.

  These base conditions represent the highest type of multilane rural and suburban highways.

3.3.3. Limitations of the Methodology

The methodology in this chapter does not take into account the impact of the following conditions:

- transitory blockages caused by construction, accidents, or railroad crossings,
- interference caused by parking on the shoulders (such as in the vicinity of a country store, flea market, or tourist attraction),
- three-lane cross-sections,
- effect of lane drops and additions at beginning or end of segments.

Possible queuing delays when traffic transitions from a multilane segment to a two-lane segment are neglected,

- differences between median barriers and two-way left-turn lanes, and
- free-flow speeds below 70 km/h.

3.3. Data Collection Techniques and Equipment

Different types of data were collected for the purpose of this research mainly through primary sources and some data were acquired through secondary sources. For the primary data collection internationally reputable and recommended techniques of traffic data collection were used.

1. Video Recording with Manual Transcription
2. Manual Traffic Volume Count at Different Sections

In addition to the above traffic flow data collection techniques other field measurements were done to gather data on the geometrical features of the segments for capacity analysis. These include, number of lanes, lane width, configurations of lanes, grade, width of median, movement policy e.tc. These measures were done for the segments whose level of service or LOS is going to be determined.

The other kind of primary data collection technique used was questionnaire type. A structured questioner was developed to gather additional information on the perception of road users' about the segments traffic congestion. The questionnaire also helped the researcher to identify congested segments both in the city as well as the intercity road sections and the possible causes of traffic congestion on the same. The questioners were distributed randomly for road users (mid bus drivers, private car owners, public transport users and commercial heavy vehicles drivers) along the road corridor.

3.3.1. Video with Manual Transcription

Video recording and manual transcription or tracing were used to collect travel time data. This method of travel data collection relies on video cameras to collect or capture the traffic flow in the field and human personnel to transcribe or trace vehicles into a database at the office after the actual time of data collection. According to travel time collection handbook; though it is costly, Video capturing techniques is preferred over the manual collection (pen and paper method) because it:

- provides a permanent, easily-review record and show the traffic conditions at any time;
- permits the reading of required parameters in a controlled environment in which plate characters can be closely examined;
- provides additional information about traffic flow characteristics such as traffic volume and vehicle headway; and
- can provide a time stamp for accurate determination of arrival times.
- has better accuracy than manual methods; and
- enables to capture a larger sample of the total number of vehicles.

Therefore, in order to exploit the above advantage and due to its convenience video cameras with tripod were arranged at convenient height where maximum possible view could be captured and visibility was maximized. The locations for video capturing were the roof & floors of high-rising buildings alongside the study sections. Figure 30 below shows the camera setup at one of the locations.

3.3.2. Video Capturing Equipment and Setup

Figure 30: Typical Arrangement of Video camera during recording

3.3.3. Manual Traffic Volume Count

Manual traffic counts were conducted at different locations (road mid blocks) to determine the directional traffic volume and flow at every 15 min. Furthermore, vehicle occupancy study was conducted using manual count method at different road mid-blocks and segments. However, except one week time continuous traffic count, the other traffic counts were not directly done by the researcher. The traffic counts were done by the Ethiopian Roads Authority in three seasons for each year and the raw data was availed to the researcher. The data was manipulated and transformed to the required size for the analysis.

Therefore, from this data collection the following quantitative data were generated. These include,

1. Directional Traffic Volume/Flow per 15 Min of Interval for the Two Segments or Road Mid-Blocks and
2. Vehicle Composition along the Segment

In addition to the primary data acquired in the above methods, some secondary data; mainly on traffic accident, vehicle population, population and economic growth parameters were taken from other literatures and reports. The sources of these secondary data are properly acknowledged at their respective locations.

3.4. Data Collection

To attain the objectives of this research, different types of quantitative and qualitative data namely; traffic flow or volume data, vehicle occupancy data, road geometric data, traffic accident data and road users' congestion perception data and causes of traffic congestion were required. Despite the challenges, an attempt was made to collect the data using the techniques stated in the methodology and described below at each section. As there is no a trend in the country for a permanent data acquisition and computerized system in any of the field operating system, acquiring data is highly challenging and costly. Hence, it was difficult to gather primary data at all stations or congestion spots along the stretch. Rather possible representative road sections were considered along the study corridor.

This section of the study discusses how data was sampled, collected and extracted from the data source and also presents the gathered primary and secondary data by systematically organizing and summarizing using standard formats.

3.5. Traffic Volume Data

Traffic volume and vehicle occupancy data are very important to determine and understand the flow pattern in the facility, to determine the peak flow rates and peak periods, to assess the relationship between traffic volume and congestion. Furthermore, it is extremely required to analyze the level of service of a facility and quantify the congestion intensity. Hence, acquiring a traffic volume data at selected road sections and intersections in the study corridor were mandatory and luckily enough, the raw data was available at the Ethiopian Roads Authority which was collected for their own purpose.

The traffic count was directional and hence directional traffic flow characteristics can be easily summarized and studied. As travel time data was averaged for all vehicles type and a single travel time was considered in the 15 min time interval as discussed before, it is also necessary that the vehicle volume count should be converted to passenger's equivalent unit to conduct congestion analysis. Since the three specific objectives of the thesis are somewhat broader by themselves, the secondary sources Passenger Equivalent Factors with some conditional modifications were adopted to convert the traffic volume count in to PCU. The traffic volume in PCU is summarized and presented at appendix A.

3.6. Questionnaires Response

A structured questioner was prepared in order to gather additional information for the congestion analysis. As congestion is a function of people's perception toward their time and their trip purpose, it was necessary to gather information and data on how the road users in my project or research corridor perceive the current traffic congestion and know how much delay is acceptable for them.

According to the definition by Lomax (1997) congestion is a travel delay in excess of the acceptable travel time. Hence, according to this definition the road user's element should be included to define the demarcation between congested and uncongested. Hence, the structured questioner was distributed randomly for road users (Taxi drivers, passengers, Traffic polices, company owners, lecturers and other peoples) mainly in the east-west corridor. Furthermore, respondents also requested to list at least 5 congestion spots they know and to prioritize the possible congestion causes identified from literature and asked if there was other possible congestion cause in the city.

The questioners were distributed through e-mail, through interview-questioner (the data collector interview the respondent while filling the questioner) and distributing for respondent. Accordingly, about 70 questioners were distributed and 45 were returned and analyzed. The researcher believes that statistically significant samples should be considered to draw conclusion out of analysis made on such questioner data. However, due to the fact that most of the basic analyses in this research are based on the quantitative data described before and the data on the questioner are a supplement for the result, the respondent size would be sufficient for the purpose of this study.

3.7. Traffic Accident Data

Traffic accident rate in Ethiopia is one of the highest in the world. Girma B. (2000) showed that out of the total accident in the country about 62% of the total accident occurs in the capital city Addis Ababa. Data and documents show that the traffic accident in the city is alarmingly increasing and different researches were made in this regarded. Most of these researches showed the relationship between traffic flow and traffic accident. However, none of them identify the relationship between traffic accident and traffic congestion. Hence, in this study, in order to see the relationship between traffic accident and traffic congestion, different accident data were collected from secondary data. The most important data collected from secondary sources are:

1. Accident Data/Report (from Addis Ababa City (12 years), Akaki Kality Subcity (4 years) and Finfine Zuria Oromiya Special Zone (6 years) Police Commissions)
2. Accident data by Type of Accident
3. Addis Ababa City Accident Black spot map which was prepared by National Road Safety Coordination Office

4. 0. DATA ANALYSIS AND RESULTS

The analysis was made on the gathered quantitative and qualitative data to look in to the trend of the traffic flow with in the day and identify the peak period and peak hour volumes. The level of service for the identified intersections was analyzed using HCM manual and the segments were checked if they fall as congested or not congested based on HCM 2000 criteria. Congestion analysis also made on the sections where the travel time data was collected and the results interpreted and discussed. In the congestion analysis, parameters for quantifying congestion were calculated based on travel time approach for each section. Finally, the relationship between traffic accidents with Traffic volume was seen and a regression equation was generated.

4.1. Traffic flow pattern and vehicle composition analysis at segments

4.1.1. Directional Traffic Volume

A directional traffic volume analysis was conducted on a traffic volume data which is counted at 15 min interval and for 12 solid hours of a day starting from the early morning to the late afternoon. The traffic volume analysis is done for both direction and for two segments along the research corridor. The road sections or the segments considered are:

1. Kality (*Maseltegna*) – Akaki (*Tulu Dimtu*) Segment which is the city/urban section
2. Akaki (*Tulu Dimtu*) – Dukem Bridge Segment which is the intercity/sub urban section

Sample traffic volume data for the above two segments are summarized for all class of vehicles and reported as hourly volume in the Table 9 below.

Table 9: Directional Hourly Traffic Volume within the Segment 1 (5:00-6:00 PM)

	Count at Kality (*Maseltegna*) area		Count at Kality (*Bus Station*) area	
Vehicle Types	**North Bound**	**South Bound**	**North Bound**	**South Bound**
Car	290	202	243	320
Land Rover	283	292	158	231
Small Bus	368	398	438	500
Medium Bus	58	161	19	53
Large Bus	45	83	23	31
Small Truck	64	108	112	91
Medium Truck	91	74	9	52
Heavy Truck	98	52	83	105
Truck & Trailer	241	156	71	82
Total Hourly	1538	1526	1156	1465
Total (PCU) hrly	10336	9907	6825	8645
Total Hvs.	597	634	317	414
Total Hvs.(%)	38.82	41.55	27.42	28.26

4.1.2. Kality (Maseltegna)-Akaki (Tulu Dimtu) Segment Volume

This section of the road starts at the Kality (Maseltegna) and passes through with the busiest industrial center Akaki/Kality area. This road section carries traffic from the residential, industrial, regional as well as cross border areas of the south eastern section of the nation to the commercial body district of center of Addis the capital.

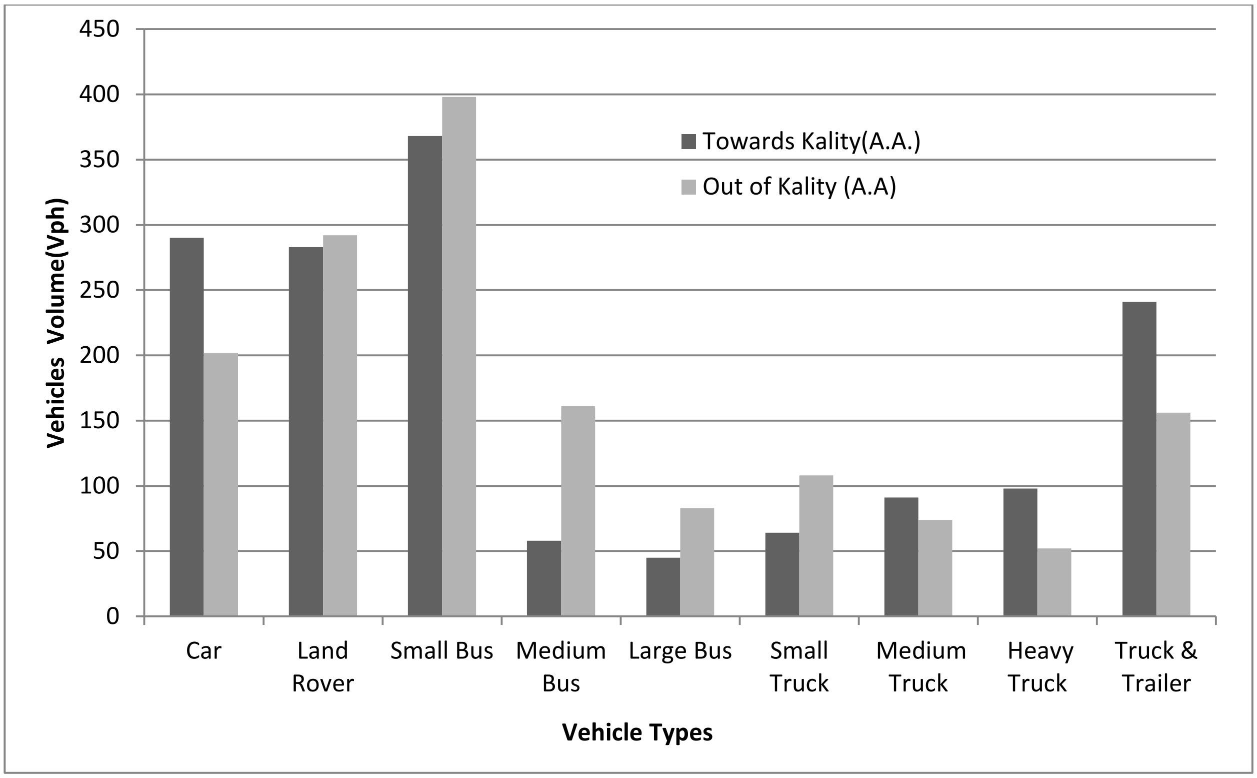


Figure 31: Traffic Volume by vehicle type in Segment 1

In this road section, most of the vehicle share is occupied by the five vehicle classes, private cars, land rovers, mini bus taxi and mid buses as well as heavy truck trailers.

4.1.3. Directional Traffic Flow on Akaki (Tulu Dimtu) - Dukem Bridge

Table 10: Directional Hourly Traffic Volume within the Segment 2

Vehicle Types	Count at Akaki Custom(*Tulu Dimtu*) area (*9:00*-10:00 AM)		Count at Glan (Town *Center*) area(*5:00*-6:00 PM)	
	North Bound	South Bound	North Bound	South Bound
Car	236	179	93	122
Land Rover	161	102	68	107
Small Bus	247	142	99	154
Medium Bus	17	15	17	28
Large Bus	7	3	10	26
Small Truck	75	34	58	49
Medium Truck	30	35	9	18
Heavy Truck	223	72	61	79
Truck & Trailer	95	61	68	46
Total Hourly	1091	643	483	629
Total (PCU) hrly	7152	3595	3283	3986
Total Hvs.	447	220	223	246
Total Hvs.(%)	40.97	40.52	46.17	39.11

This road section is a link for the traffic from Akaki (*Tulu Dimtu*) in the sub urban section with the peripheral eastern industrial zones of Gelan and Dukem towns.

Furthermore, in this road section again most of the vehicle share is occupied by five vehicle classes, private cars, land rovers, mini bus taxi and mid buses as well as heavy truck trailers.

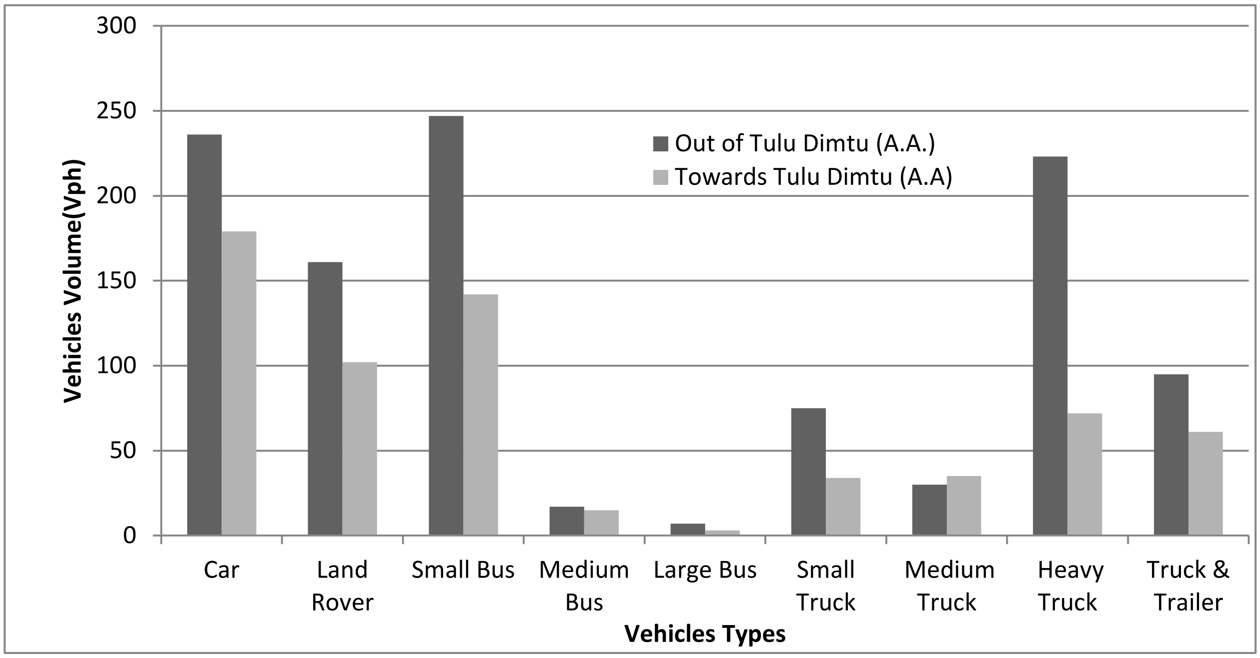


Figure 32: Traffic Volume by Vehicle Type in Segment 2

4.2. Segmental Analysis of Level of Service (LOS)

According to the methodology described above, first, it is necessary to justify that the segments and the road sections to be analyzed are in congested state based on accepted standards and norms. Accordingly, in order to check whether the segments are congested or not, analysis was made using HCM 2000 procedures. In order to analyze the LOS using the procedures, it was made with the options right-hand driving rule and HCM 2000 metric version which represent the driving rule of Ethiopia. The HCM 2000 metric version was chosen because it is widely accepted Highway capacity manual throughout the world with only minor modifications and calibration. Due to the availability of traffic flow data the level of service (LOS) was made for the two segments specifically where travel volume / time data was collected.

For the analysis purpose of the segmental level of service for the selected corridor a Two Ways – Two Lane Highway analysis procedures are utilized by subdividing the segment into two segments. That is, Kality (Maseltegna) – Akaki (Tulu Dimtu) Segment which is the city/urban section and Akaki (Tulu Dimtu) – Dukem Bridge Segment which is the intercity/sub urban section

Almost all the primary input information is gathered from the project road under analysis. These are in general the existing operational geometric feature of the highway, the current two way hourly vehicular volume, the directional split, the peak hour factor, the proportions of heavy vehicles existence, and availability of no-passing zones as well as existing access roads/points to the main corridor.

Available secondary data sources are accessed for the trend analysis purposes and to aid the research work especially twelve years traffic count data on the selected segments from Ethiopian

Roads Authority Traffic Count Team. Annual variations on the traffic volume are hence seen from these secondary data sources.

Table 11: Assumptions for the Analysis of Level of Service (LOS)

S.No.	Start Location	End Location	Length (km)
1	A.A. Center (Georgis)	Kality Ring Road (Maseltegna)	12
2	A.A. Center (Georgis)	Akaki R.Bridge(T. Beijing H.)	20
3	Kality Ring Road (Maseltegna)	Akaki (Tulu Dimtu)	11.2
4	Kality Ring Road (Maseltegna)	End of Town section (Total)	6.0
5	End of Town section (Total)	Akaki (Tulu Dimtu Check Point)	5.2
6	Kality Ring Road (Maseltegna)	Debre Zeit/ Bishoftu	33
7	Kality Ring Road (Maseltegna)	Modjo Town	66
8	Akaki (Tulu Dimtu)	Dukem Bridge (North)	13.7

Table 12: HCM uses the following PCE factors for different Terrain Types

Measurement Unit (PCE/PCU)	Terrain Types or Classes		
	Level	Rolling	Mountainous
Recreational Vehicles (ER)	1.2	2.0	4.0
Trucks (ET)	1.5	2.5	4.5
Truck & Trailers (ETT)**	2.5	3.5	5.5

*** Expected PCEf for Truck -Trailer as per the sizes/dimensions relative to recreational vehicles (buses) & those of normal trucks.*

- Since Rolling Type Terrain Class dominates, the researcher used the PCEf or PCU for the same rolling terrain class.
- Car category includes both the volumes of cars and pick up, land rovers, and the likes.
- Bus includes all types of buses irrespective of their sizes small, medium and large buses in the category.
- Truck includes all types of trucks irrespective of their sizes small, medium and large trucks in the category.
- Articulated trucks are termed as truck trailers and used as they are
- For Heavy Vehicles proportion, two classes of heavy vehicles are considered; namely, Trucks (Small, Medium, Large) & Buses (Large) in one class and Recreational Vehicles (Small, Medium) buses in another class.

Annual Variations on the Traffic Volume in AADT on Kality to Tulu Dimtu (Seg. 1) [2]

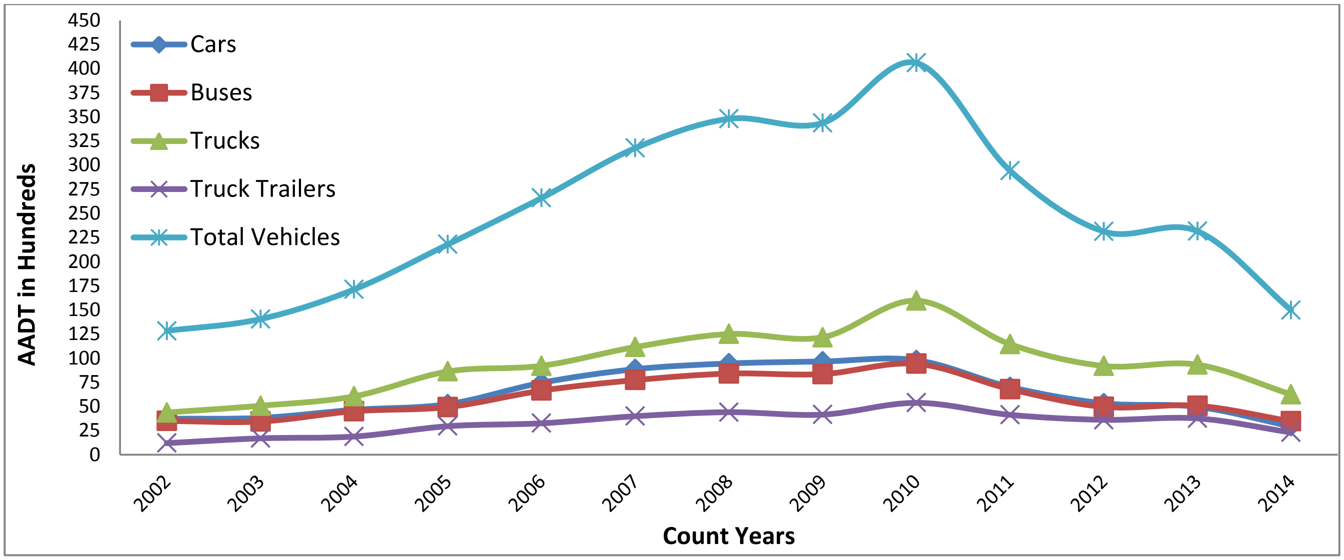


Figure 33: Traffic Volume by Count Years for Segment 1[2]

Annual Variations on the Traffic Volume in AADT on Tulu D. to Dukem B. (Seg. 2) [2]

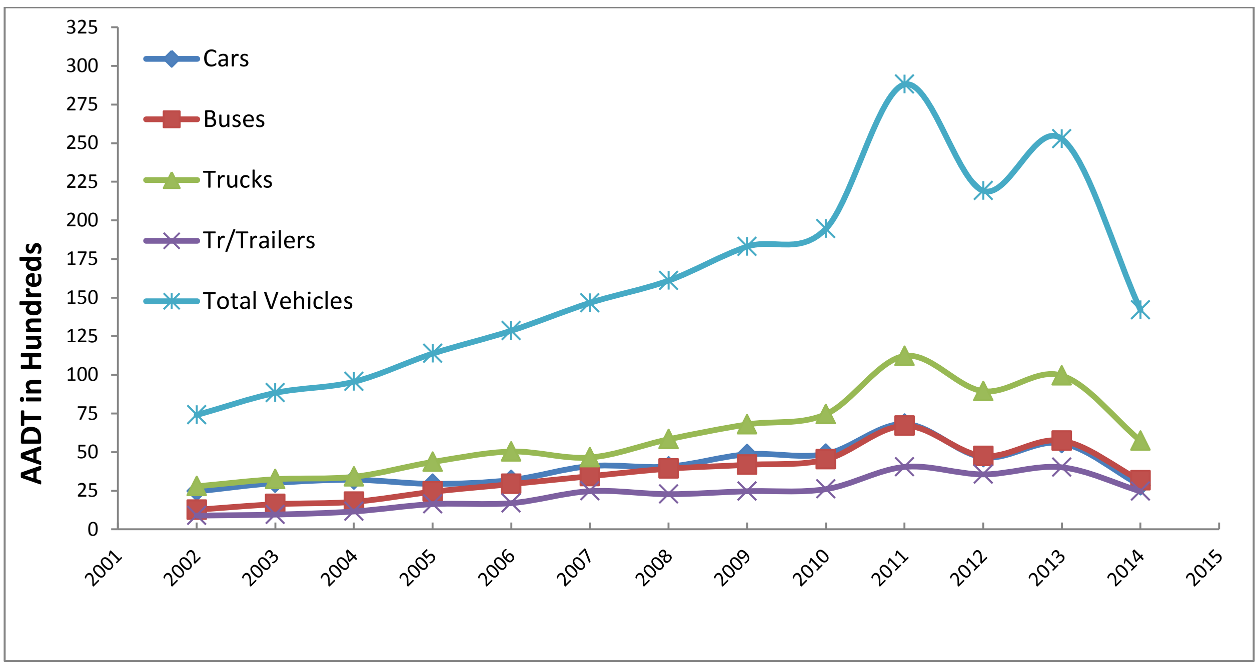


Figure 34: Traffic Volume by Count Years for Segment 2[2]

The reduction in AADT in both segments may be expected as the booming economic and industrial developments in the regional cities as well after the years 2012/2013.

Relative Percentage Vehicle Growth Representations on the two selected Segments

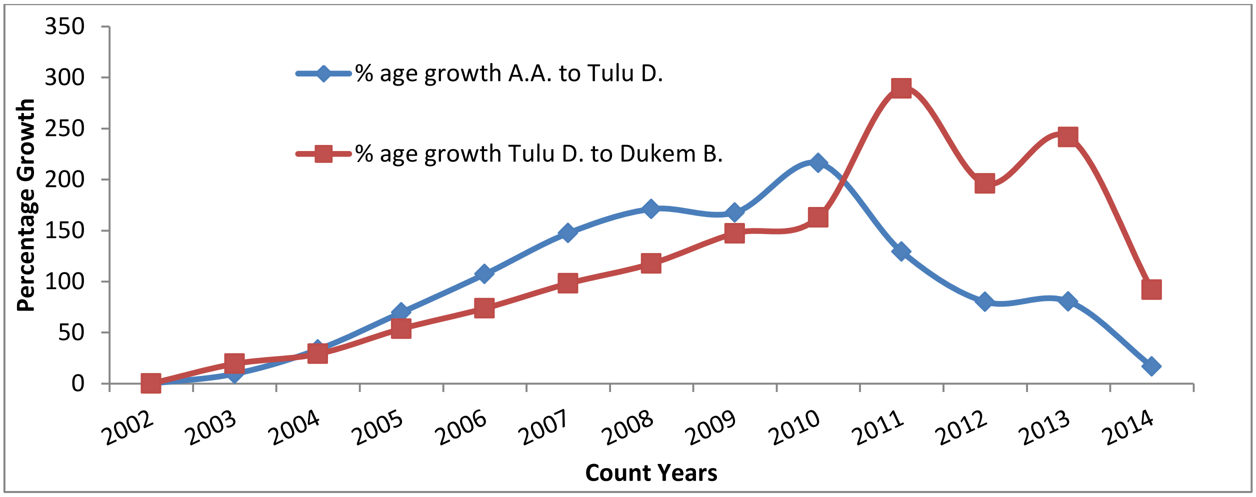


Figure 35: Relative Vehicle Growth in the two Segments

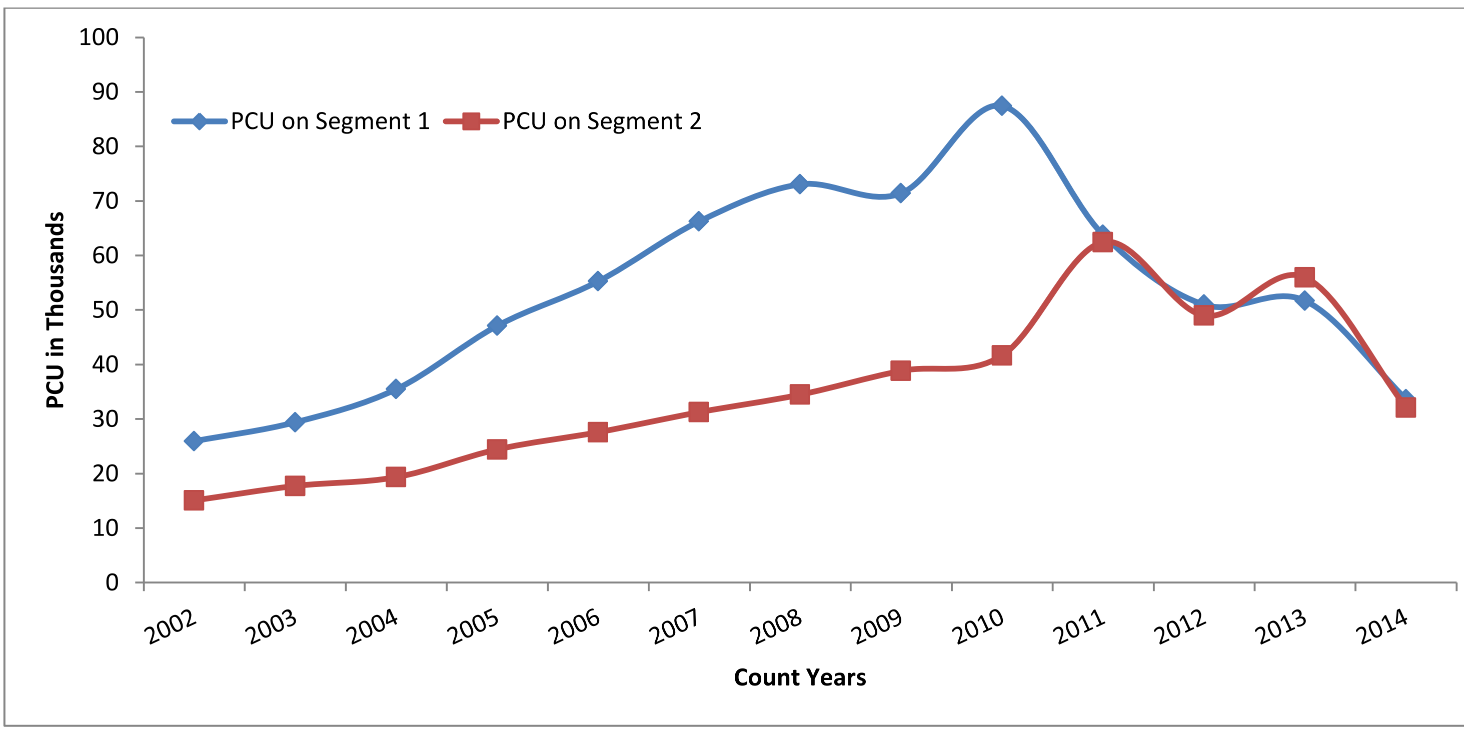


Figure 36: Relative Passenger Car Units in the two Segments [2]

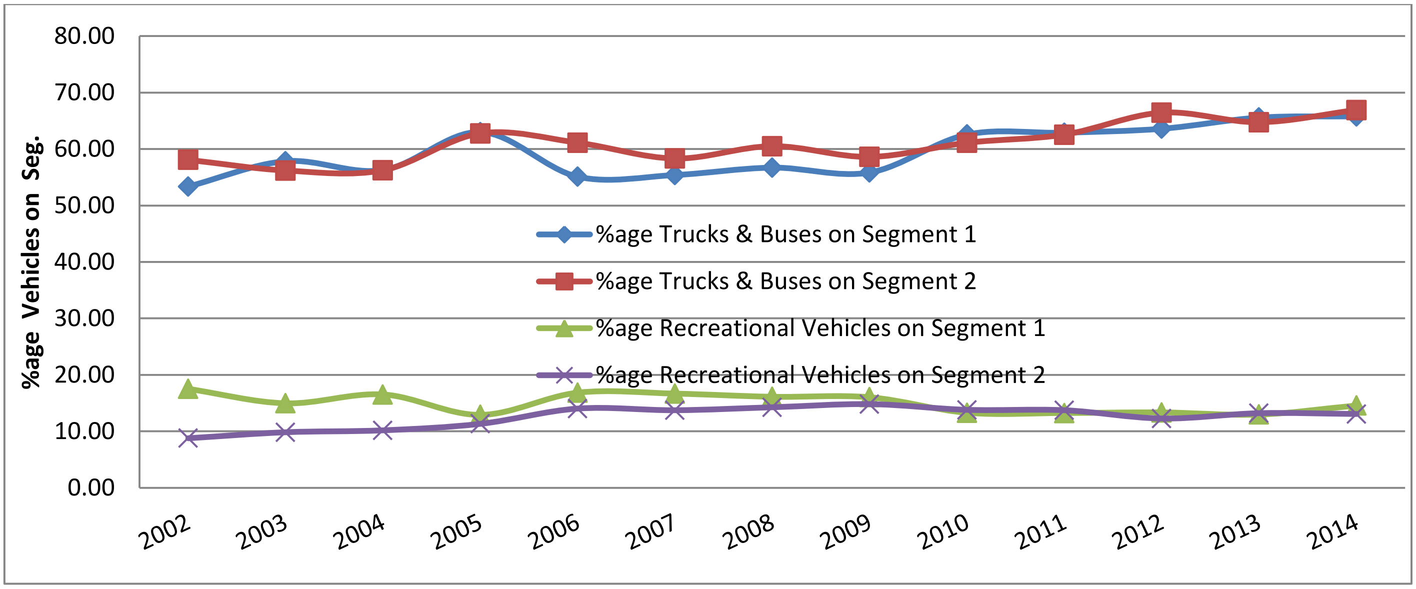


Figure 37: Relative Percentages of Trucks & Buses and Recreational Vehicles in the two Segments [2]

Table 13: Recommended Speed Limits (in km/h) for Ethiopian Highways [31]

Vehicular Weight	Urban/ Town Section	Rural/Semi Urban Section		
		1st Level Highways	2nd Level Highways	3rd Level Highways
Up to 3500kg	60	100	70	60
3500kg -7500kg	40	80*	60	50
Beyond 7500kg	30	70	50	40

* The Base Free - Flow Speed (BFFS) for the two sections or segments is estimated as 80km/hr since most of the segment 1 and all of the segment 2 were considered as rural or semi-urban sections during the construction period i.e. 1992 E.C. of Addis Ababa to Awassa Trunk Road Rehabilitation Project that had been started as 0+000 at Kality Ring Road or Drivers' & Mechanics Training Center. For the analysis purpose the average Vehicular Weight age in this case is considered. But for the 6.0km Town section 60 up to 70km/h is considered. The average value 65km/h is taken in this case.

Table 14: Level-of-Service Criteria for Two-Lane Highways in Class I [17]

Level of Service	Percent Time Spent Following	Average Travel Speed (km/h)
A	≤35	> 90
B	>35 - 50	> 80 - 90
C	>50 - 65	> 70 - 80
D	>65 - 80	> 60 - 70
E	>80	≤ 60

Note: *Level of service F applies whenever the flow rate exceeds the segment capacity.*

For the detailed definition of the *Class I Highways***,** section 2.2 of the literature review of this research paper can be referred.

All other utilized constants for the analysis of the level of services and other performance criteria of the segment road are sourced from the HCM 200 chapter 20, analysis for two - way two - lane roads adopting or simulating practicable for such types of road segments.

Assumptions for the Analysis of Class I Two way Two Lane Highways

- ✓ Traffic volume is obtained from ERA traffic count data for 13 years 2002 to 2014 except for randomly selected segments for this research purpose.
- ✓ The analysis is based on Operational Level of Service (LoS)
- ✓ The type of Highway is basically classified as Class I HW
- ✓ The terrain type for the semi urban section is categorized as Rolling Terrain
- ✓ The input data for the analysis purpose are field measured and counted values and then other adjustment factors are calculated from the existing relations
- ✓ Estimated Base Free Flow Speed (BFFS) method along with their adjustment factors are utilized rather than Free Flow Speed from Field Measurement i.e. Field Measured Speed (S_{FM})
- ✓ Both Average Travel Speed and Percent Time Spent Following analysis values are used to determine the Level of Service (LoS)
- ✓ Other Performance Measures such as v/c ; peak- hour and peak - 15 minutes vehicles-kilometers of travel as well as total travel time

Using Average Values for the two way Hourly Volumes (see Appendix B)

Table 15: Summary of output for level of service analysis using average hourly volumes

Int. No	Segment/ Section	Parameters	Determinant Values	LOS	Remark
1	Kality (Total) to Akaki(Tulu Dimtu)	Two way Hourly Volume(Average)	1127		
		Average Travel Speed	54.44	E	
		Percent Time Spent Following (PTSF)	74.64	D	
		Overall Level of Service, LOS		**E**	
		Volume –to- Capacity Ratio, v/c	0.49	D	
		$Peak_{15}$ minutes Total Travel Time	28.17	D	
2	Akaki(Tulu Dimtu) to Dukem	Two way Hourly Volume(Average)	725		
		Average Travel Speed	58.20	E	
		Percent Time Spent Following (PTSF)	55.66	D	
		Overall Level of Service, LOS		**E**	
		Volume –to- Capacity Ratio, v/c	0.39	D	
		$Peak_{15}$ minutes Total Travel Time	44.90	E	

Using Maximum Values for the two way Hourly Volumes (see Appendix B)

Table 16: Summary of output for level of service analysis using maximum hourly volumes

Int. No	Segment/ Section	Parameters	Determinant Values	LOS	Remark
1	Kality (Total) to Akaki(Tulu Dimtu)	Two way Hourly Volume(Maximum)	1691		
		Average Travel Speed	45.15	E	
		Percent Time Spent Following (PTSF)	81.63	E	
		Overall Level of Service, LOS		**E**	
		Volume –to- Capacity Ratio, v/c	0.74	E	
		$Peak_{15}$ minutes Total Travel Time	51.25	E	
2	Akaki(Tulu Dimtu) to Dukem	Two way Hourly Volume(Maximun)	1200		
		Average Travel Speed	53.31	E	
		Percent Time Spent Following (PTSF)	93.52	D	
		Overall Level of Service, LOS		**E**	
		Volume –to- Capacity Ratio, v/c	0.52	E	
		$Peak_{15}$ minutes Total Travel Time	81.14	E	

4.3. Result of the Congestion Analysis

The Two way Hourly Volume (Average or Maximum), Average Travel Speed (ATS), and Percent Time Spent Following (PTSF) with the associated determinant constant values as indicated in the HCM 2000 for the similar conditions are utilized for the analysis of the Overall Level of Service, LOS along the research study corridor. Other performance measures such as Volume to Capacity Ratio, v/c, and Peak hour total travel time in vehicle hour (veh-h) are also dealt for the performance analysis of the infrastructure.

Assumptions for the Analysis of Multilane Highways

- ✓ Traffic volume is obtained from ERA traffic count data for 13 years 2002 to 2014 except for randomly selected segments for this research purpose.
- ✓ Homogeneous sections are selected for the analysis purpose in this case and Base conditions for multilane highways against certain limitations of the analysis methodology are considered
- ✓ The analysis is based on the values of Free Flow Speed (km/h) and criterion such as Max density (pc/km/ln), Average speed (km/h), Max v/c and Max service flow rate (pc/h/ln) on speed-flow curves with LOS criteria.
- ✓ The analysis is based on Operational Level of Service (LoS) or application.
- ✓ The terrain type for the multilane section is categorized as Level Terrain
- ✓ The input data for the analysis purpose are field measured and counted values and then other adjustment factors are calculated from the existing relations
- ✓ Assumed Base Free Flow Speed (BFFS) to be 8km/h greater than the posted speed of 80km/h

  i.e.80+8 = 88km/h along with their adjustment factors are utilized in this case.

Table 17: **LEVEL-OF-SERVICE CRITERIA FOR MULTILANE HIGHWAYS**

Free-Flow Speed	Criteria	LOS				
		A	B	C	D	E
100 km/h	Max density (pc/km/ln)	7	11	16	22	25
	Average speed (km/h) Max	100.0	100.0	98.4	91.5	88.0
	v/c	0.33	0.50	0.72	0.94	1.00
	Max service flow rate (pc/h/ln)	700	1100	1575	2015	2200
90 km/h	Max density (pc/km/ln)	7	11	16	22	26
	Average speed (km/h) Max	90.0	90.0	89.8	84.7	80.8
	v/c	0.31	0.47	0.68	0.89	1.00
	Max service flow rate (pc/h/ln)	630	990	1435	1860	2100
80 km/h	Max density (pc/km/ln)	7	11	16	22	27
	Average speed (km/h) Max	80.0	80.0	80.0	77.6	74.1
	v/c	0.30	0.44	0.64	0.85	1.00
	Max service flow rate (pc/h/ln)	560	880	1280	1705	2000
70 km/h	Max density (pc/km/ln)	7	11	16	22	28
	Average speed (km/h) Max	70.0	70.0	70.0	69.6	67.9
	v/c	0.28	0.41	0.59	0.81	1.00
	Max service flow rate (pc/h/ln)	490	770	1120	1530	1900

Note: The exact mathematical relationship between density and v/c has not always been maintained at LOS boundaries because of the use of rounded values. Density is the primary determinant of LOS. LOS F is characterized by highly unstable and variable traffic flow. Prediction of accurate flow rate, density, and speed at LOS F is difficult.

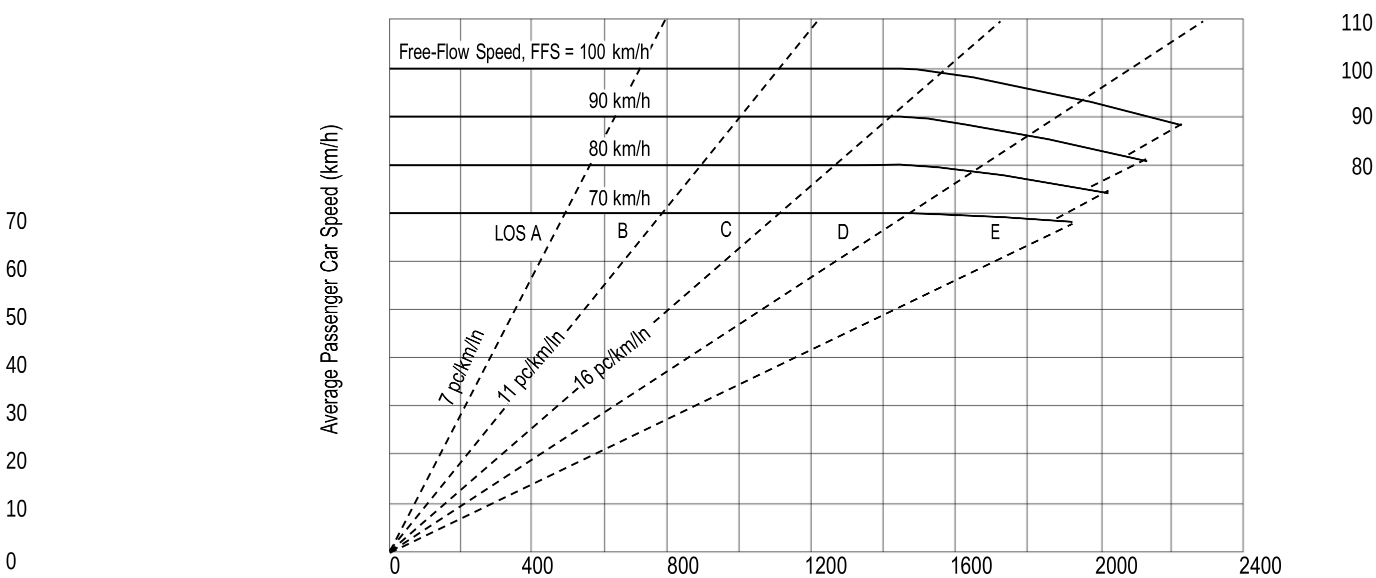


Figure 38: SPEED-FLOW CURVES WITH LOS CRITERIA

The Results A four - lane highway with lane widths of 3.2, a 0.8m median, and a total lateral clearance of 2.4m will meet operation objectives of LOS D during peak hour period with passenger car speed of 64.9km/h, and density of 17.98pc/km/ln.

4.4. Questioners Respondents' Profile

The questioner respondents profile is summarized in the Table 22 below and the each questioner data was discussed and presented at an appropriate section in the analysis and result part of this thesis. Table 19 shows that about 64% of the distributed questioners were returned and the profile of the respondents showed that most of them were aged between 25-35 and the average distance of home to work place was from 3-10 Km.

Table 18: Questionnaire respondents' profile

		Frequency	Percent
Questioner	Distributed	70	
	Returned	45	64.0%
	Total	**70**	
Age Group	Under 25	7	16%
	25- 35	25	56%
	36-45	9	20%
	above 46	4	9%
	Total	**45**	**100**
Sex	Male	36	80%
	Female	9	20%
	Total	**45**	**100**
Mode of Movement	Personal drive	9	20%
	Public Transport	16	36%
	Using driver but personal vehicle	3	7%
	Recreational Vehicles	4	9%
	Heavy Vehicles	15	33%
	Total	**45**	**100**
Average distance from Home to Work	1km- 3km	4	9%
	3km-7km	15	33%
	7km-10 km	13	37%
	10km – 14 km	4	9%
	Above 14 km	9	2%
	Total	**45**	**100**

4.5. Traffic Congestion and Traffic Accident Trend Analyses

4.5.1. Traffic Accident Trend in Addis Ababa

Traffic accident is known to be one of the major transportation problems in Addis Ababa and the subsequent loss of life; injury and property damage are significantly high. Chart 18 shows the trend of the traffic accident between the years 1995 and 2005 E.C. Accordingly, the total traffic accident is the highest during the years 2004 and 2005 as may be expected increased in a current situations as well. In addition, Figure 39 shows that the number of the total traffic accident and the property damage were increasing during the years from 1996 to mid 1997 as well as 2003 onwards whilst it was decreasing during the years 1995 and 1996 and mid 1997 to 2003 E.C. As the data is a sum of all accidents in the city, the severity of the accidents is hidden. However; as congestion usually involves a lower speed, the possible accident severity during traffic congestion would be a light collisions.

Traffic Accident Trend in Addis Ababa (See on Appendix D)

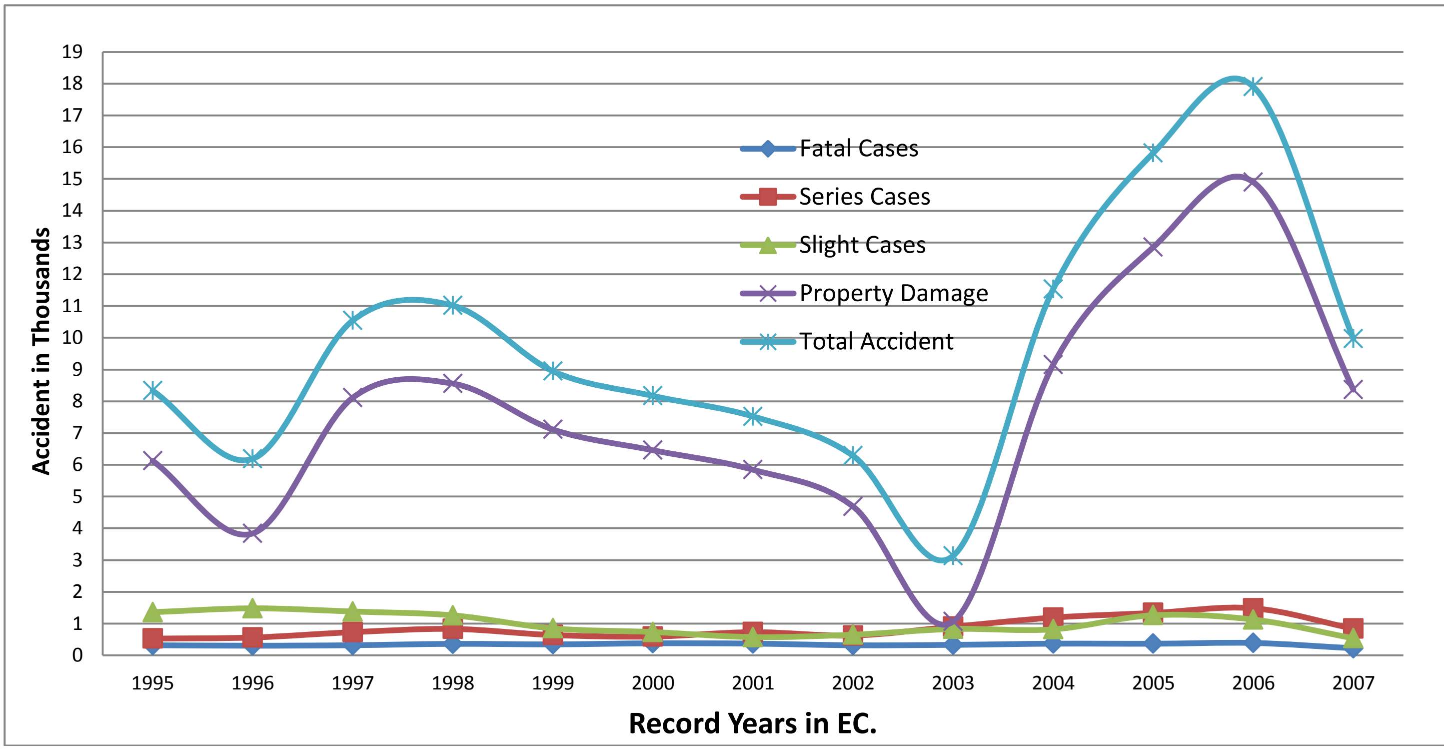


Figure 39: Relative Accident Types in Addis Ababa **(***A.A City Police Commission***)**

<u>Note:</u> *The years indicated in this chart are that of Ethiopian Calendar (E.C) since the data is used as it is for the analysis purposes. The decline in total as well as the individual accident cases may be expected from the traffic management aspect through the behavioral changes related enforcements.*

For example, from the above figure we can deduce the following comparative table for the traffic accident for the years 2008/9 and 2009/10 G.C. (i.e 2001 and 2002 E.C).

Table 19: Comparison of Accident Records in the Years 2008/9 & 2009/10

Serial No.	Accident Type	2008/9	2009/10	Difference	
				Number	%age
1	Fatal	371	318	-53	-16.67
2	Serious	731	626	-105	-16.77
3	Slight	576	652	76	11.66
4	Property	5845	4689	-1156	-24.65
	Total	7523	6285	-1238	-19.70

The decline in total as well as the individual accident cases in those years may be concluded from the traffic management aspect through the behavioral changes related enforcements.

Traffic Accident Trend in Akaki –Kality Subcity (Subcity Police Commission)
(See on Appendix D)

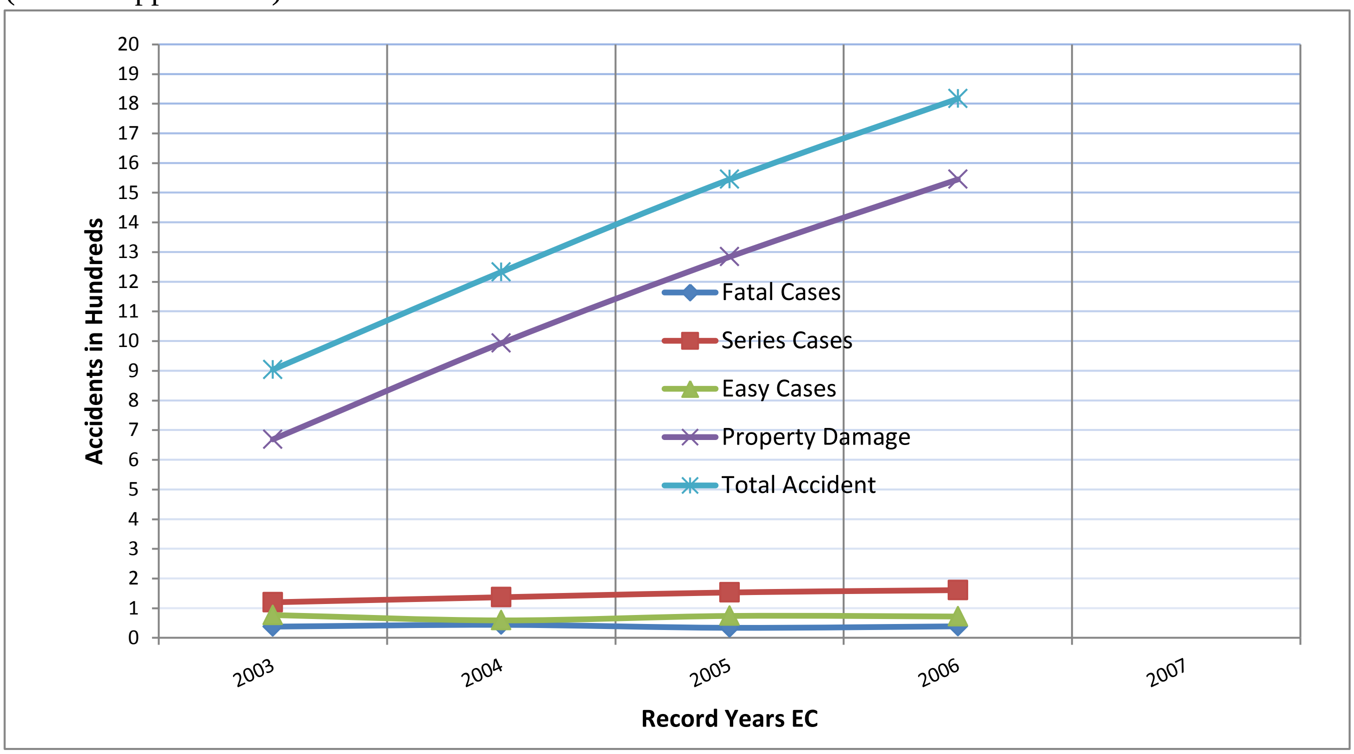


Figure 40: Relative Accident Types in Addis Ababa (Akaki Kality Subcity Police)

Finfine Zuria Oromia Special Zone Traffic Accident Trend *(Zone Police Commission)*
(See on Appendix D)

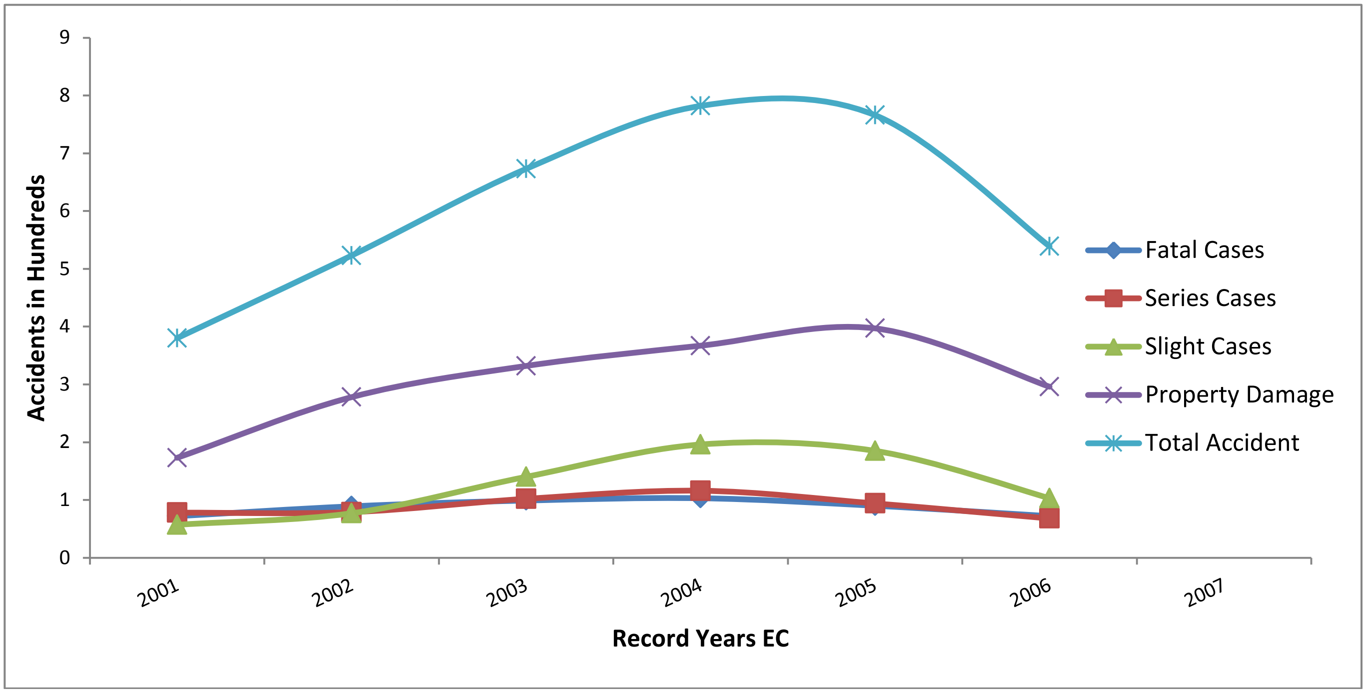


Figure 41: Relative Accident Types in Finfine Zuria Oromia Special Zone (zone traffic police)

4.5.2. Traffic Volume vs. Traffic Accident in Addis Ababa

As figures 40 & 41 above show the trend flowed by the total (bi directional) traffic volume or flow was almost similar for the two segments; namely, Kality (Maseltegna) – Akaki (Tulu Dimtu) Segment which is the city/urban section and Akaki (Tulu Dimtu) – Dukem Bridge Segment which is the intercity/sub urban section. However, certain trend variations are sensed from the years 2010 and 2011 respectively.

To make the comparison between the traffic trends between the traffic accidents and traffic volume it is logical to take the average traffic volumes of the segments as both of the segments show almost the same trend in traffic volume variation. Hence, the average annual daily traffic volume/flow AADT is plotted against with the average annual traffic accident data in Addis Ababa city as shown below in figure 43. As it is clearly visualized from the figure below, the average annual daily traffic volume for the Addis Ababa (that might also indicative for Kality to Akaki Segment) is somewhat inversely related to the annual total traffic accidents in the city. The other reason for using the whole city accident data is due to the data limitation from the sub city level during data collection.

Table 20: Records of Various Types of Accidents [A.A. traffic police]

Years	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Aveg.
Total Traffic	12839	14065	17135	21794	26604	31775	34811	34373	40591	29431	23134	23166	25810
Total Acc.	8336	6189	10543	11014	8949	8169	7523	6285	3134	11529	15815		8862
Fatal Acc.	319	305	320	363	347	381	371	318	332	369	367		345
Sever Acc.	528	563	731	833	640	594	731	626	904	1190	1336		789
Slight Acc.	1360	1482	1381	1261	850	735	576	652	831	820	1263		1019
Prop.Dam.	6129	3839	8111	8557	7112	6459	5845	4689	1067	9150	12849		6710

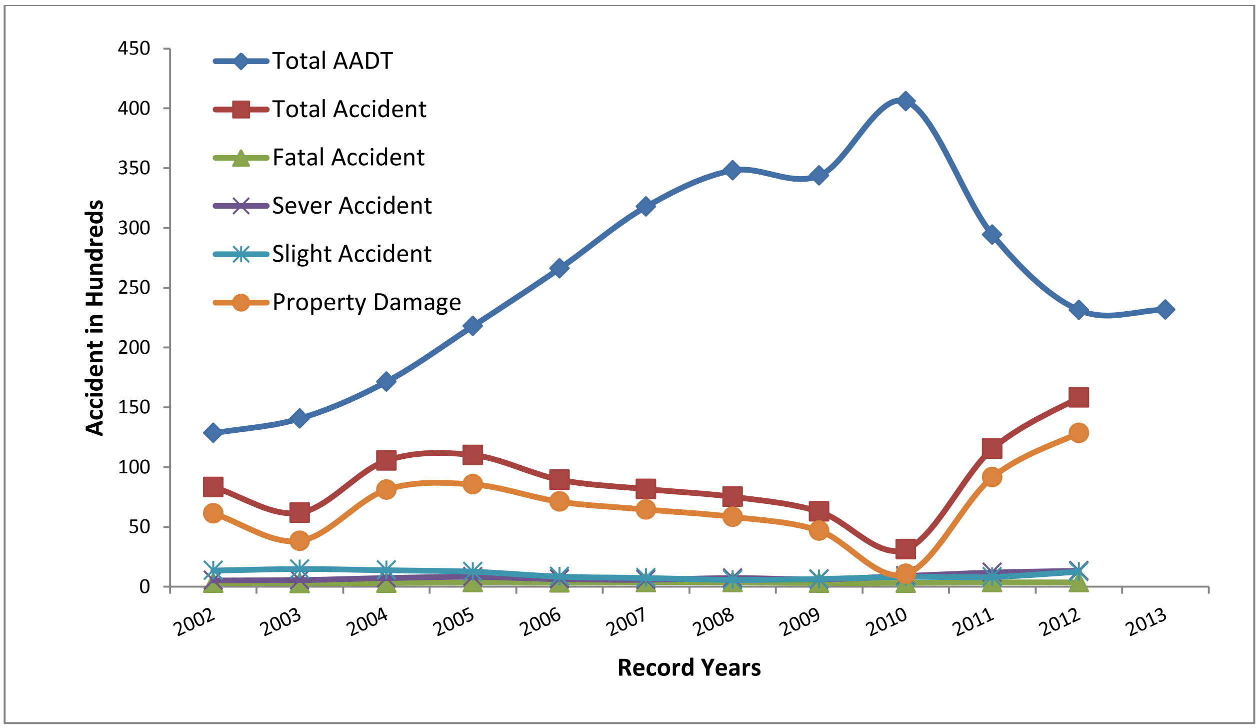


Figure 42: Various Annual Accident Types & Total Traffic Volume Trend [2 & A.A.traffic police]

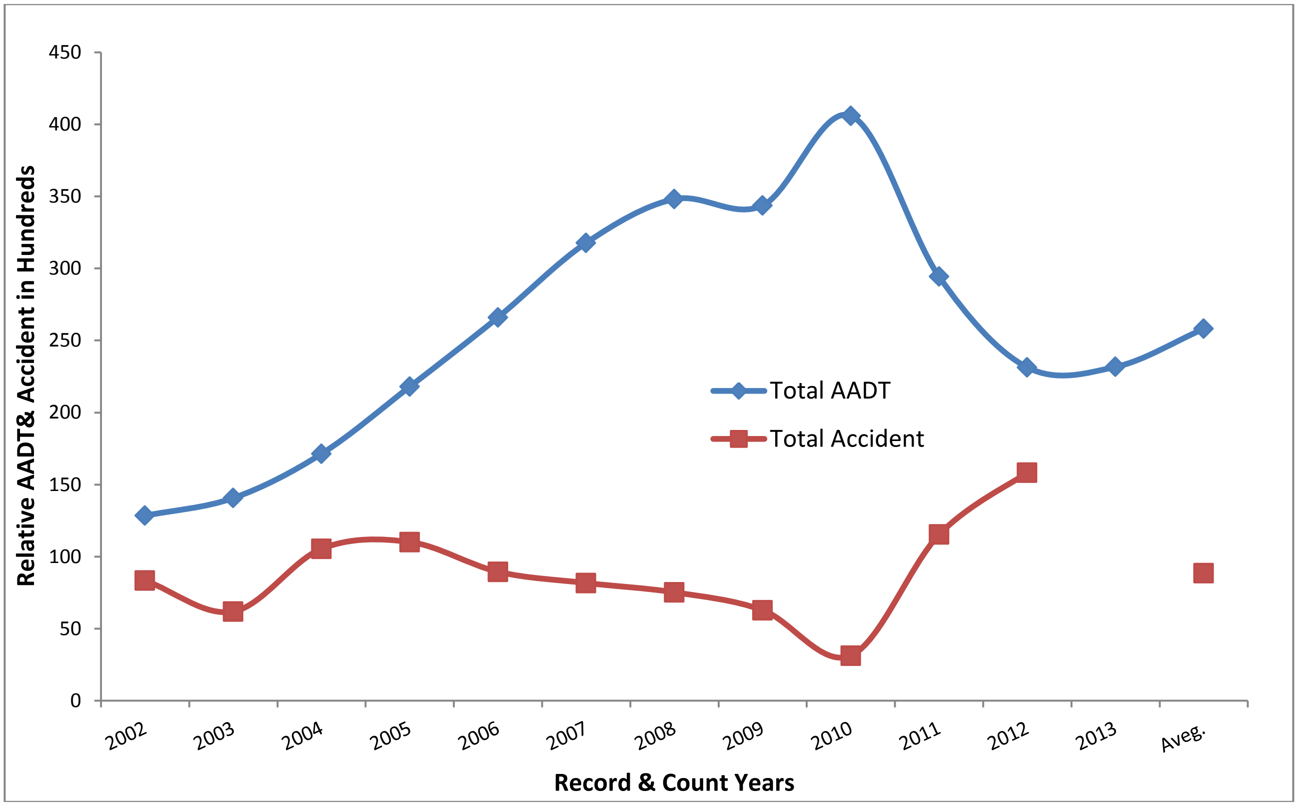


Figure 43: Total Annual Accident & Total Traffic Volume Trend [2 & A.A.traffic police]

4.5.3. Correlation of Traffic Accident with Traffic Volume

In order to see the correlation between traffic volume with traffic accident, linear equations and regression coefficients were determined as shown in figure 44 below. Accordingly, the regression coefficient of traffic volume with traffic accident is somewhat smaller than the expected regression coefficient in actual trend. Hence, the result indicates that traffic volume has a lesser relationship with traffic accident may be due to lower travel speed and more travel time in the segment this in turn means drivers in this segment are taking relatively more care except for collisions related to property damages which results from traffic congestion.

Though the regression coefficient of traffic volume is not significant due to the outlier values, values below the regression line are so close and follow a trend. Therefore, the result cannot be undermined as such.

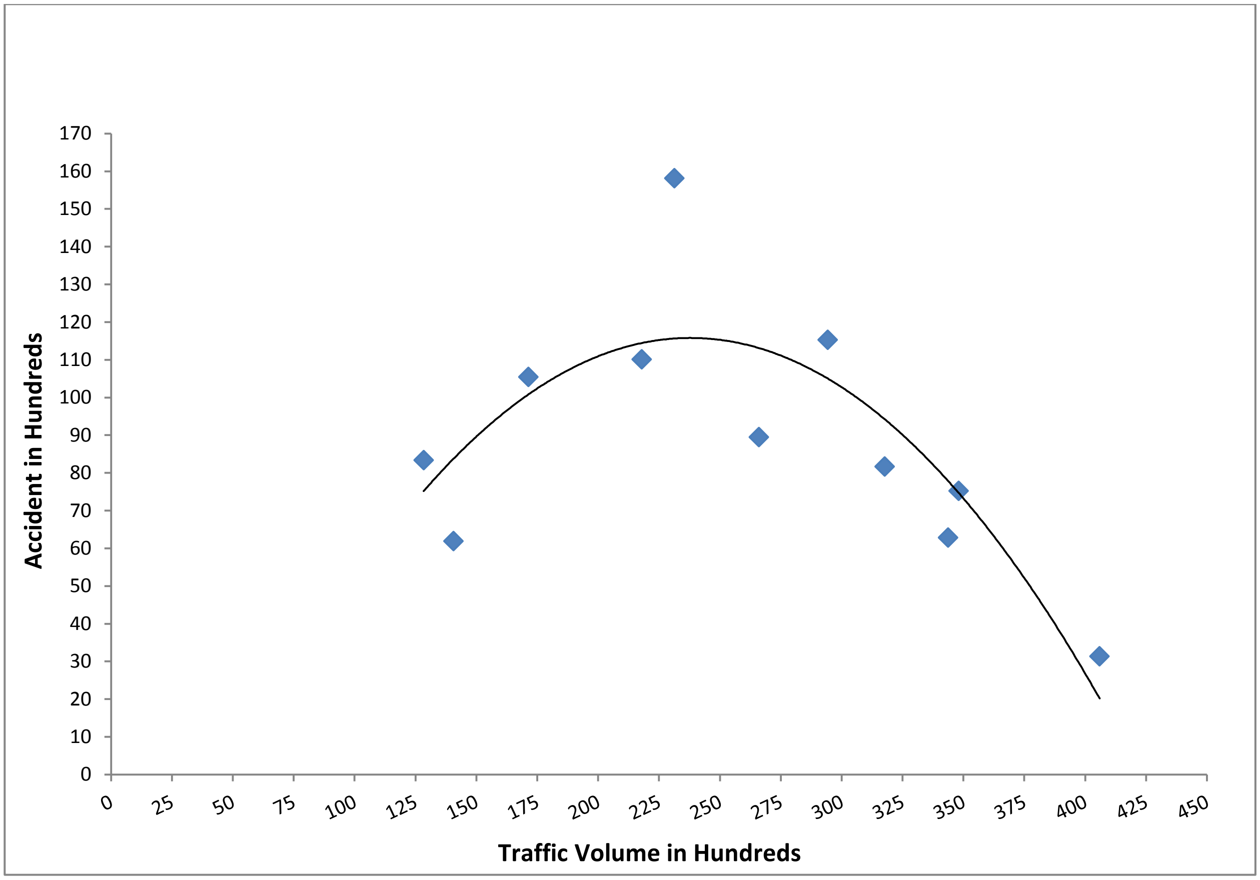


Figure 44: Total Traffic volume/ flow Vs Total Traffic Accident [2 & A.A.traffic police]

From the figure we can conclude that the total average annual traffic volume/ flow and total annual traffic accident are inversely related in the selected segment with slight correlation coefficient between them.

As revealed from the charts above the correlation between Total Traffic volume or flow and Total Traffic Accident is more considerable with Polynomial Regression than that of Linear Regression relation from the correlation coefficient R^2 that is Y = -3E-05x2 + 1.6114x - 7587.1and that of R^2 = 0.6822.

Accident and AADT Relationship on Akaki Kality Subcity

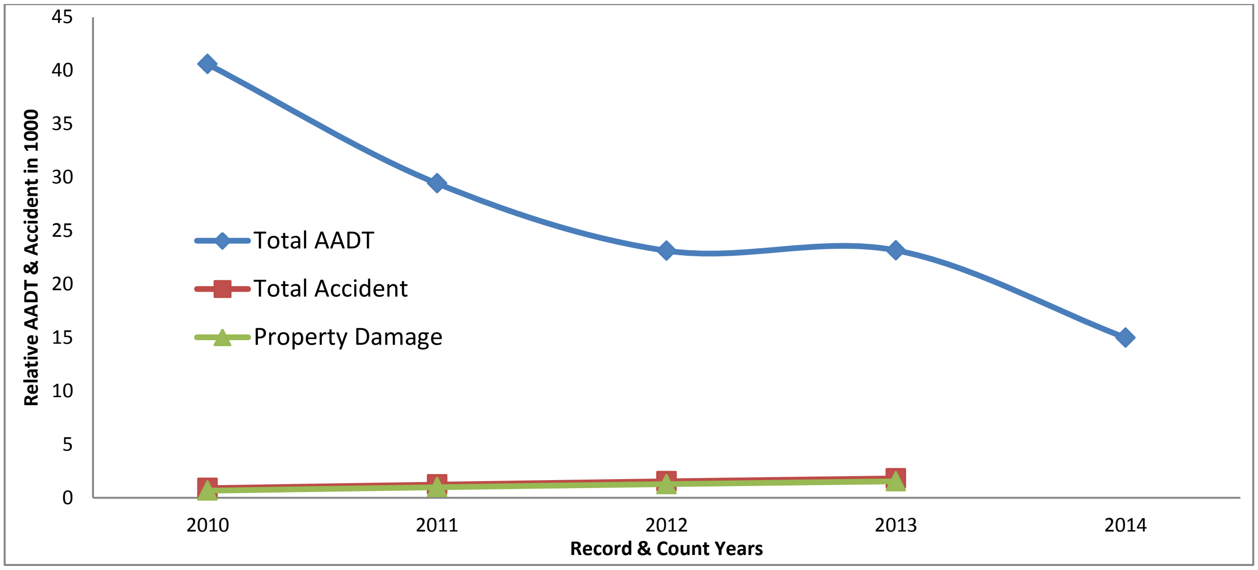


Figure 45: Accident and AADT Relationship on Akaki Kality Subcity **[***Kality traffic police]*

Accident and AADT Relationship on Tulu Dimtu - Dukem Section

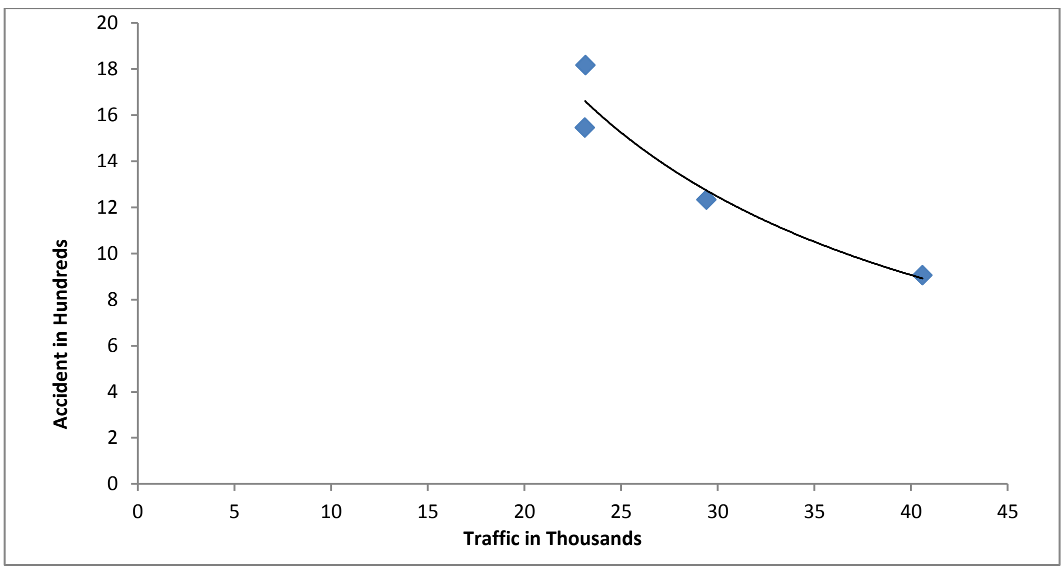


Figure 46: Accident and AADT Relationship on segment 2 Power Regression **[***Kality traffic police]*

As revealed from the figure above the correlation between Traffic volume or flow and Traffic Accident is more considerably related with Power Regression than any other regressions from the correlation coefficient R^2 that means $Y = 1E+08x^{-1.106}$ and that of $R^2 = 0.9462$.

4.5.4. Accident Spots and Congestion Spots

The traffic accident spots as identified by the Road Safety Agency are collected and plotted on a GIS map of Addis Ababa (the black dots) these accident spots are only those spots with traffic accident rate of greater than 50 accidents per year. The congestion spots were collected using questioner and the result was plotted on the GIS map as shown in the Figure 47 below. As questioners were given randomly, the congestion spots identified could not be the entire congestion spots in Addis Ababa city. However, the result shows that all the identified congestion spots are also identified as black spots by the road safety agency. Furthermore, the traffic and accident spots follow a trend that the east-west and north-south axis and concentrated at the city centers.

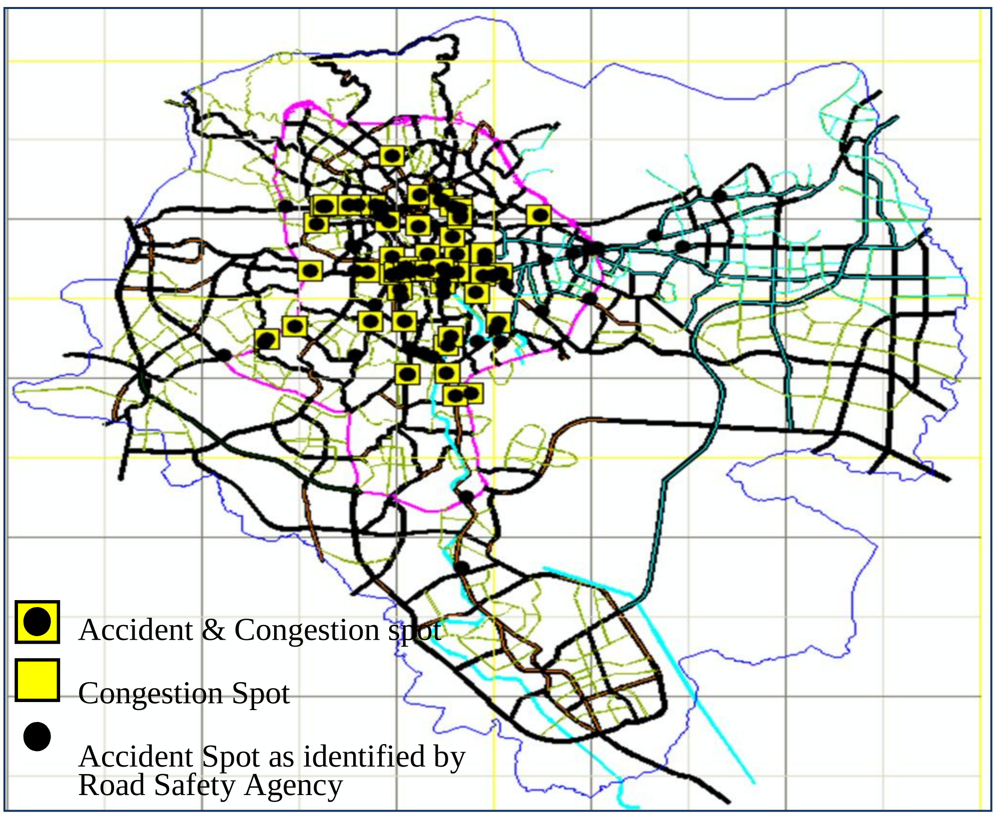


Figure 47: GIS plotting of traffic and conjunction spot [36]

4.5.5. Major Traffic Accident Black-spots in Akaki Sub-city

This sub-city is the eight in terms of total number RTAs and has 6 RTABSs as identified during the year specified. This was computed from the data obtained over one year (Jul., 2005 – Jun., 2006). Table 25 shows the list of those RTABSs together with their total accident and rank orders in the intensity of the frequencies.

Table 21: Major Road Traffic Accident Black-spots in Akaki Sub-city (Jul, 2005 -Jun, 2006) [AATPO]

Major ABSs	Total Accident		Rank
	No.	%	
Saris Abo	11	26.83	1
Cheralia Bscute Factory	8	19.52	2
Around Akaki Bridge	7	17.08	3
Near Gebriel	6	14.63	4
Akaki Health Station	5	12.19	5
Alem (World) Bank	4	9.75	6
Total	41	100	-

Akaki sub-city seems the least in its exposure to RTAs during the year specified. While the general principle to determine RTABSs in each sub-city in this study was selection of such black-spots up to the 10^{th} rank, in Akaki it was up to the 6^{th} rank because of negligible nature of accidents above the 6^{th} rank, all about 1 accident or zero. The 1^{st} rank was found to be 11and the last was set at 4. However, as there is a need for identification of RTABSs for each sub-city in Addis Ababa, relatively hazardous sites were chosen as indicated in Table 25.

4.6. Effect of Heavy Vehicles on a Congested Traffic Stream

4.6.1. Review of Selection of Simulation Model for PCEs /PCSEs Determinations

Upon careful consideration, the traffic simulation model integration was selected to perform simulation runs as it has the ability to model the performance of heavy vehicles on grades and their effect on traffic flow. Specifically, the model accounts for the larger dimensions of heavy vehicles and their inferior performance particularly acceleration performance on grades. To model grades, a separate optional input file is required. To model vehicles other than passenger cars, integration allows the user to select from many standard small and heavy vehicles when inputting the demand file. Alternatively, a vehicle with special performance characteristics (non-standard) can also be modeled using an optional input file that requires detailed information about vehicle's weight, power, aerodynamics, etc. More information on model features can be found in the user's guide [*13]*.

Consistent with the HCM analytical procedures, the effect of heavy vehicles on traffic flow was assessed through the use of passenger car equivalency factors. However, the equivalency criterion that was used in developing the PCEs in [*13]* is the Queue Discharge Flow (QDF) which is different from that used by the HCM, i.e. average density. This is because the QDF is what governs the operation of the freeway or multi-lane highway after the onset of congestion. This queue discharge flow is often considered to reflect the real long-term capacity of a recurrent or non-recurrent bottleneck. The QDF is defined by the HCM as traffic flow that has just passed through a bottleneck and is accelerating back to the free flow speed of the freeway. Studies suggest that the queue discharge flow rate from the bottleneck is slightly lower than the maximum flows observed before breakdown. Upstream queuing may occur for three or more hours a day, whereas the capacity prior to flow breakdown and queuing lasts at most an hour, and often for only 15 minutes.
In using QDF to derive the PCE factors from field data, an optimization technique was used to determine a single PCE factor that would minimize the variation in QDF observations for the many successive 5-minute intervals in each data set. The mean value of the PCE factors from all data sets were then used as an estimate of heavy vehicles' effect at that particular site.

To derive the PCE factors from simulation experiments, the QDF is first measured in terms of two separate counts: passenger cars and heavy vehicles. Knowing the capacity of the study site from empirical data in pcph (from the previous research described above), the PCE from each simulation run can be found using the following formula:

PCE = (Actual Field Capacity in pcph - Number of PCs) / Number of HVs

Where; the number of passenger cars and heavy vehicles are hourly flow rates found from simulation output. The field capacity in pcph represents the mean value of all capacities observed at the study site using the PCE factors from optimization.

4.6.2. Determinations of PCEs or PCSEs

Different researchers and scholars try to determine the Passenger Car Equivalency (PCEs) factors in different ways and procedures as convenient for their proposed functions. Equivalent standard vehicles in the mixed traffic flow is converted into, the conversion is based on the concept of 'passenger car space equivalent' (PCSE), which accounts only for the relative space taken up by the vehicle, and takes into account explicitly the speed differences of the various vehicles in the traffic stream.

For the conversion of the surveyed traffic volume in PCSE the researcher has made reference to the values recommended by HDM Manual for a two lanes road of similar geometric characteristics as well as the usual PCEs values customized in the HCM 2000.

Table 22: PCEs /PCSEs Determinations [17]

Vehicle Types	CAR	PICK-UP - 4WD	S/bus ≤27 seats	M/bus 27-45 seats	L/bus >45 seats	S/truck ≤ 3.5 T	M/truck 3.5-7.5 T	H/truck 7.5-12 T	Art.truck >12 T	Motor 2/3w.cycle	Bycicle	Animal drawn cart
Category	A	B	C	D	E	F	G	H	I	J	K	L
PCSE(HDM)	*1*	*1.2*	*1.2*	*2.0*	*2.2*	*1.4*	*1.6*	*2.2*	*2.5*	*0.3*	*0.5*	*0.5*
PCEs(HCM)	*1*	*1.0*	*1.5*	*2.0*	*2.5*	*1.5*	*2.0*	*2.5*	*3.0*	*0.5*	*0.5*	*0.5*

Assessing the Effect of Heavy Vehicles on a congested traffic stream incorporates the effects of the following input parameters:

- The effect of grade on PCE factors at various percentages of HVs,
- The effect of grade length on PCE factors at various percentages of HVs,
- The effect of heavy vehicles’ on PCE factors at various grades on a certain km two-lane highway facility,
- The effect of lane – use restriction and
- The effect of location of bottleneck relative to upgrade

4.6.3. Analysis of the Effects of Large Vehicles on the Congested Traffic Stream

Table 23: Analysis of the Effect of Grades for 8% HVs Proportion

8 % HVs	Grade (%)	1	2	3	4	5	6
		PCE in Percentage					
Grade Length (KM)	0.2	100	115	120	120	175	195
	0.6	100	114	150	200	170	245
	1	100	113	117	195	200	435
	1.4	100	112	175	225	245	460
	2	100	140	190	225	280	555

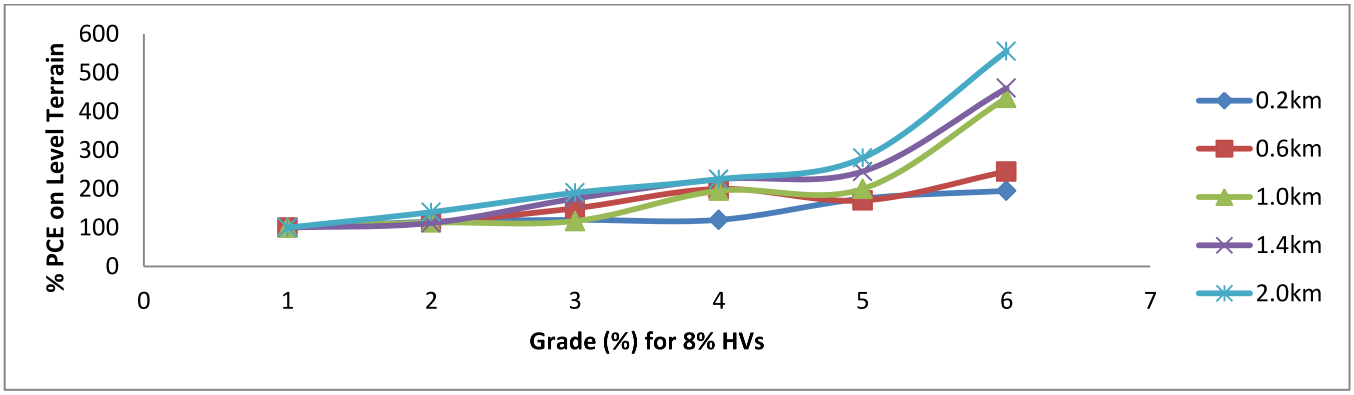


Figure 48: The effect of grade on PCE factors at 8 percentages of HVs

Table 24: Analysis on the Effect of Grades for 24 % HVs Proportion

24 % HVs	Grade (%)	1	2	3	4	5	6
		PCE in Percentage					
Grade Length (KM)	0.2	100	130	140	155	170	215
	0.6	100	131	150	165	210	295
	1	100	132	152	175	213	270
	1.4	100	135	153	195	215	320
	2	100	134	154	180	220	325

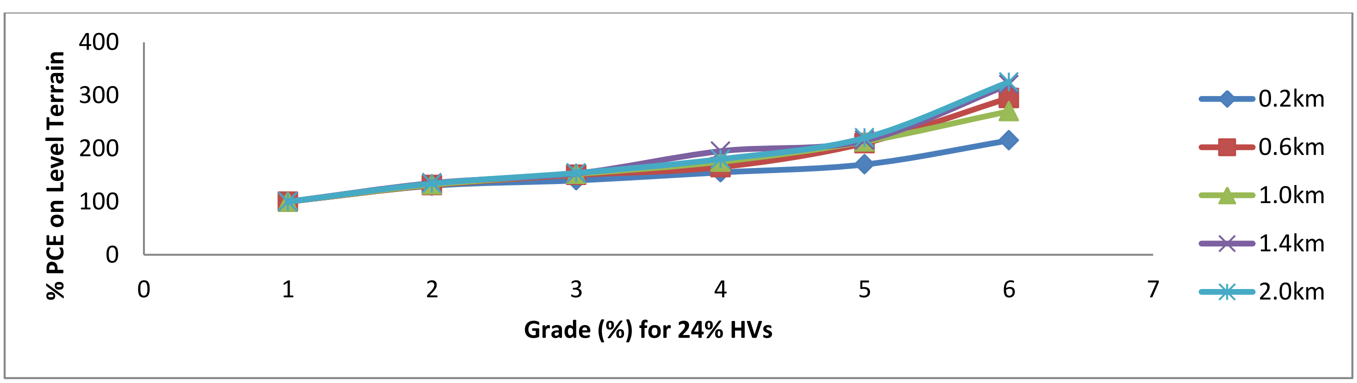


Figure 49: The effect of grade on PCE factors at 24 percentages of HVs

Table 25: Analysis on the Effect of Grades for 40 % HVs Proportion

40 % HVs	Grade (%)	1	2	3	4	5	6
		PCE in Percentage					
Grade Length (KM)	0.2	100	125	127	140	148	175
	0.6	100	126	135	142	149	178
	1	100	125	125	136	150	185
	1.4	100	126	127	143	152	180
	2	100	118	127	135	148	195

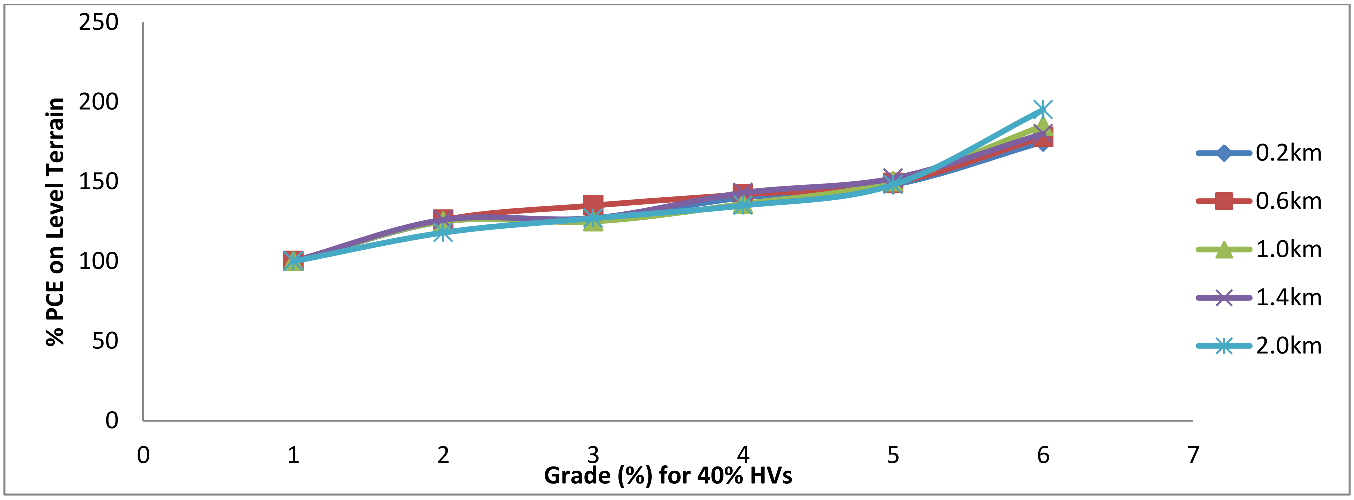


Figure 50: The effect of grade on PCE factors at 40 percentages of HVs

Figures 48, 49, and 50 above show the influence of grade on the PCE factors of heavy vehicles at three different percentages of heavy vehicles. What is shown in these figures is the PCE factor expressed as a percentage of that for the same scenario but on level terrain. These figures clearly show that, in general, the effect of heavy vehicles on traffic flow increases with the increase in grade. This trend is quite expected as the performance of heavy vehicles generally typically declines with the increase in grade percentage. The figures also show that the influence of grade on the PCE factors is generally higher at longer grade lengths and smaller percentages of heavy vehicles. Specifically, in the figure 48, the PCE factor for a 2-km 6% upgrade is around 555% of the PCE factor on level terrain when the percentage of heavy vehicles is around 8%. The effect of heavy vehicles on the same upgrade would decrease significantly when the percentage of heavy vehicles increases to 24% and 40% to 325% and 195% respectively. Further, the patterns exhibited in these figures show that grade length will not have a major effect on the PCE factors at higher percentages of heavy vehicles.

The maximum total hourly volume counted is 1691 AADT in various categories of vehicular types in this section. In general, at different grade values, grade length and proportions of large vehicles it is seen that the percentage PCE rises significantly due to the effect of such heavy vehicle compositions existence aggravating the severity of traffic congestion on the same segment.

Table 26: Analysis on the Effect of Grade Lengths at 6% Upgrade Terrain

@ 6% Upgrade	Grade Length(km)	0.2	0.6	1	1.4	2
		PCE in Percentage				
HVS Percentages	2%	100	125	230	240	290
	4%	100	148	178	180	248
	6%	100	122	118	152	215
	10%	100	142	160	165	200
	15%	100	138	120	150	150
	20%	100	123	119	153	150
	24%	100	115	118	125	135
	30%	100	102	110	108	120
	40%	100	110	115	110	115

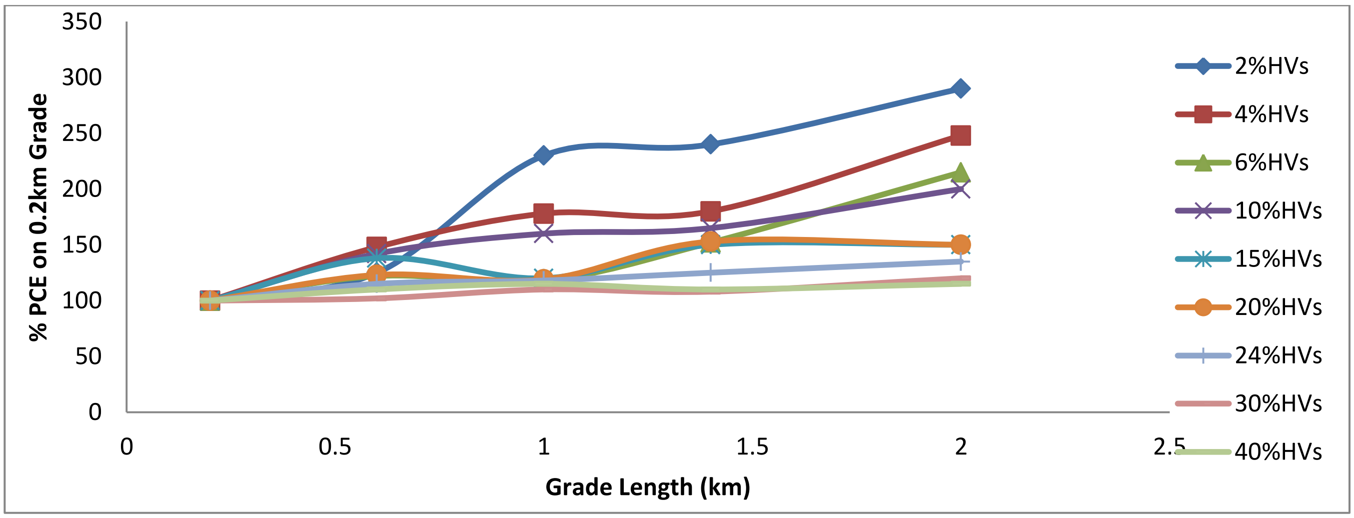


Figure 51: The effect of grade length on PCE factors at various percentages of HVs @ 6% upgrade

What is shown in this figure is the PCE factor expressed as a percentage of that for the same scenario but on 0.2 km grade length. It is clearly exhibited by this figure that the effect of grade length on PCE factors varies widely as it is a function of the steepness of grade and heavy vehicle percentage. In this figure, it is clear that the PCE factors generally increase with the increase in grade length. However, while this increase is very significant for low percentages of heavy vehicles, it becomes hardly noticeable when heavy vehicles constitute a significant proportion of the traffic mix.

The maximum total hourly volume counted is 1691AADT in various categories of vehicular types in this section. In general, for 6% grade value, at different grade length and proportions of large vehicles it is seen that the percentage PCE rises slightly due to the effect of such heavy vehicle compositions existence aggravating the severity of traffic congestion on the same segment.

Table 27: Analysis on the Effect of Heavy Vehicles' Percentages at various Grades

1-km 2-lane Highway	% HVs	2	4	6	10	15	20	24	30	40
		PCE in Percentage								
Grades (%)	0	100	100	99	100	100	98	100	105	110
	2	100	114	116	109	110	108	107	106	102
	3	100	116	135	113	125	120	112	105	113
	4	100	92	92	92	93	82	78	72	68
	5	100	114	101	98	93	81	76	68	59
	6	100	87	64	73	60	55	52	45	41

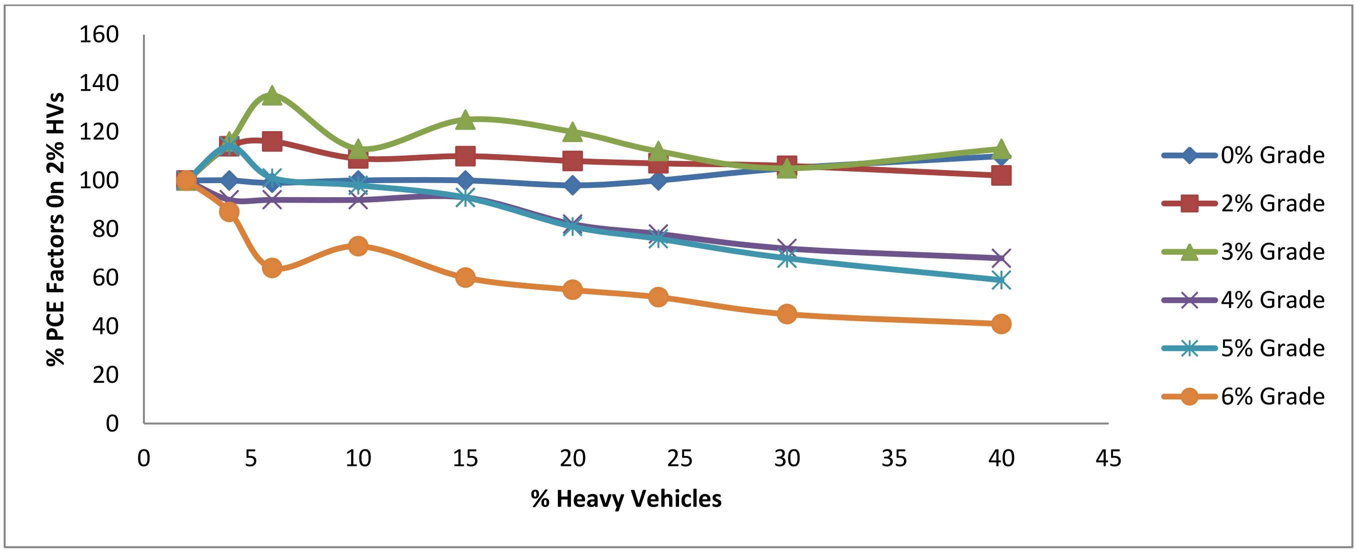


Figure 52: The effect of heavy vehicles percentage on PCE factors at various grades

5.0. DISCUSSIONS

5.1. Traffic Volume / Flow Trend on Segments and Congestion Analysis

The directional traffic flow analysis with respect to some geometric features of the existing infrastructure is related to check the LOS, Capacity and other performance measures of the two segments.

As it is clearly seen from the worksheet, analysis of the HCM 2000 adaptation procedures in segment one both the maximum and average hourly traffic volumes associated with the existing infrastructure parameters and related tabular constants are utilized. Thus, the output of the worksheet concludes that the segment is currently serving near to capacity with the overall Level of Service (LOS) of E. That means, taking the maximum 1691 veh/hr from the traffic flow data for the segment, the average travel speed (ATS) in km/hr is 45.15(E) and percent time spent following PTSF (%) is 81.63 (E), indicating that the overall LOS to E. In relation to other performance measures, the Volume to Capacity is 0.74 i.e. almost near the peak hour capacity. The peak 15 minute and hour vehicle-kilometers of travel are respectively 2,314 and 8,793. Finally, the peak 15 minutes total travel time shows 51.25.

Similarly, for segment two maximum hourly traffic volumes of 1200 veh/hr from the traffic flow data for the segment, the average travel speed (ATS) in km/hr is 53.31(E) and percent time spent following PTSF (%) is 83.52(E), indicating that the overall LOS to E. In relation to other performance measures, the Volume to Capacity is 0.52 i.e. more than half of peak hour capacity. The peak 15 minute and hour vehicle-kilometers of travel are respectively 4,326 and 16,440. Finally, the peak 15 minutes total travel time shows 81.14.

5.2. Traffic Congestion Effect on Accident

The traffic accident trend within the time of a day has been studied by different researchers Girma (2000), Fanuel (2006) and Bitew (2002). Based on the peak trends of both traffic volume and traffic accident during morning and evening time, all the previous researchers conclude that there is a relationship between traffic flow and traffic accident. However, none of the researches showed the relationship between traffic congestion parameters and traffic accident. It is true that the more vehicles in the road the more likely collision would happen. However, the researcher of this paper doesn't believe that traffic flow or volume is the right parameter to be related with traffic accident. For instance at a freeway we can have the highest traffic flow or volume than other road sections. However, more of traffic accidents can happen at other section of the road.

As it is indicated on Girma (2000) and other report data "Drivers error or behavior" is highly quoted as the main (93%) cause of traffic accident in Addis Ababa accounting more than 93% of the accident. The main mistakes listed under driver's error and causing about 85% of the total accident are; *driving on the wrong side, failure to give way, following too close, improper overtaking, speeding, improper turning.*

As it can be seen together with other road and environmental factors, behavioral factors contribute a lot for the traffic accident in Addis Ababa. Hence, the researcher of this paper believes that having the other road parameters constant, traffic accident would be more related with the behavioral and vehicle to vehicle headway factors than the traffic volume or flow. One of the factors that affect driver behavior is the stress and frustration resulted from delay due to traffic congestion. A questioner result showed that out of 20 drivers interviewed 17 (85%)

responded that the traffic congestion make them to stress and frustrate which make them to misbehave and commit wrong driving.

The effect of traffic congestion on drivers or commuters can be easily understood by the amount of delay or by the travel rate. Hence, correlation was made with the traffic accident and traffic volume as shown above in Figures 42 & 43. According to the result, traffic accident shows a lower R^2 or goodness of fit result for traffic volume or flow which indicates as such not better relation or fitness with traffic volume.

Further to the correlation between the traffic volume and traffic accident, the assessment of traffic accident spots and congestion spots shows a clear relationship among the traffic accident and traffic congestion in Addis Ababa. The traffic spots plotted in the GIS map of Figure 47 are identified by Ethiopian Road Safety Agency and the traffic congestion spots are identified from the questioner result. Plotting the two spot on a single GIS map shows that most of the traffic accident and congestion happen at or near intersection and all the identified congestion spots fits with the accident black spots.

Therefore, the link between the traffic accident and the traffic congestion in Addis Ababa is so significant and the researcher believes efforts made to mitigate the traffic congestion will also minimize the traffic accident.

Conversely, as it is clearly observed on the segments traffic accidents and road side parking are aggravating the incidence and the formation of traffic line up or queuing which in turn results in the probability of traffic congestion lowering the capacity and level of service of the infrastructure.

On the other hand, one can argue congestion can reduce the high speeds on expressways and as a result of that the accident rate is reduced. But in a congested road section vehicles are closely packed and as a result of that rear - end collisions, back-up collisions as well as side collisions can occur.

5.3. Assessing the Effect of Heavy Vehicles on the Congested Traffic Stream

An investigation into the effect of heavy vehicles on traffic flow during congestion is presented in this section. Several factors that are thought of as determinants of this effect were considered in this investigation. Passenger car equivalency factors applicable in HCM 2000 and HDM were utilized as an indicator of heavy vehicles' effect. While study results suggest some similarities between free-flow and congested traffic regimes concerning heavy vehicles' effect, some important differences exist due to the different mechanisms that govern heavy vehicles' performance in the two regimes. Also, lane-use restriction and the location of bottleneck relative to upgrade were found to have considerable influence on heavy vehicles' effect during congestion.

5.3.1. The Effect of Grade

In general, heavy vehicles exhibit inferior performance on highway upgrades and particularly on steeper upgrades. This is true when traffic operates at the free-flow (non-congested) regime as well as at the forced flow (congested) regime. At the free-flow regime on level terrain, the effect of heavy vehicles is mainly attributed to the larger space taken up by those vehicles due to its larger dimensions (in general) and the larger gaps in front of and behind these vehicles. At the free-flow regime on upgrades, the effect of heavy vehicles may also be attributed to traveling at crawling speed which could be considerably lower than the speed of passenger cars. After the onset of congestion, another important factor contributes to the effect of heavy vehicles both on level terrain and on upgrades. This factor is the inferior acceleration performance of trucks during stop-and-go conditions, or upon leaving the front end of the queue.

5.3.2. The Effect of Grade Length

Grade length is another important factor that is believed to have an important influence in determining the effect of HVs on traffic flow. As grade length increases the effect of heavy vehicles actually seen on the PCE as higher grades have significantly lower performance rates on the heavy vehicles than level grades.

5.3.3. The Effect of Heavy Vehicles' Percentages

The influence of the proportion of heavy vehicles on the PCE factor generally shows that a small increase in the PCE factor as the percentage of heavy vehicles increases.

The first phenomenon is that as the number of heavy vehicles increases, the likelihood of occupying the two lanes at the location of bottleneck by heavy vehicles would increase thus increasing the impedance to traffic and consequently the PCE factor. The other phenomenon is that higher percentage of heavy vehicles would increase the likelihood of successive arrivals of heavy vehicles at the bottleneck location (platooning). The effect of these successive arrivals (platoons) of heavy vehicles on smaller vehicles in the traffic stream would be noticeably lower than the sum of their individual effects on traffic if arrived separately. Heavy vehicles accelerating on the upgrade at the location of bottleneck would cause less impedance on other heavy vehicles than on passenger cars and other smaller vehicles. Apparently, the impact of the first phenomenon is dominant at level terrain and low grades while the impact of the second phenomenon is more evident at steeper grades where the acceleration performance of heavy vehicles climbing the upgrade becomes an issue.

5.3.4. The Effect of Lane-Use Restriction

Restrictions on the use of the traveled lanes by all or some heavy vehicles may have an important influence on their effect on traffic flow. This is expected as lane-use restriction rules will result in some kind of partial segregation between the smaller vehicles (mainly automobiles) and heavy vehicles. However, the parameter, the effect of lane – use restriction is not observed in this section since there is no such condition on the studied segments.

5.3.5. The Effect of Location of Bottleneck Relative to Upgrade

The location of bottleneck relative to upgrade is expected to have an effect on the PCE factor for heavy vehicles. This expectation is based on the fact that the impedance imposed by heavy vehicles on passenger cars during stop-and-go conditions is different when the queue occupies a level highway segment or an upgrade segment.

As acceleration performance of trucks and other heavy vehicles is greatly affected on grades, it is logical to expect that the PCE factor when the bottleneck is at the top of upgrade would be higher than the PCE factor when the bottleneck is at the bottom of upgrade.

6. 0. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

This thesis discusses segmental assessment of level of traffic congestion on the selected section of the road by splitting into two segments that is segment one the city section Kality RR (commonly *Maseltegna*) to Akaki - Tulu Dimtu 11.2km which in turn is subdivided into 6.0km multilane town section and 5.2km two lane two way town section for the categorized analysis. The other segment, the Akaki - Tulu Dimtu to Dukem Bridge (North) 13.7km intercity section is also treated as two lane two way segmental analysis. The study included both the Addis Ababa city section and its peripheral Oromia region intercity road segment on the nation's largest south east skirt trunk road corridor.

The traffic flow on the two directional two way two lane segments is almost the same with 50/50 directional split and 95% peak hour factor. Due to prevalence of low mobility and business activity, traffic congestion during the evening peak hour is more than that of the morning peak hours and during the mid day the roads are relatively uncongested provided that there is no occurrence of traffic accidents and or excessive illegal road side parking.

The traffic congestion or bottlenecks on Kality round about area, Kality bus station intersection and Tulu Dimtu customs station have a significant effect on the overall traffic flow pattern on the selected road segments. Both segments in the north-south study corridor of Addis Ababa and Oromia Special Zone are currently performing on their capacity and during the peak periods the volume to capacity ratio is greater than 70% for the first segment and 50% for the second segment and the overall level of service for both falls to LOS of ***E***.

During both morning and evening peak periods about half to an hour and one hour of the travel time are needed to travel the 5.2km Kality bus station to Tulu Dimtu and Tulu Dimtu to Dukem Bridge (North) 13.7km two way segments, respectively. The correlation and spot analysis indicated that the traffic congestion in Addis Ababa and its immediate periphery is strongly linked with the traffic accident.

Results suggest that the effect of heavy vehicles when the location of bottleneck is at the top of the upgrade (or at any other point on the upgrade) is higher than the effect when the bottleneck is at the bottom of the upgrade. Similar to traffic operations at free-flow conditions, the effect of heavy vehicles increases with the increase in grade percentage on a congested traffic stream as have been observed on simulation model for PCEs/PCSEs.

6.2. Recommendations

The thesis work on *segmental assessment of level of traffic congestion on Kality RR to Dukem Bridge section* suggests that more studies should be conducted to understand the impact of congestion on traffic accidents and the counter effect as well. The study proposes High, Medium and Low cost engineering associated countermeasures which are recommended to reduce the level of road traffic congestion and its impacts along these segments either through traffic management procedures or building better infrastructure development which of them best fits to the nation's economical level.

The policy makers shall deduce relevant measures to minimize the external costs of both traffic accidents and traffic congestion especially by implementing appropriate transportation system management that is optimizing system capacity operations through HOV priority systems, carpooling programs, pricing, and utilization of integrated ITS technologies making trade of with development of different integrated demand and supply management approaches for reduction of traffic congestion in Addis Ababa and its immediate periphery.

Traffic congestion is a product of both supply - and demand - side factors, addressing the demand-side causes is essential for effective managing it. Transportation Demand Management (TDM) involves a range of strategies that can reduce traffic congestion by encouraging reduced car commuting at critical locations. It contrasts with supply-side that is Transportation Supply Management (TSM) approaches that seeks to relieve congestion by supplying extra road space. In absence of demand management strategies demonstrates that the city's, in particular and the nation's in general, main approach to congestion remains dominated by expensive supply - side initiatives, focused on expanding road and public transport capacity.

TDM has not been effectively used in Addis as a tool for managing traffic congestion rather than that of TSM demanding expensive investments in expanding the infrastructure capacity of the city. In addition to increasing road capacity, strategies addressing the demand -side causes can also assist in reducing demand for road travel and associated congestion. Hence, the development of different appropriate integrated demand and supply management approaches by way of securing sufficient budget for the reduction of traffic congestion is a vital issue in the current situation of the city, Addis and its surrounding intercity road segments. So, implications for future investment decisions of the nation (the city in particular) should consider integration of these TDM & TSM approaches for mitigation of traffic congestion in Addis Ababa and its periphery.

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APPENDICES

APPENDIX A:

TRAFFIC VOLUME DATA

Traffic Count Format

Location____________________ Direction__________________

Date______/______/______

Enumerator: _________________ Supervisor: _________Weather Condition: ______

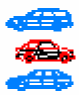
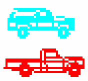
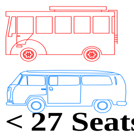
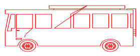
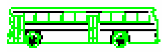
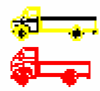
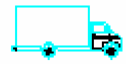
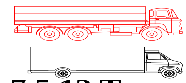
Hourly Interval	Car 	Land Rover 	Small Bus  < 27 Seats	Medium Bus  27-45 Seats	Large Bus  >45 Seats	Small Truck  3.5 Tones	Medium Truck  7.5Tones	H/Truck  7.5-12 Tones
12-1								
1-2								
2-3								
3-4								
Sub Total								
Grand Total								

Chart 9: Traffic Count Formats

A1: Addis Ababa/Kality Akaki/Tulu Dimtu 11.2km Segment

VEHICLE TYPES	YEARS												
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average
CAR	3739	3826	4663	5248	7465	8873	9461	9668	9806	7023	5335	4972	**2944**	**6919**
BUS	3508	3447	4518	4948	6651	7740	8418	8364	9430	6806	4969	5082	**3471**	**6446**
TRUCK	4382	5083	6060	8633	9222	11164	12514	12177	15970	11461	9206	9337	**6554**	**10122**
TRUK&TRAILER	1210	1709	1894	2965	3266	3998	4418	4164	5385	4141	3624	3775	**2315**	**3575**
TOTAL(Vehicles)	12839	14065	17135	21794	26604	31775	34811	34373	40591	29431	23134	23166	**14984**	**27059**
TOTAL(PCU)	25945	29409	35478	47104	55253	66256	73045	71413	87439	63781	50972	51691	**33624**	**57617**
Total Hvs.	6851	8135	9640	13732	14658	17602	19740	19194	25393	18510	14711	15189	**9857**	**16101**
Total Hvs. (%)	53.36	57.84	56.26	63.01	55.10	55.40	56.71	55.84	62.56	62.89	63.59	65.57	**65.78**	**64**
Rec.(S.Buses)	2249	2104	2832	2814	4481	5300	5610	5511	5392	3898	3088	3005	**2183**	**4039**
Rec.%	17.52	14.96	16.53	12.91	16.84	16.68	16.12	16.03	13.28	13.24	13.35	12.97	**14.57**	**16.25**
Growth Rate (%)		9.55	33.46	69.75	107.21	147.49	171.13	167.72	216.15	129.23	80.19	80.43	**16.71**	**102.42**

A2: Akaki/Tulu Dimtu – Dukem 13.7km Segment

VEHICLE TYPE	YEARS												
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average
CAR	2453	3001	3208	2946	3195	4096	4063	4864	4880	6828	4664	5571	**2841**	**4384**
BUS	1270	1628	1783	2433	2929	3441	3928	4179	4521	6705	4746	5736	**3165**	**3872**
TRUCK	2785	3248	3403	4361	5037	4652	5832	6793	7454	11225	8944	9952	**5732**	**6618**
TRUK&TRAILER	892	957	1159	1634	1697	2472	2279	2468	2603	4042	3559	4015	**2461**	**2520**
TOTAL(Vehicles)	7400	8834	9553	11374	12858	14661	16102	18304	19458	28800	21913	25274	**14199**	**17394**
TOTAL(PCU)	15078	17727	19338	24434	27585	31260	34476	38843	41668	62448	48973	55976	**32115**	**37493**
Total Hvs.	4298	4964	5373	7140	7859	8551	9743	10728	11891	18016	14560	16364	**9502**	**10749**
Total Hvs. (%)	58.08	56.19	56.24	62.77	61.12	58.32	60.51	58.61	61.11	62.56	66.44	64.75	**66.92**	**66**
Rec.(S.Buses)	649	869	972	1288	1804	2014	2296	2712	2687	3956	2689	3339	**1856**	**2261**
Rec.%	8.77	9.84	10.17	11.32	14.03	13.74	14.26	14.82	13.81	13.74	12.27	13.21	**13.07**	**14**
Growth Rate (%)		19.38	29.09	53.70	73.76	98.12	117.59	147.35	162.95	289.19	196.12	241.54	**91.88**	**127**

APPENDIX B:

LEVEL OF SERVICE ANALYSIS WORK SHEET USING HCM 2000

B1: Two Ways – Two Lane Highway Work Sheet Segment 1 on Average

General Information	**Site Information**
Analyst: ____________________ Agency/Company: ____________ Date Performed: ______________ Analysis Time Period: _________	Highway: _____________*segement 1*______ From/To: *Kality (Round About) to Tulu Dimtu* Jurisdiction: ______________________ Analysis Year: ____________________
☐ Operational(LoS) ☐ Design(Vp) ☐ Planning (LoS) ☐ Planning (Vp)	
Input Data	
1.2 m *3.4* m Segment Length, Lt = *5.2* km	☐ Class I HW ☐ Class II HW Terrain ☐ Level ☐ Rolling Two way hourly volume *1127* *(Avg.)* Veh/hr Directional Split *50/50* Peak Hour Factor, PHF *0.95* % Trucks & Buses, Pt *64 %* % Recreational Vehicles, Pr *16.25 %* % No- Passing Zone *50 %* Access Points/km *3* / km
Average Travel Speed	
Grade Adjustment Factor, $f_{G\ (Exhibit\ 20\text{-}6)}$	*0.99*
Passenger Car Equivalency for Trucks, $E_{T(Ex\ 20\text{-}8)}$	*1.5*
Passenger Car Equivalency for RVs, $E_{R(Exh.\ 20\text{-}8)}$	*1.1*
Heavy Vehicle Adjustment Factor, f_{HV}	*0.748*
Two way Flow Rate, V_p (Pc/hr)	*1601*
V_p*Highest directional speed from field measure	*801*
Free Flow Speed from Field Measurement	**Estimated Free Flow Speed**
Field Measured Speed, S_{FM} ___________km/hr Observed Volume, V_f ________________Veh/hr Free Flow Speed, FFS _______________ km/hr $FFS = S_{FM} + 0.0125\ (V / f_{HV})$	Base free-flow speed, BFFS *80* km/h Adj.for lane width and shoulder width, $f_{LS(Exh.\ 20\text{-}4)}$ *2.8* km/h Adj. for access points, $f_{A\ (Exhibit\ 20\text{-}5)}$ *1.25* km/h Free-flow speed, FFS *75.95* km/h $FFS = BFFS - f_{LS} - f_{A} = 80 - 2.8 – 1.25 = 75.95$
Adj. for no-passing zones, f_{np} (km/h)$_{(Exhibit\ 20\text{-}10)}$	*1.5*
Average travel speed, ATS (km/h) $ATS = FFS - 0.0125v_p - f_{np}$	*54.44(E) Refer Table 16 above*
Percent Time Spent Following	
Grade Adjustment Factor, $f_{G\ (Exhibit\ 20\text{-}7)}$	*1.00*
Passenger Car Equivalency for Trucks, $E_{T\ (Exh.\ 20\text{-}9)}$	*1.0*
Passenger Car Equivalency for RVs, $E_{R\ (Exh.\ 20\text{-}9)}$	*1.0*

Heavy Vehicle Adjustment Factor, f_{HV}	*1.000*
Two way Flow Rate, V_p (Pc/hr)	*1186*
V_p*Highest directional speed from field measure	*593*
Base percent time spent following, BPTSF (%) $BPTSF = 100(1 - e^{-0.000879Vp})$	*64.74*
Adj. for directional distribution and no-passing zone, fd/np (%)(Exhibit 20-11)	9.9
Percent time spent following, PTSF (%) $PTSF = BPTSF + f_{d}/_{np}$	*74.64(D)Refer Table 16 above*
Level of Service and Other Performance Measures	
Level of service, LOS	***E***
Volume-to-Capacity ratio, v/c $_{V/C} = V_p/3200$	*0.49*
Peak 15-minute vehicles-kilometers of travel, VKT_{15} (veh-km) $VKT_{15} = 0.25L_t$ (V/PHF)	*1,542*
Peak hour vehicle-kilometers of travel, VKT_{60} (veh-km) $VKT_{60} = VL_t$	*5,860*
Peak 15-minute total travel time, TT_{15} (veh-h) $TT_{15} = VKT_{15}/ ATS$	***28.17***
Notes	
1. If vp ≥ 3200 pc/h, terminate further analysis. LOS F will occur. 2. If highest directional split vp ≥ 1700 pc/h, terminate further analysis. LOS F will occur.	

B2: Two Ways – Two Lane Highway Work Sheet Segment 1 on Maximum

General Information	**Site Information**
Analyst: ______________________ Agency/Company: _____________ Date Performed: ________________ Analysis Time Period: __________	Highway: _______________*segement 1*_______ From/To: *Kality (Round About) to Tulu Dimtu* Jurisdiction: ________________________ Analysis Year: ______________________
☐ Operational(LoS) ☐ Design(Vp) ☐ Planning (LoS) ☐ Planning (Vp)	
Input Data	
1.2 m *3.4* m Segment Length, Lt = *5.2* km	☐ Class I HW ☐ Class II HW Terrain ☐ Level ☐ Rolling Two way hourly volume *1691* *(Max.2010)*Veh/hr Directional Split *50/50* Peak Hour Factor, PHF *0.95* % Trucks & Buses, Pt *64 %* % Recreational Vehicles, Pr *16.25 %* % No- Passing Zone *50 %* Access Points/km *3* / km
Average Travel Speed	
Grade Adjustment Factor, $f_{G\ (Exhibit\ 20\text{-}6)}$	*0.99*
Passenger Car Equivalency for Trucks,$E_{T(Ex\ 20\text{-}8)}$	*1.5*
Passenger Car Equivalency for RVs, $E_{R(Exh.\ 20\text{-}8)}$	*1.1*
Heavy Vehicle Adjustment Factor,f_{HV}	*0.763*
Two way Flow Rate, V_p (Pc/hr)	*2356*
V_p*Highest directional speed from field measure	*1178*
Free Flow Speed from Field Measurement	**Estimated Free Flow Speed**
Field Measured Speed, S_{FM} ____________km/hr Observed Volume, V_f _________________Veh/hr Free Flow Speed, FFS ________________ km/hr FFS = S_{FM} + 0.0125 (V /f_{HV})	Base free-flow speed, BFFS *80* km/h Adj.for lane width and shoulder width, $f_{LS(Exh.\ 20\text{-}4)}$ *2.8* km/h Adj. for access points, $f_{A\ (Exhibit\ 20\text{-}5)}$ *1.25* km/h Free-flow speed, FFS *75.95* km/h FFS = BFFS - f_{LS} - f_A = 80 - 2.8 – 1.25 = 75.95
Adj. for no-passing zones, f_{np} (km/h)$_{(Exhibit\ 20\text{-}10)}$	*1.35*
Average travel speed, ATS (km/h) ATS = FFS - 0.0125v_p - f_{np}	*45.15 (E)Refer Table 16 above*

Percent Time Spent Following	
Grade Adjustment Factor, f_{G} (Exhibit 20-7)	*1.00*
Passenger Car Equivalency for Trucks, E_R (Exh. 20-9)	*1.0*
Passenger Car Equivalency for RVs, E_R (Exh. 20-9)	*1.0*
Heavy Vehicle Adjustment Factor,f_{HV}	*1.000*
Two way Flow Rate, V_p (Pc/hr)	*1780*
V_p*Highest directional speed from field measure	*890*
Base percent time spent following, BPTSF (%) BPTSF = $100(1 - e^{-0.000879Vp})$	*79.10*
Adj. for directional distribution and no-passing zone, fd/np (%)(Exh. 20-11)	2.55
Percent time spent following, PTSF (%) PTSF = BPTSF + $f_d/_{np}$	*81.63(E)Refer Table 16 above*
Level of Service and Other Performance Measures	
Level of service, LOS	***E***
Volume-to-Capacity ratio, v/c $_{V/C}$ = $V_p/3200$	*0.74*
Peak 15-minute vehicles-kilometers of travel, VKT_{15} (veh-km) $VKT_{15} = 0.25L_t$ (V/PHF)	*2,314*
Peak hour vehicle-kilometers of travel, VKT_{60} (veh-km) $VKT_{60} = VL_t$	*8,793*
Peak 15-minute total travel time, TT_{15} (veh-h) $TT_{15} = VKT_{15}$/ ATS	***51.25***
Notes	
1. If vp ≥ 3200 pc/h, terminate further analysis. LOS F will occur. 2. If highest directional split vp ≥ 1700 pc/h, terminate further analysis. LOS F will occur.	

B3: Two Ways – Two Lane Highway Work Sheet Segment 2 on Average Veh/hr

General Information	**Site Information**
Analyst: ____________________ Agency/Company: ____________ Date Performed: ______________ Analysis Time Period: _________	Highway: segement 2 From/To: Tulu Dimtu to Dukem Bridge Jurisdiction: _____________________ Analysis Year: ____________________
☑ Operational(LoS) ☐ Design(Vp) ☐ Planning (LoS) ☐ Planning (Vp)	
Input Data	
1.2 m *3.4* m Segment Length, Lt = *13.7* km	☑ Class I HW ☐ Class II HW Terrain ☐ Level ☑ Rolling Two way hourly volume *725 (Avg.)* Veh/hr Directional Split *50/50* Peak Hour Factor, PHF *0.95* % Trucks & Buses, Pt *66 %* % Recreational Vehicles, Pr *14 %* % No- Passing Zone *50 %* Access Points/km *2* / km
Average Travel Speed	
Grade Adjustment Factor, f_{G} (Exhibit 20-6)	*0.99*
Passenger Car Equivalency for Trucks, E_{T} (Ex 20-8)	*1.9*
Passenger Car Equivalency for RVs, E_{R} (Exh. 20-8)	*1.1*
Heavy Vehicle Adjustment Factor, f_{HV}	*0.622*
Two way Flow Rate, V_p (Pc/hr)	*1240*
V_p*Highest directional speed from field measure	*620*
Free Flow Speed from Field Measurement	**Estimated Free Flow Speed**
Field Measured Speed, S_{FM} ___________km/hr Observed Volume, V_f ________________Veh/hr Free Flow Speed, FFS _______________ km/hr $FFS = S_{FM} + 0.0125\ (V / f_{HV})$	Base free-flow speed, BFFS 80 km/h Adj.for lane width and shoulder width, f_{LS} (Exh. 20-4) *2.8* km/h Adj. for access points, f_A (Exhibit 20-5) *1.2* km/h Free-flow speed, FFS *76* km/h $FFS = BFFS - f_{LS} - f_{A} = 80 - 2.8 – 1.2 = 76$
Adj. for no-passing zones, f_{np} (km/h)(Exhibit 20-10)	*2.3*
Average travel speed, ATS (km/h) $ATS = FFS - 0.0125v_p - f_{np}$	*58.2 (E) Refer Table 16 above*
Percent Time Spent Following	
Grade Adjustment Factor, f_{G} (Exhibit 20-7)	*1.00*
Passenger Car Equivalency for Trucks, E_{T} (Exh. 20-9)	*1.0*
Passenger Car Equivalency for RVs, E_{R} (Exh. 20-9)	*1.0*

Heavy Vehicle Adjustment Factor, f_{HV}	*1.000*
Two way Flow Rate, V_p (Pc/hr)	*763*
V_p*Highest directional speed from field measure	*382*
Base percent time spent following, BPTSF (%) $BPTSF = 100(1 - e^{-0.000879Vp})$	*48.86*
Adj. for directional distribution and no-passing zone, fd/np (%)(Exhibit 20-11)	6.8
Percent time spent following, PTSF (%) $PTSF = BPTSF + f_d/_{np}$	*55.66 (C)Refer Table 15 above*
Level of Service and Other Performance Measures	
Level of service, LOS	***E***
Volume-to-Capacity ratio, v/c $_{V/C} = V_p/3200$	*0.39*
Peak 15-minute vehicles-kilometers of travel, VKT_{15} (veh-km) $VKT_{15} = 0.25L_t$ (V/PHF)	*2613*
Peak hour vehicle-kilometers of travel, VKT_{60} (veh-km) $VKT_{60} = VL_t$	*9932*
Peak 15-minute total travel time, TT_{15} (veh-h) $TT_{15} = VKT_{15}/ ATS$	*44.90*
Notes	
1. If vp ≥ 3200 pc/h, terminate further analysis. LOS F will occur. 2. If highest directional split vp ≥ 1700 pc/h, terminate further analysis. LOS F will occur.	

B4: Two Ways – Two Lane Highway Work Sheet Segment 2 on Maximum Veh/hr

General Information	**Site Information**
Analyst: ____________________ Agency/Company: ____________ Date Performed: ______________ Analysis Time Period: _________	Highway: segement 2 From/To: Tulu Dimtu to Dukem Bridge Jurisdiction: ______________________ Analysis Year: ___________________
☑ Operational(LoS) ☐ Design(Vp) ☐ Planning (LoS) ☐ Planning (Vp)	
Input Data	
1.2 m *3.4* m Segment Length, Lt =*13.7* km	☑ Class I HW ☐ Class II HW Terrain ☐ Level ☑ Rolling Two way hourly volume *1200* *(Max.2011)*Veh/hr Directional Split *50/50* Peak Hour Factor, PHF *0.95* % Trucks & Buses, Pt *66 %* % Recreational Vehicles, Pr *14 %* % No- Passing Zone *50 %* Access Points/km *2* / km
Average Travel Speed	
Grade Adjustment Factor, $f_{G\ (Exhibit\ 20\text{-}6)}$	*0.99*
Passenger Car Equivalency for Trucks,$E_{T(Ex\ 20\text{-}8)}$	*1.5*
Passenger Car Equivalency for RVs, $E_{R(Exh.\ 20\text{-}8)}$	*1.1*
Heavy Vehicle Adjustment Factor,f_{HV}	*0.760*
Two way Flow Rate, V_p (Pc/hr)	*1679*
V_p*Highest directional speed from field measure	*839*
Free Flow Speed from Field Measurement	**Estimated Free Flow Speed**
Field Measured Speed, S_{FM} ___________km/hr Observed Volume, V_f _______________Veh/hr Free Flow Speed, FFS ______________ km/hr $FFS = S_{FM} + 0.0125 (V / f_{HV})$	Base free-flow speed, BFFS *80* km/h Adj.for lane width and shoulder width, $f_{LS(Exh.\ 20\text{-}4)}$ *2.8* km/h Adj. for access points, $f_{A\ (Exhibit\ 20\text{-}5)}$ *1.2* km/h Free-flow speed, FFS *76* km/h $FFS = BFFS - f_{LS} - f_A = 80 - 2.8 – 1.2 = 76$
Adj. for no-passing zones, f_{np} (km/h)$_{(Exhibit\ 20\text{-}10)}$	*1.7*
Average travel speed, ATS (km/h) $ATS = FFS - 0.0125v_p - f_{np}$	*53.31(E) Refer Table 14 above*
Percent Time Spent Following	
Grade Adjustment Factor, $f_{G\ (Exhibit\ 20\text{-}7)}$	*1.00*
Passenger Car Equivalency for Trucks, $E_{T\ (Exh.\ 20\text{-}9)}$	*1.9*
Passenger Car Equivalency for RVs, $E_{R\ (Exh.\ 20\text{-}9)}$	*1.0*
Heavy Vehicle Adjustment Factor,f_{HV}	*1.000*
Two way Flow Rate, V_p (Pc/hr)	*2051*

V_p*Highest directional speed from field measure	*1026*
Base percent time spent following, BPTSF (%) BPTSF = $100(1 - e^{-0.000879Vp})$	*83.52*
Adj. for directional distribution and no-passing zone, fd/np (%)(Exhibit 20-11)	9.7
Percent time spent following, PTSF (%) PTSF = BPTSF + $f_d/_{np}$	*93.52(E) Refer Table 14 above*
Level of Service and Other Performance Measures	
Level of service, LOS	***E***
Volume-to-Capacity ratio, v/c $_{V/C} = V_p/3200$	*0.52*
Peak 15-minute vehicles-kilometers of travel, VKT_{15} (veh-km) $VKT_{15} = 0.25L_t$ (V/PHF)	*4,326*
Peak hour vehicle-kilometers of travel, VKT_{60} (veh-km) $VKT_{60} = VL_t$	*16,440*
Peak 15-minute total travel time, TT_{15} (veh-h) $TT_{15} = VKT_{15}/$ ATS	*81.14*
Notes	
1. If vp ≥ 3200 pc/h, terminate further analysis. LOS F will occur. 2. If highest directional split vp ≥ 1700 pc/h, terminate further analysis. LOS F will occur.	

MULTILANE HIGHWAYS WORKSHEET

General Information

Analyst: Solomon S.
Agency or Company: AAiT/Thesis Purpose
Date Performed: 5/16/2015
Analysis Time Period: AM

Site Information

Highway/Direction of Travel: KA TD (East)
From/To: KA - TD
Jurisdiction: ______
Analysis Year: 2015

☒ Oper. (LOS) ☐ Des. (N) ☐ Des. (v_p) ☐ Plan. (LOS) ☐ Plan. (N) ☐ Plan. (v_p)

Flow Inputs

Volume, V: 1691 veh/h
Peak-hour factor, PHF: 0.95
Annual avg. daily traffic, AADT ______ veh/day
% Trucks and buses, P_T: 6 4
Peak-hour proportion of AADT, K ______
% RV's, P_R: 16.25
Peak-hour direction proportion, D ______
General terrain: ☒ Level ☐ Rolling ☐ Mountainous
DDHV = AADT * K * D ______ veh/h
Grade: Length 6 km Up/Down ______ %
Driver type: ☒ Commuter/Weekday ☐ Recreational/Weekend
Number of lanes: 2

Calculate Flow Adjustments

f_p: 1.00
E_T: 1.5
E_R: 1.1
$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$: 0.763

Speed Inputs

Lane width, LW: 3.2 m
Total lateral clearance, LC: 2.4 m
Access points, A: 6 A/km
Median type, M: ☒ Undivided ☐ Divided
FFS (measured): 64.9 km/h
Base free-flow Speed, BFFS: 65+11= 76 km/h

Calculate Speed Adjustments and FFS

f_{LW}: 5.6 km/h
f_{LC}: 1.5 km/h
f_A: 4.0 km/h
f_M: 0.0 km/h
FFS = BFFS - f_{LW} - f_{LC} - f_A - f_M: 64.9 km/h

Operational, Planning (LOS); Design, Planning (v_p)

Operational (LOS) or Planning (LOS)

$v_p = \frac{V \text{ or } DDHV}{(PHF * N * f_{HV} * f_p)}$: 1167 pc/h/ln
S: 64.9 km/h
D = v_p/S: 17.98 pc/km/ln
LOS: D

Design (v_p) or Planning (v_p)

LOS ______
v_p ______ pc/h/ln
V = v_p * PHF * N * f_{HV} * f_p ______ veh/h
S ______ km/h
D = v_p/S ______ pc/km/ln

Design, Planning (N)

Design (N) or Planning (N) 1st Iteration

N ______ assumed
$v_p = \frac{V \text{ or } DDHV}{(PHF * N * f_{HV} * f_p)}$ ______ pc/h/ln
LOS

Design (N) or Planning (N) 2nd Iteration

N ______ assumed
$v_p = \frac{V \text{ or } DDHV}{(PHF * N * f_{HV} * f_p)}$ ______ pc/h/ln
LOS
S ______ km/h
D = v_p/S ______ pc/km/ln

Glossary

N	- Number of lanes	S	- Speed
V	- Hourly volume	D	- Density
v_p	- Flow rate	FFS	- Free-flow speed
LOS	- Level of service	BFFS	- Base free-flow speed
DDHV	- Directional design hour volume		

Factor Location

E_T	- Exhibit 21-8, 21-9, 21-11	f_{LW}	- Exhibit 21-4		
E_R	- Exhibit 21-8, 21-10	f_{LC}	- Exhibit 21-5 f_p	f_M	- Exhibit 21-6
LOS, S, FFS, v_p	- Exhibit 21-2, 21-3	f_A	- Exhibit 21-7		

The Results Level of service = D

Speed = 64.9 km/h

Density = 17.98 pc/km/ln

Flow Rate = 1167 pc/h/ln

APPENDIX C:

TRAFFIC ACCIDENT DATA

C1: Traffic Accident Report (Addis Ababa City Police Commission)

S. No.	Incidence Year(e.c)	Fatal Cause	Serious Cause	Slight Cause	Property Damage	Total No. of Incidence	Property Damage Monetary Value
1	1995	319	528	1360	6129	8336	20,365,227.00
2	1996	305	563	1482	3839	6189	22,436,120.00
3	1997	320	731	1381	8111	10543	26,268,564.00
4	1998	363	833	1261	8557	11014	27,300,115.00
5	1999	347	640	850	7112	8949	23,049,667.00
6	2000	381	594	735	6459	8169	29,603,014.00
7	2001	371	731	576	5845	7523	31,117,838.00
8	2002	318	626	652	4689	6285	29,345,713.00
9	2003	332	904	831	1067	3134	45,728,573.00
10	2004	369	1190	820	9150	11529	52,013,101.00
11	2005	367	1336	1263	12849	15815	72,687,411.00
12	2006						

C2: Traffic Accident Report (Akaki - Kality Sub City Police Commission)

S. No.	Incidence Year(e.c)	Fatal Cause	Serious Cause	Slight Cause	Property Damage	Total No. of Incidence	Property Damage Monetary Value
1	2003	38	120	77	669	904	3,774,380.00
2	2004	44	137	59	993	1233	7,501,930.00
3	2005	34	153	74	1284	1545	7,586,130.00
4	2006	39	161	72	1545	1817	11,956,961.11

C3: Traffic Accident Report (Finfine Zuria Oromia Special Zone Police Commission)

S. No.	Incidence Year(e.c)	Fatal Cause	Serious Cause	Slight Cause	Property Damage	Total No. of Incidence	Property Damage Monetary Value
1	2001	114	116	121	173	524	4,392,300.00
2	2002	114	150	195	278	737	12,096,490.00
3	2003	134	215	302	332	983	15,768,866.00
4	2004	119	166	260	367	912	14,116,995.00
5	2005	114	145	294	397	950	15,992,864.00
6	2006	109	125	208	296	740	7,923,408.00
7	2007						

C4: Traffic Accident Black Spot Report (Akaki - Kality Sub City Police Commission)

Accident Location	no	Type severity	Crash hour	Day of the week	date	Crash Reason
Akaki Kaliti K01/03 Tirunesh Bejing Hospital	1	fatal	1745	Friday	11/2/2002	driving without precaution for pedestrian
Akaki Kaliti Turunesh Bejing Hospital	2	fatal	1500	Saturday	15/8/2003	not dicided
	3					
Akaki Kaliti k07 Near to bridge	4	fatal	1830	Thursday	28/11/2003	out of the roadway
Akaki Kalit k07 Akaki river Bridge	5	fatal	1230	Wednesda	4/4/2004	driving without precausion
Akaki Kaliti k09 Akaki Bridge	6	fatal	1200	Sunday	7/2/2004	driving without precausion
	7					
Akaki kaliti k11/12 Zenbaba Hospital	8	fatal	540	Wednesda	13/11/2003	fall passenger
Akaki Kaliti K12/13 ring road Zenbaba Hospital	9	fatal	805	Sunday	2/12/2004	priority
Akaki Kaliti K12/13 Zenbaba Hospital	10	fatal	1345	Sunday	12/29/2003	rollover and collision with fixed object
	11					
Akaki Kaliti Wereda Jote Kidanemiret	12	fatal	745	Wednesda	5/9/2004	collied with parked vehicle
Akaki Kaliti k09 Kidanemihiret	13	fatal	1330	Friday	6/2/2004	out of the roadway
Akaki Kaliti K08 Jote Kidanemiret	14	fatal	600	Saturday	6/24/2004	priority
Akaki Kaliti 08 Jote Kidane mihiret	15	fatal	1200	Saturday	6/24/2004	priority
	16					
Akaki Kaliti K10/11 Kaliti cheralia	17	fatal	2130	Saturday	2/11/2004	unknown
Akaki Kaliti k10/11 Kaliti cheralia Biscut factory	18	fatal	1600	Saturday	8/27/2004	sidewalk + out of roadway
	19					
Akaki Kaliti k11 Abo Cherch	20	fatal	800	Saturday	11/10/2002	priority
Akaki Kaliti k12/13 Abo Mazoria	21	fatal	1950	Sunday	2/21/2003	priority
Akaki Kaliti k12/13 Saris Abo junction	22	fatal	1120		4/5/2003	priority
Akaki Kaliti k12/13 Ring road Abo Round about	23	fatal	1830	Sunday	2/5/2004	priority
Akaki Kaliti Abo Mazoria	24	fatal	2030	Saturday	8/13/2004	zebra crossing for priority
Akaki Kaliti K12/13 Saris Abo	25	fatal	1930	Saturday	3/23/2004	priority
	26					
Akaki Kaliti k01/03 Fantu Sefer	27	fatal	1700	Friday	3/22/2004	wrong overtaking
Akaki Kaliti K01/03 Fantu Fantu Sefer	28	fatal	830	Tuesday	3/19/2004	not decided
	29					
Akaki Kaliti k05/06 Akaki Police station	30	fatal	545	Friday	6/16/2004	prdestrian sleeped on the sidewalk
Akaki kaliti wereda 08 total police station	31	fatal	130	Friday	10/22/2004	priority
	32					
Akaki kaliti K12/13 Saris Agricultural Marketing e	33	fatai	1500	Tuesday	11/13/2002	priority
Akaki Kaliti K12/13 Saris Agriculture Marketing	34	fatal	1520	Friday	2/7/2003	out of the roadway
	35					
Akaki Kaliti k02/04 Akaki kela	36	fatal	1500	Saturday	12/29/2002	priority
Akaki k02/04 Akaki kela	37	fatal	445	Wednesda	2/3/2003	priority
Akaki kaliti k02/04 Kela	38	fatal	1300	Monday	3/6/2003	rollover
Akakai kaliti k02/04 Akaki kela juction	39	fatal	1530	Wednesda	5/11/2003	vehicle to vehicle collision
Akaki Kaliti k02/04 Akaki Kela	40	fatal	2030	Wednesda	9/1/2004	unknown (driver disappered)
Akaki kaliti k02/04 Kela area Michael Church	41	fatal	1830	Tuesday	11/13/2002	priority
	42					
Akaki Kaliti K12/13 Customs office	43	fatal	1100	Sunday	6/20/2003	priority
Akaki Kaliti K10/11 Kaliti Drivng testing center	44	fatal	2000		19/07/03	priority
Akaki kaliti k12/13 Kaliti Roundabout	45	fatal	1135	Saturday	18/10/2003	driving without precausion
Akaki Kaliti K12/13 Customs	46	fatal	2140	Saturday	30/11/2003	driving without precausion

Akaki Kaliti K12/12 Customs	47	fatal	1530	Thursday	12/4/2003	nose-tail
Akaki Kaliti k12/13 custom offic	48	fatal	940	Saturday	9/11/2004	priority
	49					
Akaki Kaliti k10/11 Kaliti Gebrail church	50	fatal	940	Thursday	13/8/2003	priority
Akaki Kaliti K10/11 Kaliti Gebrail	51	fatal	600	Friday	6/21/2004	priority
Akaki kaliti werda 7 St Gebrail	52	fatal	1000	Sunday	10/3/2004	priority
	53					
Akaki kaliti k09 King Hotel	54	fatal	1900	Sunday	3/5/2003	priority
Akakai Kalit K09 King Hotel	55	fatal	1225	Tuesday	5/24/2003	priority
	56					
Akaki Kaliti k07 K.K. Textile Factory	57	fatal	1330	Wednesda	1/12/2003	fall passenge
Akaki Kaliti k09 K.k. Textile factory	58	fatal	1900	Thursday	9/23/2004	priority
	59					
Akaki Kaliti k10/11 Prison office	60	fatal	2355	Wednesda	1/19/2003	vehicle to vehicle collision
Akaki Kaliti K10/11 Kaliti Prison Office	61	fatal	2400	Monday	19/07/2003	driving without precausion
Akaki Kaliti k10/11 Crawn Hotel	###	fatal	2200	Tuesday	2/14/2004	driving without precausion
	62					
Akakai Kaliti k07 K.K Factory	63	fatal	1110	Monday	6/14/2003	priority
Akaki Kaliti 07 K.k.	64	fatal	1730	Friday	24/10/2003	insufficient overtaking distance
	65					
Akaki kaliti k10 gelan Bulbula river	66	fatal	1100	Saturday	2/27/2003	rollover
Akaki Kaliti k10/11 Medroc	67	fatal	430	Sunday	3/5/2003	priority
Akaki kaliti k07 kebele bars	68	fatal	1530	thuersday	3/16/2003	priority
Akaki Kaliti k10/11 Kaliti health center	69	fatal	650	Sunday	3/26/2003	priority
Akaki Kaliti k12/13	70	fatal	1355	Sunday	3/3/2003	priority
Akaki Kaliti k12/13 Fafa Food Factory	71	fatal	700	Tuesday	4/25/2003	priority
Akaki Kaliti 07 Solomon Blg	72	fatal	1425	Tuesday	5/10/2003	driving without precaution
Akaki Kaliti k01/03 Fero Bridge	73	fatal	2030	Friday	5/27/2003	priority
Akaki Kaliti k01/03	74	fatal	2225	Monday	11/19/2002	wrong directiondriving with negligent
Akakai k07/08/09 Negele Borena Hotel	75	fatal	420	Saturday	12/1/2002	sleep on roadway
Akaki Kaliti K 07 Stadium	76	fatal	2010	Tuesday	6/15/2003	priority
Akaki Kaliti K01/03 Fero Mesque	77	fatal	1320	Friday	6/18/2003	driving without precaution
Akaki Kaliti k10/11 Coffee board	78	fatal	1415	thuersday	6/17/2003	priority
Akaki Kaliti k05/06 Engida Miller	79	fatal	1800	Tuesday	6/15/2003	priority
Akaki kaliti k12/13 Awash Leather Factory	80	fatal	1330	Monday	25/6/2003	vehilce to vehicle collision
Akaki kaliti k12/13 efoyta entrance	81	fatal	2030	Saturday	26/6/2003	Right turn without precausion
Akakai Kaliti 02/04	82	fatal	1545	Wednesda	30/6/2003	priority
Akaki Kaliti 05/06 Sale Hotel	83	fatal	545	Sunday	4/7/2003	without driving licence
Akaki Kaliti k10/11 SABA Engineering	84	fatal	440		12/2/2003	priority
Akaki Kaliti k10/11 Kaliti	85	fatal	615	Wednesda	7/7/2003	priority
Akaki Kaliti K12/13 Addis Sefer	86	fatal	830	Friday	30/7/2003	priority
Akaki Kaliti k10/11 in front ofkifle ketema	87	fatal	2000	Thursday	6/8/2003	priority
Akaki Kaliti k10/11	88	fatal	1300	Friday	14/8/2003	negligently parked vehicle
Akaki Kaliti K12/13	89	fatal	1030	Saturday	1/1/2003	vehicle to vehicle collision and pedestrian
Akaki Kaliti k15 Bedlu bldg	90	fatal	1130	Thursday	20/8/2003	driving without precausion
Akaki Kaliti k12/13 infront of commercial Bank	91	fatal	1600	Saturday	22/8/2003	priority
Akaki Kaliiti K 05/06	92	fatal	1030	Saturday	11/10/2003	driving without precausion
Arada K11/12	93	fatal	1230	Sunday	17/11/2003	backward driving
Akaki kaliti k02/04 Agri Ston Factory	94	fatal	1030	Saturday	23/11/2003	not dicided
Akaki Kaliti k02/04 Tikur Abay Agreggate crusher	95	fatal	1800	Tuesday	9/28/2004	driving without precausion
Akaki Kaliti K12/13 Noh Transport	96	fatal	1130	Sunday	12/8/2003	priority
	97	fatal	1345	Sunday	12/29/2003	rollover and collision with fixed object

Akakai Kaliti k12/13	98	fatal	830	Friday	4/13/2003	priority
Akaki Kaliti k10/11 Green Hotel	99	fatal	2130	Wednesda	1/3/2004	driving without precausion
Akaki Kaliti k12/13 Saris	###	fatal	655	Friday	1/5/2004	priority
Akaki Kaliti K12/13 Shoe Factory	###	fatal	500	Monday	1/8/2004	collision with fixed object
Akaki Kalit k12/13 Fafa Factory	###	fatal	1700	Wednesda	1/10/2004	vehicle to vehicle collision and pedestrian
Akaki K12/13 School Area	###	fatal	900	Friday	1/19/2004	driving without precausion
Akaki Kaliti k10/11 Ring road Kadisko	###	fatal	800	Thursday	2/16/2004	priority
Akaki Kaliti k09 Sert Mariam	###	fatal	1145	Sunday	4/1/2004	rollover
Akaki Kaliti K01/03 world bank village	###	fatal	750	Thursday	4/26/2004	driving without precausion
Akaki Kaliti K02/04 Water development	###	fatal	800	Monday	5/14/2004	priority
Akaki Kaliti Alem Bank	###	fatal	1330	Tuesday	5/17/2004	driving without precausion
Akaki Kaliti k12/13 Kaliti Awash Leatherr factory	###	fatal	930	Tuesday	5/15/2004	wrong overtaking
Akaki Kaliti K01/03 Yeshi Total	###	fatal	345	Saturday	3/30/2004	driving without precausion
Akaki Kaliti K09 Bartina Hotel	###	fatal	1930	Sunday	6/4/2004	driving without precausion
Akakaki Kaliti k12/13	###	fatal	1930	Thursday	6/22/2004	priority
Akaki Kaliti k09 Green Gold	###	fatal	500	Tuesday	7/3/2004	unknown (driver disappered)
Akaki Kaliti K12/13 Saris	###	fatal	1930	Sunday	7/23/2004	priority
Akaki Kaliti 01/03 Mission school	###	fatal	600	Thursday	7/27/2004	collision pedestrian on sidewalk
Akaki Kaliti 09/07 Selam Grocery	###	fatal	1754	Saturday	8/6/2004	priority
Akaki Kaliti K10/11	###	fatal	1645	Monday	8/15/2004	priority
Akaki kaliti k10/11 Taye sefer	###	fatal	1630	Saturday	7/29/2004	driving without precausion
Akaki Kalaiti K01/03	###	fatal	545	Monday	8/22/2004	wrong direction driving
Akaki Kaliti k10/11 kaliti Shoa Backery	###	fatal	1500	Wednesda	6/15/2004	priority
Akaki Kaliti K09 interstete bus terminal	###	fatal	1810	Friday	9/17/2004	priority
Akaki kaliti k10/11 Mamco Facroty entrance	###	fatal	1040		4/9/2004	right turn without precausion
Akaki Kaliti wereda 09 Kilito	###	fatal	1630	Friday	9/24/2004	driving without precausion
Akaki kaliti k12/13 Awash tannary	###	fatal	1800	Wednesda	10/6/2004	priority
Akaki Kaliti k10/11 kaliti school junction	###	fatal	2320	Saturday	10/9/2004	priority
Akaki kaliti k12/13 Adey Abeba factory	###	fatal	1550	Monday	10/11/2004	priority

APPENDIX D:

HAND GPS RAW DATA FOR THE EFFECT OF HEAVY VEHICLES ANALYSIS

D1: Effect of Heavy Vehicles on the Traffic Stream during Congestion

Table D11: **Values of Main Factors to be investigated on Segement 1**

S.No.	FACTORS					Actual Location Name/Indications
	Grade (%)	Grade Length (km)	Cum. % of Heavy Vehicles	Lane Use Restriction by Vehicle Type	Location of Bottleneck w.r.t. Grade	
001	-	-	2	None		T. Bejg. Overpass
2	5.71	0.07	4	None		Akaki R. Bridge(S)
3	6.62	0.11	6	None		Akaki R. Bridge(N)
4	7.87	0.16	8	None		Access 1 (rt)
5	9.03	0.26	10	None		Curve 1
6	9.86	0.36	12	None		Curve 2
7	11.38	0.66	14	None	+	Access 2 (both side)
8	12.07	0.86	16	None		Access 3 (lt)
9	12.64	1.06	18	None		Access 4(rt)
10	12.98	1.16	20	None	+	St.Mary Church
11	13.22	1.26	22	None		Total 1
12	13.8	1.56	24	None		DH Geda Factory
13	14.2	1.76	26	None	+	Akaki Stadium (end of Town Section)
14	15.12	2.16	28	None		Total 2 (Junction to AASTU)
15	15.53	2.96	30	None	+	KAFDAM PLAZA
16	15.75	3.66	32	None	+	Kality Bus Station
17	15.79	4.66	34	None	+	Charalia Factory
18	15.88	5.46	36	None		Gabriel Police Stn.
19	15.93	5.96	38	None		Branching Road
20	16.01	6.66	40	None		Saba Eng. Interchg.
21	16.05	7.16	42	None	+	Akir Enterance
22	16.09	7.66	44	None	+	Wuha Limat Enter
23	16.15	8.36	46	None	+	Dri&Mech. Traing.
24	16.16	8.76	48	None	+	Ring Road/Round
25						

Table D12: **Values of Main Factors to be investigated on Segement 2**

S.No.	FACTORS					Actual Location Name/Indications
	Grade (%)	Grade Length (km)	Cum. % of Heavy Vehicles	Lane Use Restriction by Vehicle Type	Location of Bottleneck w.r.t. Grade	
001	-	-	2	None		Dukem Bridge 3
2	1.88	0.80	4	None		Dukem Bridge 2
3	2.88	1.00	5	None		Dukem Bridge 1
4	8.21	1.30	6	None		Detour Connection
5	11.41	1.80	8	None		Abyssinia 37km
6	15.41	2.30	10	None		
7	19.61	2.80	15	None	+	Near Arose Hotel
8	20.41	3.30	20	None		
9	22.81	3.80	25	None		
10	26.01	4.30	30	None	+	Entrance to Dry Gelan Port
11	28.21	5.80	35	None		Wase Fuel Station
12	29.21	5.90	40	None		Ahead of Wase
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						

D2: GPS Output Raw Data for the Analysis

Type	Identity	Latitude	Longitude	Y-Projection	X-Projection	Altitude	Time
WAYPOINT	70	8.863036	38.800509	979508.3974	477969.6627	2104.36792	2015-02-13T11:45:37Z
WAYPOINT	71	8.866424	38.799055	979883.051	477809.9895	2099.761719	2015-02-13T11:49:41Z
WAYPOINT	72	8.871259	38.796637	980417.7393	477544.4115	2098.726074	2015-02-13T11:50:39Z
WAYPOINT	73	8.872858	38.795877	980594.566	477460.9442	2098.257812	2015-02-13T11:50:59Z
WAYPOINT	74	8.874487	38.795018	980774.7157	477366.5941	2095.00708	2015-02-13T11:51:19Z
WAYPOINT	75	8.876056	38.793133	980948.2948	477159.4305	2086.213379	2015-02-13T11:51:40Z
WAYPOINT	76	8.876417	38.787196	980988.5748	476506.6691	2073.938965	2015-02-13T11:53:02Z
WAYPOINT	77	8.876477	38.785261	980995.3307	476293.9161	2071.345459	2015-02-13T11:53:27Z
WAYPOINT	78	8.876499	38.784598	980997.8052	476221.0195	2071.422119	2015-02-13T11:53:39Z
WAYPOINT	79	8.876591	38.782923	981008.0837	476036.8562	2077.912354	2015-02-13T11:54:04Z
WAYPOINT	80	8.877143	38.781535	981069.2008	475884.279	2084.502686	2015-02-13T11:54:30Z
WAYPOINT	81	8.877901	38.780744	981153.0545	475797.3568	2088.543945	2015-02-13T11:54:49Z
WAYPOINT	82	8.880574	38.77895	981448.6912	475600.2799	2105.690186	2015-02-13T11:55:21Z
WAYPOINT	83	8.882689	38.777571	981682.6105	475448.7981	2115.031738	2015-02-13T11:55:58Z
WAYPOINT	84	8.88403	38.776763	981830.9213	475360.0477	2119.158203	2015-02-13T11:56:26Z
WAYPOINT	85	8.884966	38.776459	981934.4231	475326.6854	2122.131836	2015-02-13T11:56:38Z
WAYPOINT	86	8.887493	38.776112	982213.8246	475288.7016	2128.684326	2015-02-13T11:57:06Z
WAYPOINT	87	8.890897	38.775396	982590.2096	475210.2063	2145.717773	2015-02-13T11:57:42Z
WAYPOINT	88	8.89458	38.773241	982997.5369	474973.5184	2156.787109	2015-02-13T11:58:39Z
WAYPOINT	89	8.896629	38.771179	983224.2085	474746.9486	2159.555176	2015-02-13T12:00:03Z
WAYPOINT	90	8.900927	38.767573	983699.6315	474350.7818	2165.76001	2015-02-13T12:01:33Z
WAYPOINT	91	8.903778	38.766554	984014.9016	474238.947	2171.909424	2015-02-13T12:02:16Z
WAYPOINT	92	8.906138	38.765699	984275.8768	474145.1102	2169.867432	2015-02-13T12:02:58Z
WAYPOINT	93	8.909573	38.764499	984655.7259	474013.4201	2168.517578	2015-02-13T12:03:43Z
WAYPOINT	94	8.912629	38.763387	984993.668	473891.3806	2171.529785	2015-02-13T12:04:57Z
WAYPOINT	95	8.914389	38.762987	985188.2776	473847.5289	2170.854736	2015-02-13T12:05:21Z

Type	Identity	Latitude	Longitude	Y-Projection	X-Projection	Altitude	Time
WAYPOINT	91	8.903778	38.766554	984014.9016	474238.947	2171.909424	2015-02-13T12:02:16Z
WAYPOINT	92	8.906138	38.765699	984275.8768	474145.1102	2169.867432	2015-02-13T12:02:58Z
WAYPOINT	93	8.909573	38.764499	984655.7259	474013.4201	2168.517578	2015-02-13T12:03:43Z
WAYPOINT	94	8.912629	38.763387	984993.668	473891.3806	2171.529785	2015-02-13T12:04:57Z
WAYPOINT	95	8.914389	38.762987	985188.2776	473847.5289	2170.854736	2015-02-13T12:05:21Z
WAYPOINT	96	8.919893	38.763644	985796.7407	473920.1489	2174.36792	2015-02-13T12:06:11Z
WAYPOINT	97	8.922875	38.764565	986126.3591	474021.6128	2177.503418	2015-02-13T12:07:20Z
WAYPOINT	98	8.924861	38.765812	986345.8395	474158.8448	2179.51001	2015-02-13T12:08:14Z
WAYPOINT	99	8.927594	38.767468	986647.8786	474341.0915	2182.816162	2015-02-13T12:11:25Z
WAYPOINT	100	8.92971	38.768309	986881.7606	474433.6951	2182.82373	2015-02-13T12:12:51Z
WAYPOINT	101	8.933883	38.765871	987343.2871	474165.9637	2186.582764	2015-02-13T12:13:51Z

Raw Hand GPS Data for Segment 1 of the Selected Route

X,Y,ELEV,LABEL,LAYER,ELEVATION,gpxx:DisplayMode,sym

476469.609,980983.686,2059.254,001,Waypoint,2059.2541504,SymbolAndName,Flag

476293.227,980987.480,2059.014,002,Waypoint,2059.0136719,SymbolAndName,Flag

476232.118,980992.358,2061.898,003,Waypoint,2061.8977051,SymbolAndName,Flag

476178.824,980992.156,2061.898,004,Waypoint,2061.8977051,SymbolAndName,Flag

475988.574,981009.514,2068.867,005,Waypoint,2068.8674316,SymbolAndName,Flag

475858.473,981074.908,2075.116,006,Waypoint,2075.1157227,SymbolAndName,Flag

475668.969,981330.463,2089.295,007,Waypoint,2089.2951660,SymbolAndName,Flag

475559.854,981495.767,2095.303,008,Waypoint,2095.3032227,SymbolAndName,Flag

475484.056,981609.819,2100.35,009,Waypoint,2100.3503418,SymbolAndName,Flag

475367.260,981781.762,2109.483,010,Waypoint,2109.4826660,SymbolAndName,Flag

475316.839,981930.337,2113.088,011,Waypoint,2113.0876465,SymbolAndName,Flag

475302.728,982141.654,2120.538,012,Waypoint,2120.5375977,SymbolAndName,Flag

475278.094,982351.043,2124.623,013,Waypoint,2124.6232910,SymbolAndName,Flag

475213.438,982629.974,2137.361,014,Waypoint,2137.3608398,SymbolAndName,Flag

475021.124,982947.480,2149.137,015,Waypoint,2149.1367188,SymbolAndName,Flag

474755.005,983225.054,2157.067,016,Waypoint,2157.0673828,SymbolAndName,Flag

474252.718,983977.325,2166.921,017,Waypoint,2166.9211426,SymbolAndName,Flag

474028.155,984613.505,2166.921,018,Waypoint,2166.9211426,SymbolAndName,Flag

473864.180,985083.270,2167.161,019,Waypoint,2167.1613770,SymbolAndName,Flag

473956.571,985989.917,2175.813,020,Waypoint,2175.8132324,SymbolAndName,Flag

474183.120,986387.338,2179.178,021,Waypoint,2179.1777344,SymbolAndName,Flag

474432.659,986812.895,2180.62,022,Waypoint,2180.6196289,SymbolAndName,Flag

474234.944,987237.926,2182.542,023,Waypoint,2182.5422363,SymbolAndName,Flag

474165.619,987360.137,2184.465,024,Waypoint,2184.4648438,SymbolAndName,Flag

Raw Hand GPS Data for Segment 2 of the Selected Route

X,Y,ELEV,LABEL,LAYER,ELEVATION,gpxx:DisplayMode,sym

484420.592,975589.824,2117.173,025,Waypoint,2117.1730957,SymbolAndName,Flag

484660.935,975386.111,2102.994,026,Waypoint,2102.9938965,SymbolAndName,Flag

485575.221,974860.130,2072.232,027,Waypoint,2072.2319336,SymbolAndName,Flag

486107.921,974580.637,2054.207,028,Waypoint,2054.2072754,SymbolAndName,Flag

486731.445,974413.880,2041.951,029,Waypoint,2041.9506836,SymbolAndName,Flag

487052.805,974266.041,2038.346,030,Waypoint,2038.3457031,SymbolAndName,Flag

487412.570,973943.636,2016.716,031,Waypoint,2016.7160645,SymbolAndName,Flag

487620.624,973615.796,1996.769,032,Waypoint,1996.7687988,SymbolAndName,Flag

487808.374,973378.442,1981.148,033,Waypoint,1981.1477051,SymbolAndName,Flag

488081.490,973039.674,1964.565,034,Waypoint,1964.5649414,SymbolAndName,Flag

488239.728,972839.942,1963.123,035,Waypoint,1963.1230469,SymbolAndName,Flag

APPENDIX E:

Questionnaires for Road Users

Questionnaire

Commuters' and Road User's Perception can be gathered through structured questionnaire as follows:

I. <u>General</u>

a) Interview Date ____

b) Interviewee Status:

Address ________ Age ____Sex ________Educational Status______________

II. <u>Interview Questions</u>

Please answer the following questions to your convenient perception:

1. How often do you use this route for your movement purposes?

   A) Frequently B) Sometimes C) Rarely D) Not before

2. What is the mode of travel you most of the time use on this corridor?

   A) Public Transport B) Passenger Car C) Heavy Vehicles D) Non- Motorized Transport

3. How long you would exercise the average distance from your home to work?

   A) 1 – 3 km B) 3– 7 km C) 7 – 10 km D) 10 – 14 km E) Above 14 km

4. How long do you estimate the travel time on this route?

   A) 30 minutes B) 45 minutes C) 60 minutes D) 90 minutes E) more

5. What is the purpose of your journey on this route?

   A) Educational B) Recreational C) Business D) Other

6. Is there any inconvenient traffic conditions occurred while using this route during your journey on this road segment? A) Yes B) No

7. If your response is yes for (Q.5) what type of inconvenience to the transport system of this corridor has ever occurred?

8. How could you explain the traffic delay or traffic jam level ever seen on the specified road segment? A) Low B) Medium C) High D) Very High

9. Have you ever seen any traffic accident occurrences while using this road segment?

10. What type of Traffic Accident events have you ever observed at the corridor during your journey? A) Sever Fatality B) Property Damage C) Both of them D) None of them

11. What is your view and expectations about the traffic movement system in this route?

12. In your opinion, who will be responsible for the current inconvenient traffic movement system in this corridor?
13. What do you recommend as a remedial solution for the existing unsafe traffic movement system in this segment?