Jimma University

School of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Highway Engineering Stream

Investigation of traffic congestion and possible remedies; a case study of at Harambee Hotel Intersection, Kirkos sub city, Addis Ababa

A Thesis submitted to the school of graduate study of Jimma University in Partial fulfillment of the requirements for the degree of Master of Science in Civil and Environmental Engineering (Highway Engineering)

By

Tebebu Abera Asfaw

January, 2018

Jimma, Ethiopia

Jimma University

School of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Highway Engineering Stream

Investigation of traffic congestion and possible remedies; a case study of at Harambee Hotel Intersection, Kirkos sub city, Addis Ababa

A Thesis submitted to the school of graduate study of Jimma University in Partial fulfillment of the requirements for the degree of Master of Science in Civil and Environmental Engineering (Highway Engineering)

By

Tebebu Abera Asfaw

Advisor: Prof.Dr.-Ing Alemayehu Gebissa

Co-Advisor: Eng Murad Mohammed (MSc.)

January, 2018

Jimma, Ethiopia

DECLARATION

This thesis report is my original work and I have made all the necessary effort as it has not been presented for a Master degree in any other university, and that all sources of material used for the research paper have been duly acknowledged.

By

Tebebu Abera	___________________	____________________
	Signature	Date

Approved by Board of Examiners

Alemayehu Gebissa (Prof.)	___________________	___________________
Main Advisor	Signature	Date
Murad Mohammed (MSc.)	___________________	___________________
Co-Advisor	Signature	Date
Bikila Teklu (Dr.)	___________________	___________________
External Examiner	Signature	Date
Tarekegn Kumela (MSc.)	___________________	___________________
Internal Examiner	Signature	Date
Salem Habekiristos (MSc.)	___________________	___________________
Chair Person	Signature	Date

ACKNOWLEDGEMENT

First of all I would like to gratefully acknowledge the almighty God to get the chance of this program. My deepest gratitude goes to my advisor Prof. Dr.-Ing Alemayehu Gebissa and my co-advisor Eng. Murad Mohammed for all their limitless efforts in guiding me through my work and providing me useful reference materials. Finally my deepest appreciation goes to Jimma University School of Graduate studies, Jimma Inistitute of Technology, Faculty of Civil and Environmental Engineering, Highway Engineering Stream.

ABSTRACT

Transportation plays an important role in economic growth and development, though most of the time cause air pollution, traffic congestion and utilize large amount of land.

Nowadays traffic congestion is increasing and becoming a challenge in the transportation sector. There are many reasons to mitigate traffic congestion, like: delays time, wastes money, accidents and emissions. But the most serious consequence of traffic congestion is increase emissions of greenhouse gases and accident. Nowadays it is common to see traffic congestion at junctions in Addis Ababa, particularly during rush time. Intersection at Harambe hotel was one which affected by traffic congestion especially during rush time.

The objective of the research was investigating traffic congestion and possible remedies in general and particularly, quantifying level of congestion (indicators Capacity and LOS), possible causes of traffic congestion, effects of traffic congestion and possible remedial measures to reduce traffic congestion.

The study area was at the center of Addis Ababa, Kirkos sub-city intersection at Harambe hotel and Filwuha. Population under study was vehicles, geometric features, traffic police, drivers and passengers. Tools used to investigate traffic congestion were manual and video camera for traffic counting, questionnaire for the perception of traffic police and road users, and HCM 2000 for analysis. The data collection period was traffic count 7 days for each intersection, questionnaire 2 days and geometric features measurement 1 day.

The results of the research were level of service (LOS) F for both approaches and intersection, and jam density for all approaches and level of service (LOS B) for un-signalized intersection at Filwuha.

Overall, the research was investigated traffic congestion, causes of traffic congestion, its effect and possible mitigation measures to reduce traffic congestion.

Finally, the possible remedies of the research to reduce traffic congestion were grade separation and congestion pricing policy.

KEYWORDS: Traffic Congestion, signalized intersection, Un-signalized intersection, LOS, HCM-2000 Manual, Jam density.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

ACRONYMS

AACRA	Addis Ababa City Road Authority
C	Cycle Length
c	Lane Group Capacity
CES	Consumer Electronic Shows
CMS	Congestion Management System
EB	East Bound
ERA	Ethiopian Road Authority
ERTA	Ethiopian Road Transport Authority
FHWA	Federal Highway Administration
HCM 2000	Highway Capacity Manual 2000
HOV	High Occupancy Vehicle
L	Lost Time
LT	Left Turning
LOS	Level of Service
NB	North Bound
PCU	Passenger Car Unit
PCE	Passenger Car Equivalent
RT	Right Turning
SB	South Bound
TDM	Transportation Demand Management
TRB	Transportation Research Board
WB	West Bound

CHAPTER ONE

INTRODUCTION

1.1.Background

Transportation mobility is a basic human need throughout their life. From the times immemorial, every one 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 human civilization. For instance, one could easily observe the strong correlation between the evolution of human settlement and the proximity of transport 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, confortable, convenient, economical and eco-friendly for both men and materials (Wondwossen, 2011).

Traffic congestion is one of many serious global problems of both developed and developing countries. It always exerts a negative externality up on society. It poses severe threat to economy as well as the environment. Congestion become common characteristics in urban road transportation system of the cities of developing countries which results in high operation cost, loss of time, high delay, high travel time and increase fuel consumption (Haregewoin, 2010).

To reduce the traffic congestion and delay including their associated effects of intersection at Harambee hotel in this case, it is necessary to adequately collect information that describe the extent of the problems. Such information is usually collected by organizing and conducting traffic surveys and studies. Systematic traffic studies involve the collection of data under operational condition and include studies of traffic volume, delay, travel time, level of congestion and density. 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 expected economic development bound with the specified scope of the work.

Normally, transportation projects are justified for the improvements in traffic flow and safety, saving 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 traffic congestion of intersection at Harambee hotel was studied through the research that was conducted based on the parameters of Traffic volume, geometric feature, Capacity and level of services (LOS) of the existing infrastructure and the traffic management aspect was assessed accordingly. The scope of the problem will be defined and, the analysis and discussion part will be followed. Then the most probable improvement measures or possible engineering solutions in this regard will be amended as recommendation.

1.2.Statement of problem

Traffic congestion is not expected to disappear in the near future in road intersection. However innovative measures are needed to alleviate the situation. In many cases where traffic demand far exceeds the capacity, the intersection can be inefficient. Lane addition is one resort available to traffic engineers and has been used extensively to increase the capacity of the intersections. Although adding turning or through lanes may provide a short term relief, that solution is often infeasible because of the land value around the intersection like, high raised building, historical building (R. Kakooza et. al, 2005).

There are many reasons to mitigate traffic congestion like, delays time and wastes money, and it increases the risks of accidents and localized pollutants emissions. But the most serious consequence of traffic congestion is increase emissions of greenhouse gases and accident. Despite all this facts, there is no significant counter measure to reduce the traffic congestion, delay and its negative impacts on community as well as mobility of human and materials. Hence to reduce the congestion problem it is important to assess the possible causes of congestion, the performance of intersection and measure traffic congestion and the level of services (LOS) in order to make traffic flow smooth and effective. Now a days, it is common to see traffic congestion at junctions in Addis Ababa particularly during rush time. For example at Legehar, Biherawi, St. Urael, Mexico, Stadium etc. intersection areas had large number of vehicles form long queue. Hence, traffic police need to intervene in situation to regulate the traffic flow. Otherwise it would be practically impossible to have normal traffic flows (Haregewoin, 2010).

Intersection at Harambe hotel was very congested during rush time. Depends up upon the analysis result and road concerned bodies perception, the possible remedies will recommended to reduce the traffic congestion.

1.3.Research Questions

The major research questions were as follows:

- What is the level of service (LOS) of studied intersections?
- What are the main causes of traffic congestion on study area?
- What are the effects of traffic congestion?
- What are the possible solutions to reduce traffic congestion on study area?

1.4.Objectives

1.4.1. General objective

The main objective of this research was to investigate traffic congestion and possible remedies of an intersection on study area

1.4.2. Specific Objectives

- To analyze the level of service (LOS) for selected intersections
- To assess the causes of traffic congestion on study area
- To investigate the effects of traffic congestion on road users and the city
- Investigating capacity and LOS for the different solution scenarios of traffic congestion

1.5.Significance of the Study

Nowadays traffic congestion has a serious effect on once country development, so without a doubt the research on traffic congestion evaluation has a wide range of significance for the researchers, sub city, city administration and the country. The researchers will have better understanding regarding the determination of causes, effects and measures. For city administration the research will help them to identify the cause of congestion and prepare master plan how to control this effect. Effects and congestion measure analysis shows the existing situation and using these result we can predict what will happen in the future.

1.6.Justification of the study

The rationale for investigating this study will be provides the bench marks under which the traffic flow is improved. Facts show that in Addis Ababa city almost in all area the road network is still very poor. To mitigate this inconsistency the traffic police, Addis Ababa City Road Authority and Government are face to get the boulder solution. However it may be a chance to solve this problem, but it needs different investigation and analysis around the city.

1.7.Scope

The scope of study was limited to investigate traffic congestion of intersection at Harambee hotel in general and the causes, effects of traffic congestion & possible remedies to reduce traffic congestion in particular.

1.8.Limitation of the study

Problems that happened during study this research were:

- Data collection problem: during questionnaire distribution there were many problems. They were feel fear to fill the questionnaire because problem of awareness
- Internet access problem: for additional information to strengthen the research study internet access was very low.
- Conflict with drivers and traffic police: during traffic data collection there were many questions from the traffic police and drivers for legality assurance

CHAPTER TWO

LITERETURE REVIEW

2.1.Introduction

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 insure safe and effective transportation of people and goods (O'Flaherty, 2002).

Highway engineers must take in to account future traffic flows, design of highway intersections/interchanges, geometric alignment and design, structural design of pavement thickness, and pavement maintenance (Ministry of Transport &Communication, 2010).

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 queuing (www.tafficdata.info, 2017).

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 (of the intersection 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 (O'Flaherty, 2002).

Traffic congestion is an extremely annoying feature of road transport. In consumes substantial amounts of valuable time, creates difficulties for scheduling and on time deliveries, and thus reduces the potential advantages of road transport. Congestion typically occurs at times of high travel demand or as a consequence of accidents or other non-recurring incidents that temporarily reduce a road's capacity it is associated with external costs in the sense that an additional driver on a road forces everyone else using the same road at the same time to adapt to the higher traffic value by lowering driving speeds, so other drivers need more time to cover a given distance (Schrage, 2006).

It is clear that increasing traffic congestion does impose costs upon travelers and affect broader business operations; it has been difficult to develop and apply empirical measures of the extent of the traffic congestion and its economic costs. Even though, proper measuring the extent or level of congestion is an important step for understanding the performance of the existing road networks, for evaluation of proposed congestion mitigation measures and for evaluation of cost of congestion (Weisbrod et. al, 2003).

2.2.Definition of traffic congestion

The definition of congestion is imprecise and is made more difficult since people have different perceptions and expectations of how the system should perform based on whether they are in rural or urban areas, in peak or off peak, and as a result of the history of an area (Bertini, 2005).

There is no consistence definition of congestion in terms of a single measure or set of measures that considers severity, duration and spatial extent. Measures related to travel time and speed are the most flexible and useful for a wide range of analysis (R. Narayanana, 2003).

For instance, the Federal Highway Administration (FHWA) defines traffic congestion as “the level at which transportation system performance is no longer acceptable due to traffic interference.” Accordingly traffic congestion definition depends on the understanding of the road users. Based on this definition divided as congestion and unacceptable congestion and it is defined as:

- Congestion is travel time or delay in excess of that normally incurred under light or free flow travel condition
- Unacceptable congestion is travel time or delay in excess of an agreed upon norm.

Traffic congestion refers to incremental delays and vehicle operating costs caused by interactions among vehicles, particularly as traffic volumes approach roadway capacity.

Generally definitions of traffic congestion fall in to two major categories. These are definitions which based on the cause and the impact of traffic congestion. Traffic congestion may be recurrent and non-recurring. Recurrent congestion occurs at the same place at the same time every weekday or weekend. It is a capacity problem and is logically combated with raising roadway capacity. Non-recurring congestion results from incidents such as accidents, inclement weather or roadway maintenance (Lomax et. al, 1997).

2.3.Traffic Transportation Related Parameters

2.3.1. Capacity

The capacity of a facility 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 road way 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 those factors, segments with different prevailing conditions will have different capacities (Getu, 2007).

Vehicle capacity is the maximum number of vehicles that can pass a given point during a specified period under prevailing roadway, traffic, and control conditions. This assumes that there is no influence from downstream traffic operation, such as queues backing into the analysis point (HCM, 2010).

2.3.2. 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 (Getu, 2007).

2.3.3. Density

The number of vehicles occupying a given length of lane or roadway averaged over time, usually expressed as vehicles per kilometer or vehicles per kilometer per lane. "Breakdown" condition occurs when traffic becomes unstable and exceeds 67 vehicles per mile. "Jam density" refers to extreme traffic density associated with completely stopped traffic flow, usually in the range of 185–250 vehicles per mile per lane (HCM, 2010).

2.3.4. Level of services (LOS)

‘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 this condition 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 in letter designations, from A to F, with LOS A representing the best operating conditions, and LOS F the worst a simple concept analogous to school letter grades and comprehensible by non-most technical audiences. Each level of service represents a range operating conditions and the driver’s perception of those conditions. Safety is not included in measures which are used to establish service levels (Getu, 2007).

2.3.5. Service flow rate

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 minutes period. Typically the hourly service flow rate is defined as four times the peak 15 minute volumes (Getu, 2007).

Table 2.1 Input data needs for each analysis lane group (HCM, 2010 & HCM, 2000)

Types of Condition	Parameter
Geometric Conditions	Area type Number of lanes, N Average lane width, W (m) Grade, G (%) Existence of exclusive LT (left turn) or RT (right turn) lanes
Traffic Conditions	Demand volume by movement, V (veh/h) Base saturation flow rate, s_o (pc/h/ln) Peak-Hour Factor, PHF Percent heavy vehicles, HV (%) Approach pedestrian flow rate, V_{ped} (p/h) Arrival type, AT
Signalization Conditions	Cycle length, C (s) Green time, G (s) Yellow plus all red change and clearance interval (Inter-green), y (s)

	Actuated or pre-timed operated Minimum pedestrian green, G_p (s) Analysis period

Table 2.2 Required data for signalized intersections (HCM, 2010)

Item	Default
Geometric Data	
Exclusive Turn Lanes	From the field
Demand Data	
PHF Length of analysis period	0.95 0.25 h
Intersection Data	
Cycle Lost time g/C	Chapter 10 4 s From the field
Saturation Flow Data	
Base saturation flow rate Lane widths Heavy vehicles Grades Area type	From the field s_o= 3600/h, h=headway From the field From the field From the field Other than Central Business District(CBD)

2.3.6. Geometric Condition

Intersection geometry is the physical nature of roadway and includes all relevant information as follows:

2.3.6.1.Lane Width

Urban street widths can be as narrow as 3.0 meters. The typical width is 3.6 meters. The lane closest to a raised median may be extra wide to allow for some shy distance between vehicles and the median. The rightmost lane may be several meters wider than the standard. Lanes greater than 6.0 meters in width should be evaluated to determine if drivers use the lane as two lanes or as a single wide lane. This is often the case for the rightmost through lane (curb lane) which may be extra wide (HCM, 2010).

2.3.6.2. Grades

The approach grade becomes important only when the grades are significantly steeper than 4 percent. The maximum grades encountered on urban street typically range from 6 to 11 percent, but can reach 31 percent in unusual situations, such as in the city of San Francisco, California. The analyst in the absence of specific local data can use 0 percent for essentially flat approaches, 3 percent for moderate grades, and 6 percent for relatively steeper grades (HCM, 2010).

2.3.6.3.Area Type

Only two area types are recognized for signalize intersection analysis; Central Business District (CBD) and others. The base saturation flow rate for an intersection is reduced 10 percent for CBD conditions compared with other areas. This adjustment is in addition to the saturation flow reductions for the higher number of parking maneuvers, pedestrian flows, and bus stops typical of CBDs.

2.3.7. Traffic Condition

Traffic volumes (for over saturated conditions, demand must be used) for the intersection must be specified for each movement on each approach. This volumes are the flow rates in vehicles per hour for the 15-minute analysis period, which is the duration of the typical analysis period. Vehicle type distribution is quantified as the present of heavy vehicles (% HV) in each movement, where heavy vehicles are defined as those with more than four tires touching the pavement. The number of local buses on each approach should also be identified, including only those buses making stops to pick up or discharge passengers at the intersection (on either the approach or departure side). Buses not making such stops are considered to be heavy vehicles. Pedestrian and bicycle flows are needed, because this will be interfere with permitted right or left turns (HCM, 2010).

2.3.7.1.Pedestrian

Field counts are the best source of information for pedestrian flows. In the absence of counts the defaults may be used (HCM, 2010).

Table 2.3 Defaults for Pedestrian Flows (HCM, 2000)

Area type	Pedestrian Volume (P/hr)
Central Business District (CBD)	400
Urban	200
Suburban	50
Rural	0

2.3.7.2.Heavy Vehicles

The local Highway Performance Management System (HPMS) may be used to obtain local information on the percent heavy vehicles by facility and area type. The breakdown between RVs, trucks, and buses is not used in the computation of adjusted saturation flow rates at signalized intersections (HCM, 2010).

2.3.8. Signalization Condition

Complete information regarding signalization is needed to perform an analysis. This includes a phase diagram illustrating the phase plan, cycle length, green times, and change and clearance intervals. If pedestrian timing requirements exist, the minimum green time for the

Phase should indicate and must be provided for in the signal timing. The minimum green time for a phase is estimated by empirical formula (HCM, 2010):

$$\text{Gp} = 3.2 + \frac{L}{Sp} + \frac{(0.81 * (Nped))}{WE} \dots\dots\dots\dots\dots\dots\dots.\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.1)$$

for W_E>3.0m

$$\mathrm{Gp} = 3.2 + \frac{L}{Sp} + (0.27 * Nped) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. (2.2)$$

for W_E<=3.0m

Where:

G_p=minimum green time, s.

L= crosswalk length, m.

S_p= average speed of pedestrians, m/s.

N_{ped}= number of pedestrians crossing during an interval, P.

3.2= pedestrian start-up time, s.

W_E= effective crosswalk width, m.

It is assumed that the 15th-walking speed of pedestrians crossing a street is 1.2 m/s in this computation. This value is intended to accommodate crossing pedestrians who walk at speeds slower than the average.

2.4.Saturation Flow Rate

The saturation flow rate is the flow in vehicles per hour that could be accommodated by the lane group assuming that the green phase were displayed 100 percent of the time (g/C=1.0).

Saturation flow rate for each lane group is computed according to below empirical formula (HCM, 2010):

$s=s_oNf_wf_{HV}f_gf_pf_{bb}f_af_{LU}f_{LT}f_{RT}f_{Lpb}f_{Rpb}$………………………………………………………… (2.3)

Where:

s= Saturated flow rate for the subject lane group, expressed as a total for all lanes in the lane group, veh/h,

s_o= Base saturation flow rate per lane, pc/h/ln,

N= Number of lanes in the lane group,

f_w= Adjustment factor for lane width (3.6 m is base width),

f_{HV}=Adjustment factor for heavy vehicles in the traffic stream,

f_g= Adjustment factor for approach grade,

f_p= Adjustment factor for existence of a parking lane and parking activity adjacent to the lane group,

f_{bb}= Adjustment factor for the blocking effect of local buses that stop within the intersection area,

f_a= Adjustment factor for area type,

f_{LU}= Adjustment factor for lane utilization,

f_{LT}= Adjustment factor for left in the lane group,

f_{RT}= Adjustment factor for right in the lane group,

f_{Lpb}= pedestrian adjustment factor for left-turn movements, and

f_{Rpb}= pedestrian/bicycle adjustment factor for right-turn movements

2.4.1. Adjustment Factors

Computations being with the selection of a base saturation flow rate, passenger cars per hour per lane (pc/h/ln), and adjust this value for a variety of conditions.

Table 2.4 Adjusted factors for saturated flow rate (HCM, 2010 & HCM, 2000).

Factor	Formula	Definition of variables	Notes
Lane Width	$f_w = 1+(w-3.6)/9$	W= lane width	w>=2.4 if w>4.8, a two-lane analysis may be considered
Heavy Vehicles	$f_{HV}=100/(100+\%HV(E_T-1))$	% HV = % heavy vehicles for lane group volume	
Grade	$f_g = 1-\%G/200$	% G= % grade on a lane group approach	-6<=%G<=+10
Parking	$f_p=(N-0.1-(18N_m/3600))/N$	N= number of lanes in lane group N_m=number of parking maneuvers/h	0<=Nm<=180, f_p>=0.05 f_p=1 for no parking
Bus Blockage	$f_{bb}=(N-14.4N_B/3600)/N$	N_B=number of buses stopping/h	0<=N_B<=250 f_{bb}>=0.55
Type of Area	f_a=0.9 in CBD f_a=1 in all other areas		
Lana	$f_{LU}=v_g/(v_{gl}N)$	V_g=unadjusted demand flow rate	

Utilization		for the lane group, veh/h V_{gl}=unadjusted demand flow rate on the single lane in the lane group with the highest volume, veh/h N=number of lanes in the lane group	
Left Turns	Protected phasing: Exclusive lanes: f_{LT}=0.95 shared lane: $f_{LT}=1/(1+0.05P_{LT})$	P_{LT}= proportion of LT in lane group	
Right Turns	Exclusive lane: f_{RT}=0.85 Shared lane: $f_{RT}=1-0.15P_{RT}$ Single lane: $f_{RT}=0.9-0.13P_{RT}$	P_{RT}=proportion of RT in lane group	
Pedestrian/ Bicycle Blockage	LT Adjustment: $f_{LPb}=1-P_{LT}(1-A_{PbT})(1-P_{LTA})$ RT Adjustment: $f_{RPb}=1-P_{RT}(1-A_{PbT})(1-P_{RTA})$	P_{LT}= proportion of LT in lane group A_{PbT}= permitted phase adjustment P_{LTA}=proportion of LT protected green over total LT green P_{RT}=proportion of RT in lane group P_{RTA}= proportion of RT protected green over total RT green	

2.4.2. Lane Grouping

The methodology for signalized intersections is disaggregating; that is, it is designed to consider individual intersection approaches and individual lane groups within approaches. Segmenting the intersection into lane groups is a relatively simple process that considers both the geometry of the intersection and the distribution of traffic movements. In general, the smallest number of lane groups is used that adequately describes the operation of the intersection (HCM, 2010).

2.5. Capacity and Volume-Capacity ratio (v/c)

Capacity at signalize intersections is based up on the concept of saturation flow and saturation flow rate. The flow ratio for a given lane group is defined as the ratio of the actual or projected demand flow rate for the lane group (v_i) and the saturation flow rate (s_i). The flow ratio is given by the symbol $(v/s)_i$ for lane group i. the capacity of a given lane group may be stated as (HCM, 2010):

$c_i = s_i*(g_i/C)$……………………………………………………………………..(2.4) where

c_i = capacity of lane group i, veh/h,

s_i = saturation flow rate for lane group i, veh/h, and

g_i/C = effective green ratio for lane group i.

2.6. Performance measures

Performance measures can be calculated from each capacity type with a defined method for assessing capacity and level of service. Travel speed and density of 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 (RTA, 2011).

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 (Cambridge, 2008).
2. A 'relative phenomena' to user's expectation versus road performance (Joint Transport Research Center, 2004).
3. It cannot be fully described using one dimensional parameter (T.Thianniwet et.al, 2009).

2.6.1. Headway

The headway between vehicles can be observed as the vehicles cross the stop line of the intersection. The first headway would be the elapsed time, in seconds, between tire initiation of the green and the front wheels of the first vehicle crossing over the stop line. The second headway would be the elapsed time between the front bumpers (or wheels) of the first and second vehicles crossing over the stop line. Subsequent headways are measured similarly (HCM, 2010)

$$h = H + l1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

$$l1 = \sum_{i=0}^{n} ti \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.6)$$

Where

h=Total headway (s/veh),

H=Constant headway (s/veh),

l_1 = total start-up lost time (s),

t_i = lost time for ith vehicle in queue (s), and

n = last vehicle in queue

2.6.2. Control Delay

Delay is additional travel time experienced by a driver, passenger or pedestrian beyond what would reasonably be desired for a given trip. Determination of delay is the value derived from the delay calculations represents the average control delay experienced by all vehicles which arrive in the analysis period, including delays which are incurred beyond the analysis period when the lane group is over saturated. Control delay includes movements at slower speeds and stops on intersection approaches, as vehicles move up in queue position or slow down upstream of an intersection. The average control delay per vehicle for a given lane group is given by empirical formula below (HCM, 2010):

$d=d_1PF+d_2+d_3$………………………………………………………………………… (2.7)

Where

d= control delay per vehicle, s/veh,

d_1= uniform control delay assuming uniform arrivals, s/veh,

PF= uniform delay progression adjustment factor which accounts for the effects of signal progression,

d_2= incremental delay to account for the effect of random and over saturation queues, adjustment for the duration of analysis period and the type of signal control. This delay component assumes that there is no residual demand for the lane group at the start of the analysis period, s/veh, and

d_3= supplemental delay to account for oversaturation queues that may have existed prior to the analysis period, s/veh.

2.6.2.1.Progression Adjustment

Good signal progression will result in a high proportion of vehicles arriving on the uniform delay green. Poor signal progression will result in a low proportion of vehicles arriving on the green. The progression adjustment factor, PF, applied to all coordinated lane groups, including both pre-timed control and non-actuated lane group in semi-actuated control systems. In circumstances where coordinated control is explicitly provided for actuated lane groups, PF may also applied to these lane groups. Progression primarily affects uniform delay, and for these reason, the adjustment is applied only to d1. The value of PF may be determined by the formula below (HCM, 2010):

$$PF = \frac{(1-p)f\text{PA}}{1-(g/C)} \quad (2.8)$$

Where:

PF = progression adjustment factor,

P = proportion of vehicles arriving on the green,

g/C = proportion of green time available, and

f_{PA} = supplemental adjustment factor for platoon arriving during the green.

2.6.3. Level of service (LOS)

Determination of level of service at an intersection is directly related to the average control delay per vehicle. Once delays have been estimated for each lane group and aggregated for each approach and the intersection as a whole the appropriate level of service are determined for each component. The results of an operational application of this method will yield two key outputs: volume-to-capacity ratios for each lane group and for all critical lane groups within the intersection as a whole, and average control delays for each lane group and approach and for the intersections as a whole along with corresponding levels of service. Any v/c ratio greater than 1 is an indication of actual or potential break down. In such cases, multi-period analyses are advised. These analyses encompass all periods in which queue carry-over due to oversaturation occurs. When the overall intersection v/c ratio is less than one, but some critical lane groups have v/c ratio greater than 1, the green time is generally not appropriately apportioned, and a retiming using the existing phasing should be attempted. A critical v/c ratio greater than 1 indicates that the overall signal and geometric design provides inadequate capacity for the given flows. Improvement that might be considered include: basic changes in intersection geometry (number and use of lanes), increases in the signal cycle length if it is determined to be too short, and changes in the signal phase plan. Existing state and local policies should also be consulted in the development of potential improvements (HCM, 2010).

Table 2.5 Intersection Level of Service Distribution (HCM, 2010)

LOS	Interpretation	V/C ratio
A	Uncongested operations; all queues clear in a single signal cycle.	Less than 0.6
B	Very light congestion; an occasional approach phase is fully utilized.	0.6-0.69
C	Light congestion; occasional backups on critical approaches.	0.7-0.79
D	Significant congestion on critical approaches, but intersection functional. Cars required waiting through more than one cycle during short peaks. No long-standing queues formed.	0.8-0.89
E	Sever congestion with some long-standing queues on critical approaches. Blockage of intersection may occur if traffic signal does not provide for protecting turn movements. Traffic queues may block nearby intersections(s) upstream of critical approach (s).	0.9-0.99
F	Total breakdown, stop-and-go operation.	1.0 and greater

2.6.4. Back of Queue

The back of queue is the number of vehicles that are queued depending on the arrival patterns of vehicles and vehicles that do not clear the intersection during a given green phase (overflow). This procedure is also to analyze back of queue over multiple time periods, each having duration (T) in which over flow queue may be carried from one time period to the next. Cases I and II occur when there is no initial queue and the period is either under saturated (case I) or oversaturated (case II). In both cases d3 = 0 (HCM, 2010)

2.7. 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.

2.7.1. Level of Service (LOS) of signalized 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 highway, intersection 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 objective 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 homogeneous road segments. 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 level of service at any intersection on a highway has a significant effect on the overall operating performance of that highway. Thus, improvement of the level of service at each intersection usually results in an improvement of the overall operating performance of the highway. Analysis procedure that provides the determination of capacity or level of service at intersections is therefore an important tool for designers, operation personnel and policy makers. Factors that affect the level of service at intersection include the flow and distribution of traffic, the geometric characteristics and the signalization system. A major difference between considerations of level of service on highway segment and level of service at intersections is that only through flows are used in computing the level of service at highway segments, whereas turning flows are significant when computing the level of service at signalized intersections (Nicholy et.al, 2009).

Level of service for signalized intersections is defined in terms of control delay, which is a measure of driver discomfort, frustration, fuel consumption and increased travel time. The delay experienced by a motorist is made up of a number of factors that relate to control, geometrics, traffic, and incidents. Total delay is the difference between the travel time actually experienced and the reference travel time that would result during base condition: in the absence of traffic control, in the absence of geometric delay, in the absence of any incidents, and when no other vehicles are on the road. Control delay is the portion of the total delay attributed to traffic signal operation for signalized intersections. Control delay includes initial deceleration delay, queue move-up time, stopped delay, and final acceleration delay. Specifically, level of service (LOS) criteria for traffic signals is stated in terms of the average control delay per vehicle, typically for a 15-minute analysis period. Delay is a complex measure and is dependent upon a number of variables, including the quality of progression, the cycle length, the green ratio, and the v/c ratio for the lane group. The critical v/c ratio is an appropriate indicator of the overall sufficient of an intersection. The critical v/c ratio depends up on the conflicting critical lane flow rates and the signal phasing (HCM, 2010).

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. Highway Capacity manual (HCM) developed by the transportation research board of USA provides some procedure to determine level of service. It divides the quality of traffic into the six levels ranging from level A to level F. level A represents the best quality of traffic where the driver has the freedom to drive with free flow speed (FFS) and F represents the worst quality of traffic.

Table 2.6 Level-of-service by control delay for signalized Intersections (HCM, 2010)

level of service	Control delay/vehicle (s/veh)
A	<=10
B	>10-20
C	>20-35
D	>35-55
E	>55-80
F	>80

2.7.2. Level of Service (LOS) of Un-signalized as Traffic congestion Indicator

2.7.2.1.T-intersection

Capacity analysis at TWSC intersections depends upon a clear description and understanding of the interaction of drivers on the minor or stop-controlled approach with drivers and vehicles on the major street (HCM, 2010).

Table 2.7 Level-of-service criteria for un-signalized intersections (HCM, 2010)

level of service	Control delay/vehicle (s/veh)
A	<10
B	>10-15
C	>15-25
D	>25-35
E	>35-50
F	>50

2.7.2.2.Control Delay

The delay experienced by a motorist is made up of a number of factors that relate to control, geometrics, traffic, and incidents. Total delay is the difference between the travel time actually experienced and the reference travel time that would result during ideal conditions, in the absence of incident, control, traffic, or geometric delay. With respect to field measurements, control delay is defined as the total elapsed time from when a vehicle stops at the end of the queue until the vehicle departs from the stop line. This total elapsed time includes the time required for the vehicle to travel from the last-in-queue position to the first-in-queue position. Average control delay for any particular minor movement is a function of the capacity of the approach, and the degree of saturation.

$$d = \frac{3600}{Cm,x} + 900T\left[\frac{Vx}{Cm,x} - 1 + \sqrt{\left(\frac{Vx}{Cm,x} - 1\right)^2 + \frac{\left(\frac{3600}{Cm,x}\right)\left(\frac{Vx}{Cm,x}\right)}{450T}}\right] + 5 \ldots\ldots\ldots (2.9)$$

Where

d = Average control delay, s/veh,

V_x = Flow rate for movement x, veh/h,

$C_{m,x}$ = capacity of movement x, veh/h, and

T = analysis time period, h (T = 0.25h).

2.8. Source and Impact of Traffic Congestion

Explaining the source of traffic congestion varies with the congestion type. Hence, recurring congestion occur when the volume of traffic exceeds the roadway capacity while non-recurring congestion occur mostly by crashes and incident, vehicle breakdown, road construction activities, special events etc. (McGroarty, 2010).

Similarly, traffic congestion usually results when the road system is unable to accommodate traffic, conflict among the different types of traffic and traffic control improper uses. European Conference of Ministers of Transport suggested the sources of traffic congestion as a reduction in road capacity caused by unplanned event, for example, an accident with wrecks blocking a lane; a planned reduction in capacity due to construction or maintenance of the lane and finally a traffic demand higher than the maximum flow capacity as per European Conference of Ministers of Transport (Lomax, 1997).

Traffic congestion as several roots causes that can be Brocken down into two main categories and summarized the finding in figure 2.1 (Cambridge, 2004).

1. Too much traffic for the available physical capacity to handle:
   - Bottleneck
2. Traffic influencing events:
   - Traffic incidents such as crashes and vehicle breakdowns
   - Work zone`
   - Bad weather
   - Special events and
   - Poorly timed traffic signals

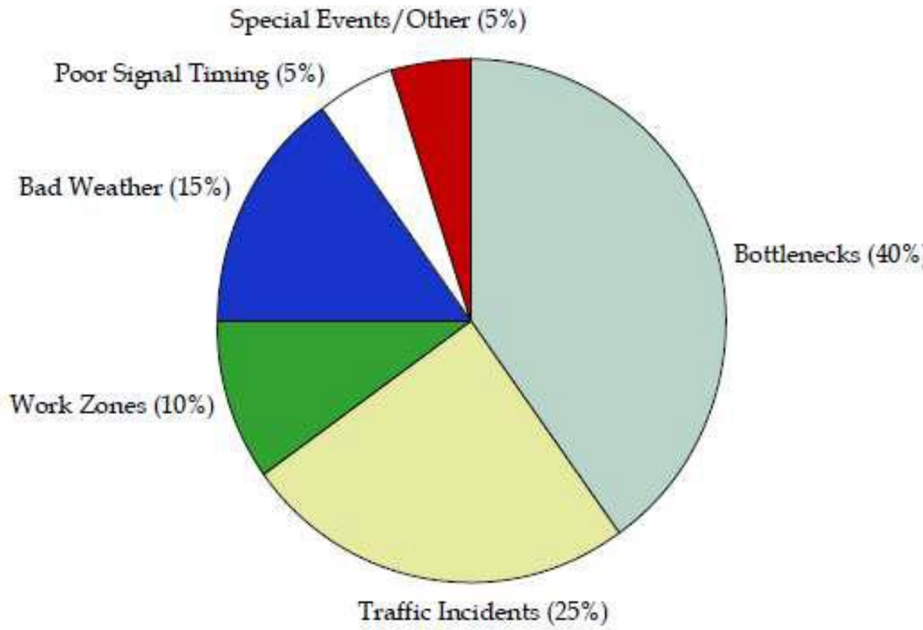


Figure 2.1 Sources of traffic congestion

The growth of traffic congestion on many streets and highways is a major concern to travelers, administrators, merchants, developers and the community at large. Its determinant impacts in terms of longer journey times, higher fuel consumption, increased emissions of air pollutants, greater transport and others affected costs, and changing investment decisions are increasingly recognized and felt across the country. Congestion reduces the effective accessibility of residents, activities, and jobs, resulting in lost opportunities for both the public and business (Herbert S. Levinson et. al, 2005).

General traffic congestion has impacts on the economy, environment and commuters' European Conference of Ministers of Transport states that congestion involves queuing, slower speeds and increased travel times, which impose costs on the economy and generate multiple impacts on urban regions and their inhabitants also it has a range of indirect impacts including the marginal environmental and resource impacts of congestion, impacts on quality of life, tresses and safety as well as impacts on non-vehicular road space users such as the users of sidewalks and road frontage properties. Although, traffic congestion increase fuel consumption and emit high level of CO_2 correspondingly high greenhouse gas emission on the environment (Spalding S., 2008).

2.9. Traffic Congestion Mitigation Strategies

Many researchers identified different traffic congestion mitigation measures depends on the causes and the type of congestion. From those researches managing urban traffic congestion, 2007 conclude there is no prescribe specific congestion management strategies science the appropriateness and applicability of these depends largely on the local context. The report suggests their strategic congestion management principles that should serve to guide policies in this field. Ensure that land use planning, and the community objectives it embodies, is coordinated with congestion management policies; Deliver predictable travel times; and manage highly trafficked roadways to preserve educate system performance. Transportation engineers and planners have developed a variety of strategies to deal with congestion. The strategies can be grouped in to three as follows and each group has key strategies to address congestion (haragewoin, 2010).

a. Adding more capacity for highway, transit and railroads

Key strategies to address congestion (Cambridge, 2004):

- Adding travel lanes on major freeways and streets (including truck climbing lanes on grades)
- Adding capacity to the transit system (muses, urban rail or commuter rail systems)
- Closing gaps in the street network
- Removing bottlenecks
- Over passes or under passes at congested intersections
- High-occupancy vehicle (HOV) lanes
- Increasing intercity freight rail capacity to reduce truck use of highways

b. Operating existing capacity more efficiently

Key strategies to address congestion (Cambridge, 2004):

- Optimizing the timing of traffic signals
- Faster and anticipatory responses to traffic incidents
- Providing travelers with information on travel conditions as well as alternative routes and modes
- Provide management of work zones
- Geometric improvements to roads and intersections converting street to one-way operations
- Access management

c. Encourages travelers to use the system in less congestion-producing ways

Key strategies to address congestion (Cambridge, 2004):

- Programs that encourage transit use and ridesharing
- Curbside and parking management
- Flexible work hours Telecommuting programs.

2.10. Congestion Measures

Traffic congestion is unavoidable part of modern-day life. To understand the nature of congestion and to control its growth, a system for measuring the severity of traffic congestion is needed. Such a measure provides the foundation for traffic engineers and policy makers to identify problems and determines the effectiveness of mitigation strategies. In addition a consistent and uniform measure will allow comparison of traffic conditions at different locations and also cover time at the same location so that priorities for improvements can be developed, which helps the public to understand the traffic conditions. Congestion continues to grow in American's urban areas. In 2003, congestion caused increase of 79 million hours and 69 million gallons of wasted fuel from 2002 to a total cost of more than $62 billion (Schrank et.al, 2005).

This result shows that how traffic congestion has a great effect on once national economy and need to be measured or quantified before it cause irreversible problem. Traffic congestions measure varies depending on the need, from the traditional volume capacity ration to more complicated empirical equations (Lomax et.al, 1997).

2.10.1. Grade separation junction

The circumstances in which the use of a grade separated junction is warranted are usually as follows:

- An at-grade junction has insufficient capacity
- The junction is justified economically from the savings in traffic delays and accident costs
- Grade separation is cheaper on account of topography or on the grounds that expensive land appropriation can be avoided by its construction

In deciding on the location of a grade-separated junction, the following factors should be taken into account:

- Trip length (travel distance)
- Size of urban areas
- Predicted traffic volumes
- Cost of junction
- Congestion control

The use of grade separation results in the separation of traffic movements between the intersecting roads so that only merging and diverging movements remain. The extent to which individual traffic movements should be separated from each other depends mainly upon capacity requirements and traffic safety aspects; it also depends upon the extent to which important traffic movements should be given free flow conditions (ERA, 2002).

2.10.2. Congestion Pricing Policy

A method used to reduce traffic by charging a fee to road users during rush hours. The user fee may vary by the time of day and day of the week, being highest during periods of peak demand and lower at less-popular hours. During low-demand times, there may be no fee at all. Economically speaking, congestion is considered a demand-side solution to traffic. An example of a supply-side solution would be increasing road capacity (Innovative Financing for Transport Schemes, 2015).

2.11. 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. Tracks, buses and Recreational vehicles (RVs) are the three groups of heavy vehicles addressed by the methods presented in HCM. Heavy vehicles adversely impact traffic in two ways (Getu, 2007):

- 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

Table 2.8 PCEs determination (HCM, 2010)

Vehicles type	Car	Land rover	Small bus	Medium bus	Large bus	Small truck	Medium truck	High truck	Articulated truck	Motor cycle	Bicycle
PCEs (HCM)	1	1	1.5	2	2.5	1.5	2	2.5	3	0.5	0.5

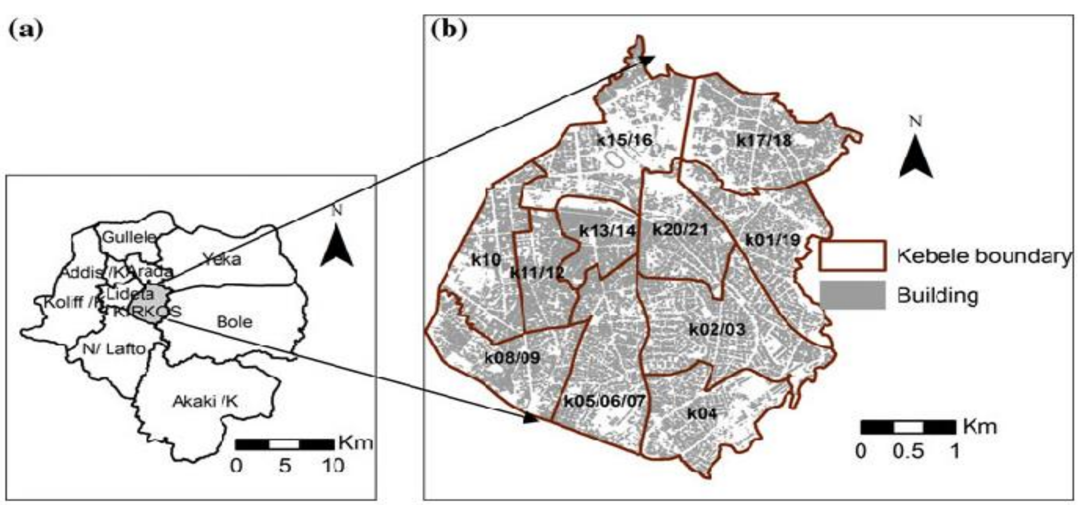
CHAPTER THREE

RESEARCH METHODOLOGY

3.1.Description of study area

The study area selected for this research was at the center of Addis Ababa, Kirkos sub-city intersection at Harambee hotel. Addis Ababa is a capital city of Ethiopia, which is administratively divided in to 10 sub-cities. Addis Ababa is not only the capital city of Ethiopia, but also the seat of African Union Head Quarter and seat for many 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 3.27 million. As it lies in the central part of the country, in addition to serving as a capital, there is a high concentration of human and vehicle populations leading to traffic congestion. Addis Ababa is one of metropolitans in Africa which is found at the horn of the continent with geographical coordinates **$9^0$01’48’’ N and $38^0$44’24’’E** and an average elevation of 2355m above mean sea level. The city has a total area of about 530.14 km^2 and population of 3,270,248 (FDRE Population Census Commission, 2013).



(a)Addis Ababa city (b) Kirkos sub city

Figure 3.1 Addis Ababa boundary and kirkos sub city (Google Map)

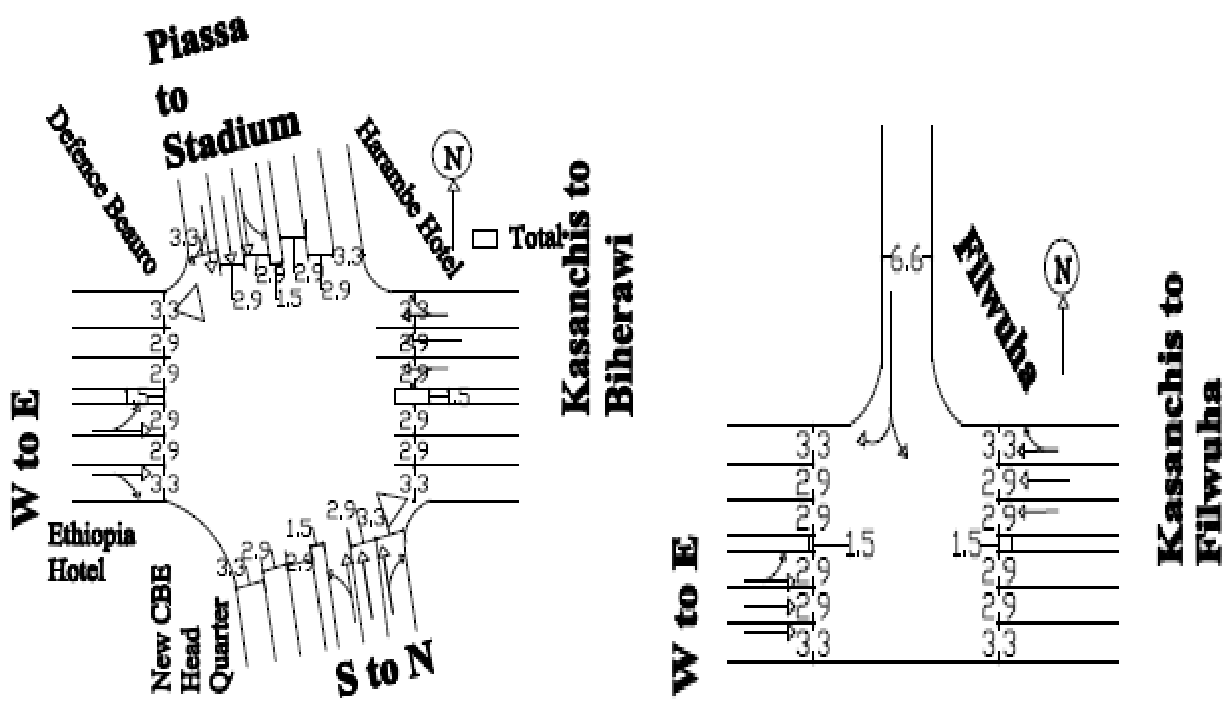
3.1.1. Study location

One signalized intersection at Harambee hotel and one un-signalized T-intersection at Filwuha. The corridor is very important due to working zone, commercial, businesses; recreational (theatre and football) and emigration are Highly performed, which may lead to high congestion occurrence.

Intersection at Harambee hotel is geographically **9^{0}01’02.4’’ N** & **38^{0}45’15.32’’E** and at Filwuha is **9^{0}01’02.2’’ N & 38^{0}45’25.1’’E** and elevation around **2326m** above mean sea level (Google Earth & http://www.eamsl.com/Addis Ababa).

(a) At Harambee hotel (b) At Filwuha

Figure 3.2 Pictures of studied intersection (Google Earth)



(a) At Harambee hotel (b) At Filwuha

Figure 3.3 Geometric features of studied intersections

3.2.Research Design

The research design was based on a purposive sampling selection process in terms of which a representative sample of more congested intersection depending upon the site observation, and after identification of study location the following was conducted:

3.2.1. Field study

- Observation: was systematic visited the studied area to identify input parameters
- Traffic Volume: was counted for selected intersections by class of vehicles into traffic count format.
- Geometric Features: were observed and measured like, lane width, left/right turn condition, median type & width, pedestrian cross walk width & length.
- Questionnaire: were distributed and collected for the levels, causes, effects and possible remedial measures of traffic congestion

3.2.2. Desk Study

- Analysis of LOS: were done to identify the level of traffic congestion of intersections *using control delay approach* by referring HCM 2010.
- Investigating Causes and Effects of Traffic congestion: were investigated from observation, analysis, questionnaire and literatures
- Recommend possible remedies: were depending upon the traffic volume, analysis, land value, and topography to recommend possible remedies.

The research approach was involved both quantitative and qualitative approaches. Quantitative data and analysis were used to determine the capacity and level of service of intersection. Observation (traffic count), direct field measurements were the main sources of quantitative data. Furthermore, qualitative data from questionnaire were also used to determine whether the congestion of an intersection considerable or not and assess other related parameters, like causes effects and possible remedies. 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. The qualitative data types were: vehicles class, level of congestion (low, medium, high or very high), nature of LT and RT, types of median. In this research the methods followed were designed in such a way that the key questions of the research be answered properly. As it shown in figure below, in order to assess whether the road intersection is congested or not; a key question "does traffic congestion exists at this intersection?" was raised and answered first using congestion indicator parameters. The congestion indicator parameters used in this research were Level of service (LOS) and road user's perception.

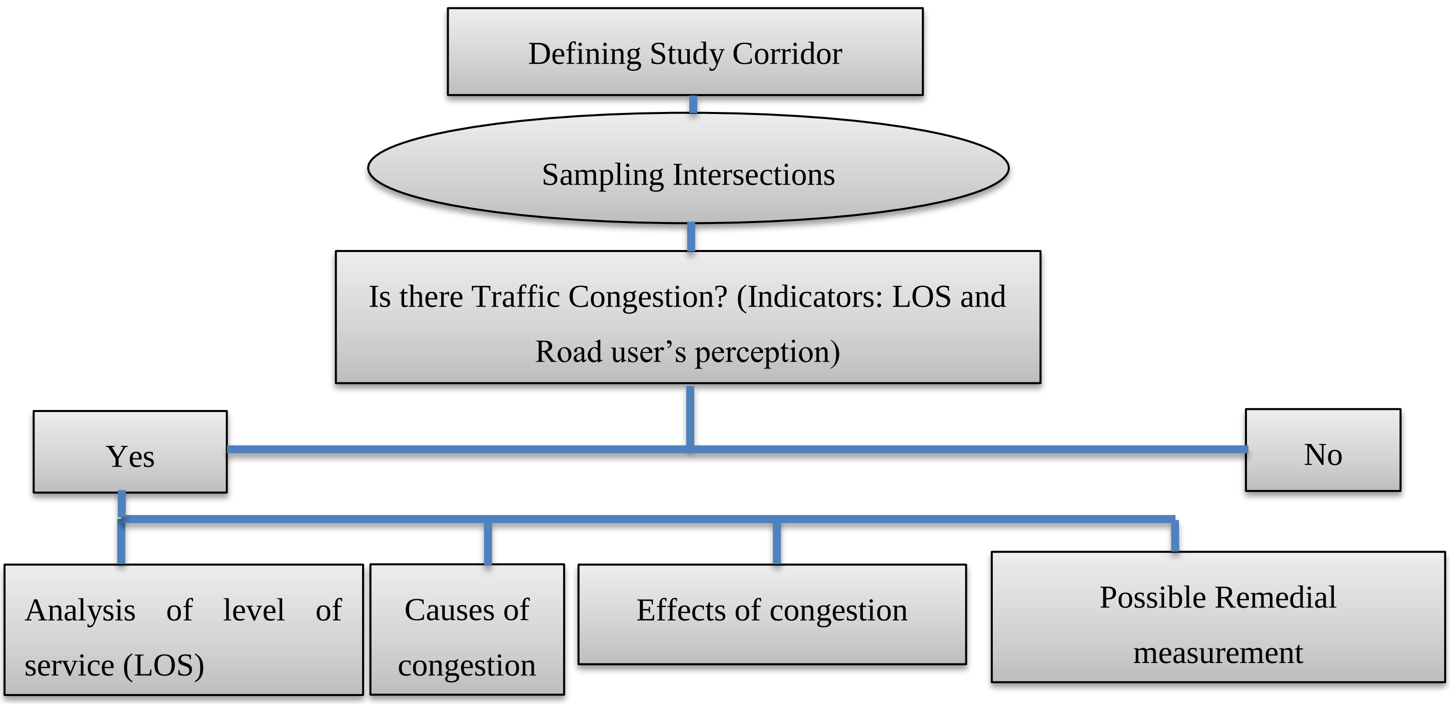


Figure 3.4 Framework for research design

3.3.Population

The population under study intersection at Harambe hotel was traffic volume, geometric features for analysis and passengers, drivers and traffic police for questionnaire. In this study the researcher was conducted the impacts of the above listed population of their values for the results of the finding. These population was enabled the researcher to obtain the necessary data for the study. The total population of the road users (passengers and drivers) and coordinator (traffic police) for questionnaire was around 25,000 from the analysis of Average Daily Traffic (ADT) (See Appendix D).

3.4.Sampling Techniques and Procedures

This study was followed a purposive of representative sampling for selection of intersection and, probability sampling and simple random sampling for questionnaire. Sample size –finite population (where the population is less than 50,000 equal to 25,000)

New SS=SS/(1+(SS-1)/Pop)=110, SS-sample size of infinite population, New SS- sample size of finite population, Pop = 25,000, take **Pop=25,000, SS= $(Z^2 * p * (1-p))/C^2$**, Z=Z-value (e.g. 1.645 for 90 percent confidence level)' P= percent of population picking a choice, expressed as decimal=**0.9**, C= confidence interval, expressed as decimal (e.g. **0.047** =-/+**4.7** percent points)

3.5.Study Variables

3.5.1. Independent Variables

- Traffic volume
- Geometric features (width and number of lane & grade)
- Vehicles length and width
- Left/Right turn condition

3.5.2. Dependent Variable

Assessments of traffic congestion (Delay, Capacity & LOS)

3.6.Data Collection Process

Data both descriptive and analytical was obtained.

3.6.1. Field Survey

Field Observation was conducted to identify the congested segments and intersections. Field data was collected by observation.

3.7.Data Collection Techniques and equipment

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

3.7.1. Manual Traffic Volume Count

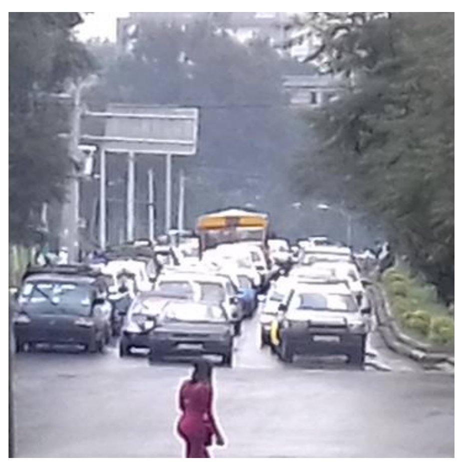
Manual traffic counts were conduct at intersections along the corridor. Traffic count was conducted for one week per intersection to get peak traffic volume, morning (6:30-9:00 AM) and afternoon (4:30-7:00 PM) directly done by researcher with supportive labors. From the week on Monday the 15 minute peak traffic volume was (6:15-6:30 PM). The data was manipulated and transformed to the required size for the analysis.

Figure 3.5 manual traffic counts

(a) West Bound

(b) East Bound

(c) North Bound



(d) South Bound

Figure 3.6 Traffic flow at Harambee hotel

Therefore, from this data collection the following quantitative data were generated. These include: Directional traffic volume /Flow per 15 min of interval for intersections; Vehicle composition of each approaches. The traffic volume in PCUs (passenger Car Units) was summarized and presented at results and discussion part.

In addition to the above traffic data collection techniques other field measurements were done to gather data on the geometric features of the intersections for the analysis. These include: lane width, grade, width of median, cross walk width and length. These measures were done for the intersections whose LOS is going to be determined.

Figure 3.7 Field measurements of geometric feature

3.8.Questionnaires

A structured questionnaire was prepared in order to gather additional information for the congestion level, causes, effects and possible remedies. As congestion is a function of people's perception toward their time and trip purpose, it was necessary to gather information and data on how the road users in this research 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 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 (drivers, passengers), and traffic police and prioritize the possible congestion causes identified from perceptions and literature. The questioners were distributed through questionnaire for respondent. Accordingly, about 110 questioners were distributed. The researcher believes that statistically significant sample should be considered to draw conclusion out of analysis made on such questioner data. However, due to the fact that most of the basis analyses in this research were based on the quantitative data and the data on the questioner were supplement for the result. The questionnaire period was from July, 17 2017-July, 19 2017

3.8.1. Profile

The questionnaire respondents profile is summarized in the table below and also each questioner data was discussed and presented at this section for supplementary to analysis and results of this research. Profile of the respondents showed that most of them were aged in between 25-45 and the most purpose of the trip was work and business.

Table 3.1 General descriptions of questionnaire

Questionnaire's Profile, distributed and returned		Drivers		Passengers		Traffic police	
		Frequency	%	Frequency	%	Frequency	%
Questionnaire	Distributed	15	100	85	100	10	100
	Returned	10	66.67	70	82.4	9	90
	Total returned	89					
Age Group	under 25	1	10	8	11.4	0	0
	25-35	5	50	35	50	2	22.2
	36-45	2	20	22	31.4	6	66.67
	above 46	2	20	5	7.14	1	11.1
	Total	89					
Sex	M	9	90	42	60	8	88.9
	F	1	10	28	40	1	11.1
	Total	89					

3.9.Data Processing and Analysis

The road network and traffic flow of study area through the segments and intersection were an input for processing and analysis. In processing all the design and analysis, identify literature review of research, and data gathered was evaluated to come up with the research output. Then compare the output with the available safety and its effect due to transportation network problem. Finally present the results of analysis according to the research objectives.

3.9.1. Capacity

The flow ratio for a given lane group is defined as the ratio of the actual or projected demand flow rate for the lane group (v_i) and the saturation flow rate (s_i). The flow ratio is given by the symbol $(v/s)_i$ for lane group i. the capacity of a given lane group may be stated as (HCM, 2010):

$c_i = s_i*(g_i/C)$……………………………………………………………………………..(3.1)

3.9.2. Control Delay Approaches

The average control delay per vehicle for a given lane group is given by empirical formula below

$d=d_1PF+d_2+d_3$……………………..……………………………………………………… (3.2)

3.9.3. Delay by Approach and Lane Group Delay

The delaying of vehicle of an intersection of single direction and depends upon the nature of lane group (shared or separated).

$d=d_1PF+d_2+d_3$……………………………………………………………………………….(3.3)

3.9.4. Intersection Delay

The delay of a given intersection that the vehicle entering intersection and leaving at the same time by the control method, either it is automatic or simple light in all approaches

Delay=sum(v*d)/sum(v)……………………………………………………………………….(3.4)

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1.Analysis of signalized Intersection (at Harambe hotel)

4.1.1. PCU for Peak Traffic volume per week

Location: At Harambee Hotel Direction: **East**

Date: June, 25 2017 at (6:15 PM-6:30 PM) Supervisor: Tebebu Abera

Enumerator: Weather Condition Cloudy

Table 4.1 PCU in east direction

Types of Vehicle	15 minute peak volume	Vehicle V, veh/h	PCEs (HCM)	PCU(pc/h)
Car	347	1,388	1	1,388
Land rover	96	384	1	384
Small bus <27 seats	132	528	1.5	792
Medium bus 27-45 seats	3	12	2	24
Large bus >45 seats	8	32	2.5	80
Small truck 3.5 T	5	20	1.5	30
Medium truck 7.5 T	7	28	2	56
High truck 7.5 - 12 T	4	16	2.5	40
Articulate truck >12 T	1	4	3	12
Motor cycle	8	32	0.5	16
Bicycle	1	4	0.5	2
Sum				**2,824**

Location: At Harambee Hotel Direction: **West**

Date: June, 25 2017 at (6:15 AM-7:30 AM) Supervisor: Tebebu Abera

Enumerator: Weather Condition Cloudy

Table 4.2 PCU in west direction

Types of Vehicle	15 minute peak volume	Vehicle V, veh/h	PCEs (HCM)	PCU (pc/h)
Car	237	948	1	948
Land rover	64	256	1	256
Small bus <27 seats	95	380	1.5	570
Medium bus 27-45 seats	1	4	2	8
Large bus >45 seats	4	16	2.5	40
Small truck 3.5 T	3	12	1.5	18
Medium truck 7.5 T	2	8	2	16
High truck 7.5 - 12 T	2	8	2.5	20
Articulate truck >12 T	1	4	3	12
Motor cycle	4	16	0.5	8
Bicycle	1	4	0.5	2
Sum				**1,898**

Location: At Harambee Hotel Direction: **North**

Date: June, 25 2017 at (6:15 PM-6:30 PM) Supervisor: Tebebu Abera

Enumerator: Weather Condition Cloudy

Table 4.3 PCU in north direction

Types of Vehicle	15 minute peak volume	Vehicle V, veh/h	PCEs(HCM)	PCU (pc/h)
Car	187	748	1	748
Land rover	55	220	1	220
Small bus <27 seats	103	412	1.5	618
Medium bus 27-45 seats	2	8	2	16
Large bus >45 seats	3	12	2.5	30
Small truck 3.5 T	4	16	1.5	24
Medium truck 7.5 T	3	12	2	24
High truck 7.5 - 12 T	2	8	2.5	20
Articulate truck >12 T	1	4	3	12
Motor cycle	4	16	0.5	8
Bicycle	1	4	0.5	2
Sum				**1,722**

Location: At Harambee Hotel Direction: **South**

Date: June, 25 2017 at (6:15 PM-6:30 PM) Supervisor: Tebebu Abera

Enumerator: Weather Condition Cloudy

Table 4.4 PCU in south direction

Types of Vehicle	15 minute peak volume	Vehicle V, veh/h	PCEs (HCM)	PCU(pc/h)
Car	185	740	1	740
Land rover	57	228	1	228
Small bus <27 seats	96	384	1.5	576
Medium bus 27-45 seats	4	16	2	32
Large bus >45 seats	4	16	2.5	40
Small truck 3.5 T	1	4	1.5	6
Medium truck 7.5 T	4	16	2	32
High truck 7.5 - 12 T	2	8	2.5	20
Articulate truck >12 T	2	8	3	24
Motor cycle	4	16	0.5	8
Bicycle	1	4	0.5	2
Sum				**1,708**

4.1.2. Total Heavy Vehicles and percentage

The vehicles these touch the pavement surface by greater than four tire. These vehicles are: medium bus, large bus, small truck, medium truck, high truck and articulated truck.

Table 4.5 Total Heavy Vehicles

	Vehicle/hour (Entering an intersection)			
Vehicles type	East	West	North	South
Car	1,388	948	748	740
Land Rover	384	256	220	228
Small bus	792	570	618	576
Medium bus	24	8	16	32
Large bus	80	40	30	40
Small truck	30	18	24	6
Medium truck	56	16	24	32

High truck	40	20	20	20
Arti. Truck	12	12	12	24
Motor cycle	16	8	8	8
Bicycle	2	2	2	2
Total hourly	2,824	1,898	1,722	1,708
Total HVs.	242	114	126	154
Total HVs (%)	**8.57**	**6.01**	**7.32**	**9.02**

4.1.3. Analysis of Level of Service (LOS)

Determination of level of service at an intersection is directly related to the average control delay per vehicle. Once delays have been estimated for each lane group and aggregated for each approach and the intersection as a whole the appropriate level of service are determined for each component.

4.1.3.1.Headway

The headway between vehicles can be observed as the vehicles cross the stop line of the intersection. The first headway would be the elapsed time, in seconds, between tire initiation of the green and the front wheels of the first vehicle crossing over the stop line. The second headway would be the elapsed time between the front bumpers (or wheels) of the first and second vehicles crossing over the stop line. Subsequent headways are measured similarly.

$$h = H + l1$$

$$l1 = \sum_{i=0}^{n} ti$$

Where

h=Total headway (s/veh),

H=Constant headway (s/veh),

l_1 = total start-up lost time (s),

t_i = lost time for ith vehicle in queue (s), and

n = last vehicle in queue.

Table 4.6 Headways

Trial h	Headway (s/veh)			
	East Bound	West Bound	North Bound	South Bound
h1	2.56	2.49	2.43	2.41
h2	2.50	2.46	2.39	2.37
h3	2.43	2.38	2.32	2.31
h4	2.33	2.29	2.23	2.21
H	2.20	2.19	2.11	2.09
H	2.20	2.19	2.11	2.09
$h=H+l_1$	2.56	2.50	2.43	2.41

Table 4.7 Parameters for Control Delay calculation and LOS Analysis

Parameters	Approaches			
	East Bound	West Bound	North Bound	South Bound
Volume V, (pc/h)	2824	1898	1722	1708
Headway h, (s/veh) from the field	2.56	2.50	2.43	2.41
Base saturation flow rate s_o,(pc/h)=3600(s/h)/headway(s/veh)	1407	1442	1484	1496
Green time (s)	36	36	36	40
Red time (s)	133	133	133	129
Yellow time (s)	3	3	3	3
Lost time (s)	4	4	4	4
Number of phase per cycle	4			
Number of lanes	3	3	3	3
Lane width (m) (outer to most inner)	3.3, 2.9 &	3.3, 2.9	3.3, 2.9 &	3.3, 2.9 &

	2.9	& 2.9	2.9	2.9
Pedestrian volume p,(p/h) by area type	200	200	200	200
Bicycle volume bic, (bic/h)	3	3	4	3
Terrain type	Level	Level	Level	level
Pedestrian average speed S_p, (m/s)	1.2	1.2	1.2	1.2
Cross walk length L, (m)	9.1	9.1	9.1	9.1
Cross walk width W_E, (m)	4	4	4	4
Cycle length C, (s)= red+green+yellow+loss	36+133+3+4=176			
Pedestrian start-up time (s)	3.2	3.2	3.2	3.2
Equivalent truck ET	2.5	2.5	2.5	2.5
Incremental delay factor K (for pre-timed signals	0.5	0.5	0.5	0.5
Upstream filtering adj. factor I, (degree of saturation at upstream signal intersection >=1)	0.09	0.09	0.09	0.09
Proportion of vehicle arriving on green P	0.63	0.57	0.48	0.41
Supplemental adjustment factor f_{PA} (for arrival type 3 of all unconditional lane groups)	1	1	1	1
Progression adjustment factor PF=(1-p)f_{PA}/(1-(g/C)), p=proportion of vehicles arriving on green, g/C=proportion of green time available	0.54 (upstream signalized)	-	-	-

Table 4.8 Level of Service Analysis at Intersection (See Appendix B1-B4)

Pedestrians/Cycle (p= pedestrians)	200p/h*1h/3600 s*175 = 9.72 p
Minimum effective green time required for pedestrians	G_p=3.2+L/S_p+(0.81*N_{ped}/W_E), W_E>3 G_p(all approach)= 3.2+18.2/1.2+(0.81*9.72/4)= 20.34 s

Compare minimum effective green time required for pedestrians to actual effective green	G_p(EB, WE and NB)=36, which is>20.34s G_p(SB) =40, which is >20.34s
Proportions of left and right turns	Proportions of left and right turn traffic are found by dividing the appropriate turning volumes by the total lane group volume P_{LT}(East Bound)=350/(350+2354+120)=0.12 P_{LT}(West Bound) =251/(251+1512+135)=0.12 P_{LT}(North Bound)= 238/(238+1367+118)=0.13 P_{LT}(South Bound)=204/(204+1402+103)=0.11 P_{RT}(EB)=120/(350+2354+120)=0.04 P_{RT}(WB)=135/(251+1512+135)= 0.07 P_{RT}(NB)=118/(238+1367+118)=0.06, but since exclusive p_{RT}= 1 P_{RT}(SB)=103/(204+1402+103)=0.06, but since exclusive p_{RT}= 1
Lane width adjustment factor	f_w=1+(w-3.6)/9 , w= 3.3, 2.9 and 2.9 m from outer to inner lane, so take an average $f_{w(mid)}$=1+(2.9-3.6)/9=0.92 $f_{w(inner)}$=1+(2.9-3.6)/9=0.92 f_w(all approach)ave=(0.92+0.92)/2=0.92
Area type adjustment factor	For others, f_a(all approaches)=1
Lane utilization adjustment factor	$f_{LU}=V_g/V_{gl}N$, V_g=demand of total lane V_{gl}= demand of single lane N= numbers of lane f_{LU}(all approach)=1

Left turn adjustment factor	f_{LT}=1/(1+0.05*p_{LT}) f_{LT} (EB)=0.994 f_{LT}(NB)=0.994 f_{LT} (WB)=0.994 f_{LT}(SB)=0.994
Right-turn adjustment factor	f_{RT}(EB)=0.998 f_{RT}(NB)=0.997 f_{RT}(WB)=0.996 f_{RT}(SB)=0.997
Left-turn pedestrians/bicycles adjustment factor	f_{Lpb}(EB)=1 f_{Lpb}(NB)=1 f_{Lpb}(WB)=1 f_{Lpb}(SB)=1
Right-turn pedestrians/bicycles adjustment factor	f_{Rpb}(EB)=0.987 f_{Rpb}(NB)=0.979 f_{Rpb}(WB)=0.978 f_{Rpb}(SB)=0.984
Saturation flow, s (veh/h)	$s=s_oNf_wf_{LU}f_af_{LT}f_{RT}f_{Lpb}f_{Rpb}$ s(East Bound)= 3620 veh/h s(North Bound)= 3268 veh/h s(West Bound)= 3743 veh/h s(South Bound)= 3290 veh/h
Lane group capacity, c (veh/h)	c=s(g/C), g=36 s for EB, WB, and NB, g= 40 s for SB, C= 176 s c(East Bound)= 740 veh/h c(North Bound)=668 veh/h c(West Bound)=766 veh/h c(South Bound)=748 veh/h
v/c ratio	v/c(EB) =2824//740= 3.81 v/c(NB)=1722/668=2.58 v/c(WB)=1898/766=2.48 v/c(SB)=1708/748= 2.28
Determine critical lane group	The highest v/c ratio of lane group in phase is considered as a critical lane group. In this case EB and NB lane groups are critical
Flow ratio of critical lane groups	v/s(East Bound)=2824/3620=0.78

	v/s(North Bound)=1722/3268=0.53
Sum of critical flow ratios	Y_c= 0.78+0.53=1.31
Critical flow rate to capacity ratio	X_c=Yc*C/(C-L), L=lost time per cycle= 4*4=16 s X_c=(1.31*176)/(176-16)=1.44
Uniform delay	d_1= 0.5*C*(1-g/C)^2/{(1-g/C)[Min(x,1)]} d_1(East Bound)=70 s/veh d_1(North Bound)=70 s/veh d_1(West Bound)=70 s/veh d_1(South Bound)=68 s/veh
Incremental delay	d_2=900T[(x-1)+((1-x)^2+(8*K*I*X) /(c*T))$^{1/2}$] d_2(EB)= 198.71 s/veh d_2(NB)= 198.79 s/veh d_2(WB)= 198.69 s/veh d_2(SB)= 198.71 s/veh
Delay adjustment factor	PF(East approach)= 0.54, extremely low value of g/C
Lane group delay	d=d_1PF+d_2+d_3, d3=0, (See Appendix B) d(East Bound)= 236.51 s/veh d(North Bound)= 198.79 s/veh d(West Bound)= 198.69 s/veh d(South Bound)= 198.71 s/veh
Intersection delay	d_I=sum(dA)(vA)/(sum vA) d_I=211.82 s/veh
Level of service by lane group, approach, and intersection	LOS(East Bound)=F LOS(North Bound)=F LOS(West Bound)=F LOS(South Bound)=F LOS Intersection=F

Table 4.9 calculation results are summarized as follows (See Appendix B1-B4)

Direction/ LnGrp	v/c ratio	g/C ratio	Unif delay d_1	Progr factor PF	Lane Grp cap	Cal Term K	Incr delay d_2	Lane Grp delay	Lane Grp LOS	Delay by Appr	LOS by Appr
EB/LTR	3.81	0.20	70	0.54	740	0.5	198.71	236.51	F	236.51	F
WB/ LTR	2.48	0.20	70	-	766	0.5	198.69	198.69	F	198.69	F
NB/ LTR	2.58	0.20	70	-	668	0.5	198.79	198.79	F	198.79	F
SB/ LTR	2.28	0.23	68	-	748	0.5	198.71	198.71	F	198.71	F

Intersection Delay=**211.81** s/veh >>**80**s/veh, Intersection LOS=**F**

Table 4.10 level of congestion (from questionnaire)

Level of congestion	Drivers		Passengers		Traffic police	
	No	%	No	%	No	%
Medium	0	0	0	0	1	11.11
High	2	20	13	18.57	2	22.22
Very high	8	80	57	81.43	6	66.67

Table 4.11 were concluded that, the response to level of traffic congestion was strongly supported the results of analysis (density and level of service).

4.2. Analysis of Un-signalized intersection (at Filwuha)

4.2.1. TWSC (Two Way Stop Control) T-intersection (at Filwuha)

The intersection: A TWSC (Two Way Stop Control) T-intersection

Facts:

Three-lane Major Street

Stop controlled minor street approach

Two- lane minor Street

Table 4.11 Pedestrians distribution

Movements	13 (Crossing major lane EB)	14 (Crossing major lane WB)	16 (Crossing minor lane)
Pedestrians (ped/h)	30	48	152

Table 4.12 Traffic count of each approach and calculation of PCU

Types of vehicle		Veh/h								
	PCE	EB			WB			SB		
		LT	TH	RT	LT	TH	RT	LT	TH	RT
Car	1	8	32			22	6	5		13
Land rover	1	3	11			13	8	4		21
Small bus	1.2	2	16			11	4	6		8
Medium bus	2	1	3			5	1	0		1
Large bus	2.2	0	0			1	0	0		0
Small truck	1.4	0	3			2	0	0		0
Medium truck	1.6	0	1			0	0	0		0
High truck	2.2	0	0			0	0	0		0
Articulated truck	2.5	0	0			0	0	0		0
Motor cycle	0.3	2	4			3	1	3		3
Bicycle	0.5	1	1			5	3	2		5
Total hourly (veh/h)		17	71			61	23	20		51
Total PCU (pc/h/ln)		17	76			68	23	18		50

Table 4.13 Two Way Stop Control T-intersection analysis (See Appendix C)

Data input	Work sheet 1 and 2
Site characteristics	Worksheet 3 - lane designation, grade, right turn channelization, and arrival type

$t_{c,x}$ and $t_{f,x}$ (critical gap for movement x, s and follow-up time for minor movement x, s) respectively	$t_{c,x} = t_{c,base} + t_{c,HV} P_{HV} + t_{c,G} G - t_{c,T} - t_{3,LT}$ $t_{f,x} = t_{f,base} + t_{f,HV} P_{HV}$ $t_{c,1}$=4.1+1.5*0+0*0.02-0-0=4.1 $t_{c,10}$=7.1+1.5*0+0.2*0.02+0.7-0.6=7.204 $t_{c,12}$=.2+1.5*0.02+0.1*0.02-0-0=6.232 $t_{f,1}$=2.2+0.95*0=2.2 $t_{f,10}$=3.5+0.95*0=3.5 $t_{f,12}$=3.3+0.95*0.025=3.32
Movement capacity $C_{m,x}$ accounting for impedance	$V_{c,12}=v_5/N+0.5*v_6+v13+v_{16}$ $V_{c,12}$=68/2+0.5*23+30+152=228 veh/h $C_{p,x}=v_{c,x}$*[(e^((-$v_{c,x}$*$t_{c,x}$)/3600))/(1-e^((-$v_{c,x}$*$t_{f,x}$)/3600)]= $C_{p,12}$=50*[(e^((-50*6.2)/3600))/(1-e^((50*3.3)/3600)]=822 veh/h $C_{m,12}=c_{p,12}*P_{p,12}$=822*0.78=642 veh/h $P_{0,i}$=1-vi/cm,i $P_{0,12}$=1-50/822=0.94
Shared lane capacity	movements 10 and 12 share the same lane C_{HS}=sum(Vy)/sum(Vy/Cm,y) C_{HS}(SB)=(23+50)/ (23/234+50/822)=459 veh/h

Control delay (Approaches) and LOS	$$d=\frac{3600}{c_{m,x}}+900T\left[\frac{v_x}{c_{m,x}}-1+\sqrt{\left(\frac{v_x}{c_{m,x}}-1\right)^2+\frac{\left(\frac{3600}{c_{m,x}}\right)\left(\frac{v_x}{c_{m,x}}\right)}{450T}}\right]+5$$ $d(SB)_{12}$=10.923 s/veh, **LOS B** $d(EB)_{10}$=14.2 s/veh, **LOS B** $d(NB)_1$= 12.9s/veh, **LOS B**
intersection control delay	dI=(d12v12+d10v10+d1v1)/(v1+v2+v3) =(10.923*50+14.2*19+12.9*17)/(50+19+17)=**12.67**, **LOS B**

4.3.The Results of both signalized and un-signalized intersection

A three lanes in each approach (i.e. East, West, North, and south) of intersection at Harambee hotel with 3.3, 2.9, 2.9 meter (m) from outer to most inner lane width respectively; and median width 2.5 m will meet operational objectives of LOS F both approaches and intersection during peak hour period.

The analysis of un-signalized **T-intersection** concluded that the level of service of traffic flow is very light congestion; an occasional approach phase is fully utilized (LOS B both approach and intersection) drivers begin to respond to the existence of other vehicles in the traffic stream. For current no or light remedial measure is needed, like improving traffic control management, road surfacing improvement; but for future it needs further forecasting analysis to cope up with current level of service or more.

4.4.Possible Causes of Traffic Congestion (Intersection at Harambee hotel)

Traffic congestion is now day unavoidable phenomena due to the rapid growth of traffic volume; reduction of road capacity; and traffic management problem. Due to traffic congestion, measures should be prepared before it is out of control than now. After performing observation for peak time of day (7:30-7:45 AM & 6:15-6:30 PM) and peak day of a week on Monday the causes of traffic congestion for study location (intersection at Harambee Hotel) were inadequate road capacity, which was difficult to flow well in given green time; working zone causes reduction of capacity by increasing traffic volume (peak time at morning and night); short distance apart between intersections (for instance, Biherawi

Theatre and Harambe hotel is less than one mile). Generally the possible causes of traffic congestion on study location were:

- Inadequate road capacity and insufficient lane width (2.9-3.3m), less than standard (3.3m for local, 3.65m for highway) which affect free flow.
- Poor traffic control management
- Short distance between intersections
- Excessing of private transport
- Lack of allowance by employers to spread work and shift starting hours
- Poor habit of using alternative roads

Table 4.14 possible causes of traffic congestion (from questionnaire)

Causes	Drivers		Passengers		Traffic police	
	No	%	No	%	No	%
High traffic volume	3	30	31	44.29	4	44.44
Poor road network	5	50	26	37.14	3	33.33
Traffic management problem	2	20	13	18.57	0	0
Traffic signal problem	0	0	0	0	2	22.22

4.5.Effects of Traffic Congestion

The effects of traffic congestion on local, regional, state, national, and international levels can be affected social, economic, political, and environmental condition. Transportation is basic for the development of local to international level in social, economic, and political. Even though, it is fact, the increment of traffic volume over the world to national level the traffic congestion will be happen, which may affect the social, economic, political, and environment. The traffic congestion as literature review is the delay of vehicle to reach the destination.

4.5.1. Social Effect

Psychologically, traffic congestion is the causes of stress. For the interaction or relationship between persons, people, group(s) or companies the role of transportation is high. These relationships are fully functional, if the transportation system is safe, comfortable, and normal traffic flow. Unless otherwise or if traffic congestion is occurred the relationship is fully disturbed, which can reduce the social interaction for the common goal and for the development of country.

4.5.2. Economic Effect

Around study area there were many sources of economic development like, Biherawi theatre, Ambassador theatre, different hotels (Harambee, Ethiopia, Sheraton, Geon), Filwuha, foreign tourists, Ethiopian Stadium those all were affected due to traffic congestion.

There are many parameters of cost of traffic congestion. Some of them are:

- Ideal time or Labor Cost: The time cost of the user of transportation as per their standard income payment, like mostly drivers, and passengers.
- Fuel Cost: The fuel consumption cost of vehicles is due to decelerating, stopping, and accelerating. Generally, due to the cost of above parameters traffic congestion had impacts on the development of our country both direct and indirect.

4.5.3. Political Effect

Politically a given country is stable, if the basic infrastructure if fulfilled. Since transportation service is basic: safe, comfortable and normal traffic flow is good characteristics of transportation system, unless traffic congestion is happen. Traffic congestion is obstacle for good administration in the way of delaying information not to reach for needed purpose on time.

4.5.4. Environmental Effect

The environmental impact of transport is significant because it is a major user of energy, and burns most of the world's petroleum. This creates air pollution, including nitrous oxides and particulates, and a significant contributor to global warming through emission of carbon dioxide. The impact of congestion was high because fuel consumption highly increased with traffic jam. On the study area due to high traffic congestion the emission of CO_2 and sound pollution was increased.

Table 4.15 Effects of traffic congestion (from questionnaire)

Effects	Drivers		Passengers		Traffic police	
	No	%	No	%	No	%
Economic	8	80	61	87.14	5	55.56
Environment	0	0	2	2.86	1	11.11
Social	2	20	7	10.00	2	22.22
Political	0	0	0	0	1	11.11

4.6. Traffic Congestion Mitigation Measures

For nonrecurring causes like work zone, traffic incident, damaged traffic signal and vehicle breakdown the sub city as well as city administration should use one of those like faster and anticipatory response to traffic incidents, access management and improvement of work zones. The most serious cause of traffic congestion is reduction in capacity, due to increase in traffic volume. To improve the capacity of the highway, there were possible solutions:

4.6.1. Interchanges

On the study area there was no space to add lane or widen the existing lane because of land value. In all approaches the land value is high to re-design, for instance harambe hotel is less than three (3m) from the curb, new CBE head quarter is also the same. Even though if it is possible to add lane(s) the congestion due to traffic volume also increased as the number of registered vehicle increased year to year alarmingly but it is not possible because of land constraint. So, the traffic volume was very high and greater than 1000 veh/h (ERA, 2002) the possible solution is grade separated with ramp. The geographical location is comfortable for grade separation from Harambee hotel to National Bank. As a result, grade separation with ramp, normalizing traffic flow from wabishabel to cherchil road; legar to cherchil road; and stadium to Ambassador by under pass, delay only for pedestrians, merging and diverging.

4.6.2. Congestion Pricing:

As secondary option by applying congestion pricing policy to reduce the traffic volume in this corridor (i.e. to develop habit of using alternative roads)

Table 4.16 possible remedial measures (from questionnaire)

Possible remedial measures	Drivers		Passengers		Traffic police	
	No	%	No	%	No	%
Capacity improvement	8	80	52	74.29	6	66.67
Signal re-design	0	0	0	0	1	11.11
Management improvement	2	20	18	25.71	2	22.22

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1.Conclusions

Traffic volume distribution and congestion were similar with theoretical principle. Traffic volume was peak at morning and evening period for all directions of an intersection. Similarly, traffic congestion during morning and evening were peak and congested and relatively uncongested during midway.

The traffic congestion of intersection at Harambe Hotel has a significant effect on overall traffic flow pattern on the selected road segment (i.e. traffic flow of legar, wabishebele, national bank and cherchil road). At an intersection of all directions was currently performing above capacity and volume to capacity ratio was greater than 100 percent.

During both morning and evening peak periods almost the movements in all direction is stop-and-move, which is very congested. The relationship between congestion and slight accident to property is most of the time direct relation, but it is not always.

A three lanes in each approach (i.e. East, West, North, and south) of intersection at Harambee hotel with 3.3, 2.9, 2.9 meter (m) from outer to most inner lane width respectively; and median width 2.5 m will meet operational objectives of LOS F both approaches and intersection during peak hour period.

This research was discussed level of traffic congestion for selected intersections at Harambee hotel (signalized) and at Filwuha (un-signalized). As a result the level of service LOS F for signalized and level of service LOS B for un-signalized intersection.

The possible causes of traffic congestion for intersection at Harambee hotel was inadequate road capacity (High traffic volume), working zone, Problem of traffic control management and short distance between intersections while forming long queue over flow to each other.

The effect of traffic congestion on study area was significant on social, economic, political and environmental. The possible remedial measures to reduce traffic congestion were Interchanges (grade separation with ramp) and congestion pricing policy.

5.2.Recommendations

Further researches should be conducted to extend all aspects of this research, data collection of traffic volume at least for several weeks. Similarly during data collection density and travel time automatic data collection are better to minimize error.

Further forecasting analysis should be conducted for un-signalized intersection to cope up the current LOS B in the future as well and more if possible.

The research was analyzed only the effects of traffic congestion in general, more studies should be conducted to interpret the impacts of traffic congestion into monetary values.

From the analysis result, it shows an intersection at Harambee hotel was serving above its capacity. Therefore, the sub-city and city administration should consider this issue and formulate capacity improvement methods, by implementing the "possible measures" of this research by controlling, assessing and evaluating. Like: Over Pass or Bridge design and construction, and congestion pricing policy.

REFERENCES

Bertini, L.R. (2005, November). You Are the Traffic Jam: An Examination of Congestion Measures. Paper Presented at 85th Annual meeting of the transportation research Board, Washington D.C.

Cambridge Systematics, Inc. &Texas Transportation Institute. (2004). Traffic congestion and Reliability: linking Solutions to problems: Final Report.

Cambridge Systematics Inc. (2008). Crush vs. Congestion: What is the cost for society? Maryland: Cambridge Systematics Inc.

FDRE Population Census Commission (2013). Summary and Statistical Report of the 2007 Population & Housing Census. Addis Ababa.

Getu Segni (2007). Causes of Traffic Accidents and Possible Counter Measures on Addis Ababa Shashemene Roads, Addis Ababa University, Faculty of Technology, Civil engineering Department.

Haragewoin, Y. (2010). Impact of Vehicle Traffic Congestion in Addis Ababa (A case study of Kolfe sub-city: Total-Ayar Tena Road): Unpublished MSc Thesis, Ethiopian Civil Service College.

HCM, Highway Capacity Manual 2010, Volume 1.

HCM, Highway Capacity Manual 2000, June, 1999 Urban Street Concepts Signalized Intersections.

HCM, Highway Capacity Manual 2000, June, 1999 Urban Street Concepts Signalized Intersections: Chapter 16: page 16-9-16-23.

Herbert S. Levinson & Timothy J. Lomax. 2005, Developing a traffic Time Congestion index. Transportation research Record#1564.

Innovating Financing for Transport Scheme, 2015

Joint Transport Research Center(OECD + ECMT), January 2004, the organization for economic Co-operation and Development and European Conference of Ministry of Transport, Summary document on Managing Urban Traffic Congestion, www. Sourceoecd.org. cited on 4/15/2013.

Lomax, T., Turner, S., & Shunk, G. (1997). NCHRP Report 398 "Quantifying Congestion". Transportation Research Board, Washington D.C: National Academy Press.

McGroarty J. (2010, Jan. 29). Recurring and Non-Recurring Congestion: Causes, Impacts, and Solutions. Paper presented at Neihoff Urban Studio.

Ministry of Transport and Communication. (2010). *Project Profile on the Establishment of Traffic Operation Center (TOC) for the City of Addis Ababa.* Addis Ababa*: (unpublished).*

Nicholas J. Garber & Lester A. Hoel (2009): Traffic and Highway Engineering Fourth Edition, University of Virginia.

O'Flaherty, Edited by C.A (2002). Highways the location, design, and maintenance of Road Pavements (4th ed.). Oxford: Butterworth-Heinemann: *ISBN 978-0-7506-5090-8.*

R. Kakooza, L.S. Luboobi and J.Y.T. Mugissha, “Modeling Traffic Flow and Management at Signalized, Signalized and Roundabout Road Intersection”, Journal of Mathematics and Statistics, 1(2005), 194-202.

R. Narayanana, R. Urdayakumar, K. Kumar & K. Subbaraj (2003). Quantification of Congestion using Fuzzy Logical and Network Analysis using GIS, Paper Presented at Map India Conference 2003.

RTA. (2011). *RTA.* Retrieved September 1, 2011, from http://www.rta.gov.et/accident.htm.

Schrage A. (2006). Traf fic Congestion and Accidents: Nr. 419. University of Regensburg Working Papers in Business, Economics and Management Information Systems, Germany.

Schrank D. & Lomax T. (2005). The 2005 Urban Mobility Report. Texas Transportation Institute. [Online] available http://www.mobility.tamu.edu.

Spalding S. (2008). RACQ Congested Roads Report: the effect on Fuel Consumption and Vehicle Emissions: version (1) 0408.

T.Thianniwet, & S. phosaard. (2009). Classification of Road Traffic Congestion Levels from GPS data using Decision Tree Algorithm and Sliding windows. *World Congress on Engineering 2009 volume I*. London, UK.

Web site: Google Earth & http://www.eamsl.com/Addis Ababa

Web Sites (www.trafficdata.info.,ITDb,accessed28/06/2017,www.Cemt.org/JTRC/index.htm Wikipedia-the free encyclopedia).

Weisbrod G., Vary D. & Treyz G. (2003). Measuring the Economic Cost of Urban Traffic Congestion to Business: Journal of the Transport Research Board: Published in Transportation Research Record, #1839.

Wondwossen, T. (2011). Assessing & Quantifying the Level of Traffic Congestion at Major Intersections in Addis Ababa (a case for East-West corridor) M.Sc. Thesis presented to school of graduate studies, Addis Ababa University, Civil Engineering Department Addis Ababa.

APPENDICIES

APPENDIX A

TRAFFIC VOLUME DATA

A. TRAFFIC COUNT FORMAT

Traffic Count Format

Location: ____________ Direction: _________

Date: ___/___/___ Supervisor: ___________

Enumerator: _________ Weather Condition: ________

Hourly Interval	car	land rove	Small bus <27 seats	Medium bus 27-45 seats	Large bus >45 saets	small truck 3.5 T	Medium truck 7.5 T	High truck 7.5 - 12 T	articulated Truck >12 T	Motor cycle	Bicycle
6:00-7:00 AM											
7:00-8:00 AM											
8:00-9:00 AM											
4:30-5:30PM											
5:30-6:30 PM											
6:30-7:30 PM											
Sub total											
Grand total											

Chart I Traffic count format

B. Traffic volume (days of the week) June, 25 2017-July, 1 2017

Peak Traffic Volume at Harambee hotel			Traffic Volume (veh/h) peak 15 minute times 4						
Approaches	Peak time	Types of vehicle	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
East Bound	6:15 PM-6:30 PM	Cars	1,388	1098	1113	1109	1234	998	1034
		land rover	384	338	341	328	362	337	366
		small bus	528	388	411	432	480	409	398
		medium bus	12	5	4	1	4	2	3
		large bus	32	21	12	18	13	12	8
		small truck	20	21	14	12	21	2	4
		medium truck	28	16	17	12	11	5	3
		High truck	16	12	11	15	6	3	5
		Artic.	4	2	3	1	4	1	2

		Truck							
		Motor Cycle	32	21	16	13	21	23	45
		Bicycle	4	1	3	0	1	28	25
West Bound	6:15 PM-6:30 PM	Cars	948	802	812	798	912	755	783
		land rover	256	211	231	201	233	198	204
		small bus	380	351	346	338	372	321	309
		medium bus	4	5	4	6	3	6	8
		large bus	16	12	15	13	12	15	6
		small truck	12	11	8	4	7	3	2
		medium truck	8	8	11	15	7	4	1
		High truck	8	3	2	1	2	1	0
		Artic. Truck	4	1	1	0	1	0	1
		Motor Cycle	16	18	17	21	11	31	35
		Bicycle	4	1	2	1	3	28	41
North Bound	6:15 PM-6:30 PM	Cars	748	701	689	561	715	652	671
		land rover	220	209	211	190	201	187	181
		small bus	412	372	388	344	396	381	377
		medium bus	8	8	4	7	8	7	8
		large bus	12	11	15	6	4	8	11
		small truck	16	13	12	13	5	2	1
		medium truck	12	4	6	7	11	6	5
		High truck	8	6	3	2	2	1	2
		Artic. Truck	4	2	4	3	4	1	2
		Motor Cycle	16	15	12	14	6	32	36
		Bicycle	4	2	1	2	2	25	31
South Bound	6:15 PM-6:30 PM	Cars	740	612	587	681	712	652	658
		land rover	228	198	202	210	221	198	211
		small bus	384	327	348	301	371	320	308
		medium bus	16	6	5	8	11	9	10
		large bus	16	5	6	7	13	11	12
		small truck	4	5	4	6	8	4	3
		medium	16	8	6	9	11	4	5

		truck							
		High truck	8	7	3	3	6	2	1
		Artic. Truck	8	2	4	2	4	1	1
		Motor Cycle	16	12	14	15	11	32	38
		Bicycle	4	1	3	2	3	29	31

Chart II Traffic volume at Harambee hotel

C. Traffic volume (days of the week) July, 2 2017-July, 7 2017

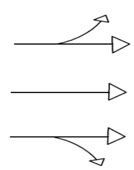
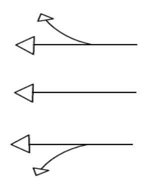
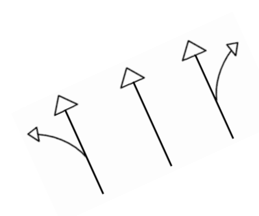
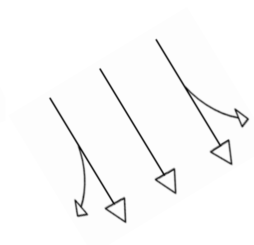
Peak Traffic Volume at Filwuha			Traffic Volume (veh/h) peak 15 minute times 4						
Appro aches	Peak time	Types of vehicle	Mond ay	Tuesd ay	Wednes day	Thurs day	Frid ay	Saturd ay	Sund ay
East Bound	6:15 PM-6:30 PM	Cars	40	32	29	22	24	21	16
		land rover	14	18	16	11	13	11	8
		small bus	18	10	11	13	10	13	9
		medium bus	4	2	3	2	2	2	3
		large bus	0	1	0	1	1	1	0
		small truck	3	2	1	0	1	0	1
		medium truck	1	1	1	1	1	1	0
		High truck	0	0	0	0	0	0	1
		Artic. Truck	0	0	0	0	0	0	0
		Motor Cycle	6	8	5	3	3	4	3
		Bicycle	2	1	4	2	3	2	2
West Bound	6:15 PM-6:30 PM	Cars	28	22	27	25	28	22	23
		land rover	23	24	22	21	20	17	18
		small bus	15	13	14	12	13	11	8
		medium bus	6	4	5	4	2	2	3
		large bus	1	1	1	1	1	1	1
		small truck	2	1	2	1	2	2	1
		medium truck	0	0	0	0	1	0	0

		High truck	0	0	0	0	0	0	0
		Artic. Truck	0	0	0	0	0	0	0
		Motor Cycle	4	5	4	5	4	3	4
		Bicycle	8	9	7	3	6	7	6
South Bound	6:15 PM-6:30 PM	Cars	18	17	15	18	17	16	15
		land rover	25	22	19	16	24	22	19
		small bus	14	12	11	5	13	17	16
		medium bus	1	1	1	2	1	0	0
		large bus	0	0	0	0	0	0	0
		small truck	0	0	0	1	0	1	0
		medium truck	0	0	0	0	0	0	0
		High truck	0	0	0	0	0	0	0
		Artic. Truck	0	0	0	0	0	0	0
		Motor Cycle	6	7	8	7	7	6	4
		Bicycle	7	5	2	3	6	5	8

Chart III Traffic volume at Filwuha

APPENDIX B

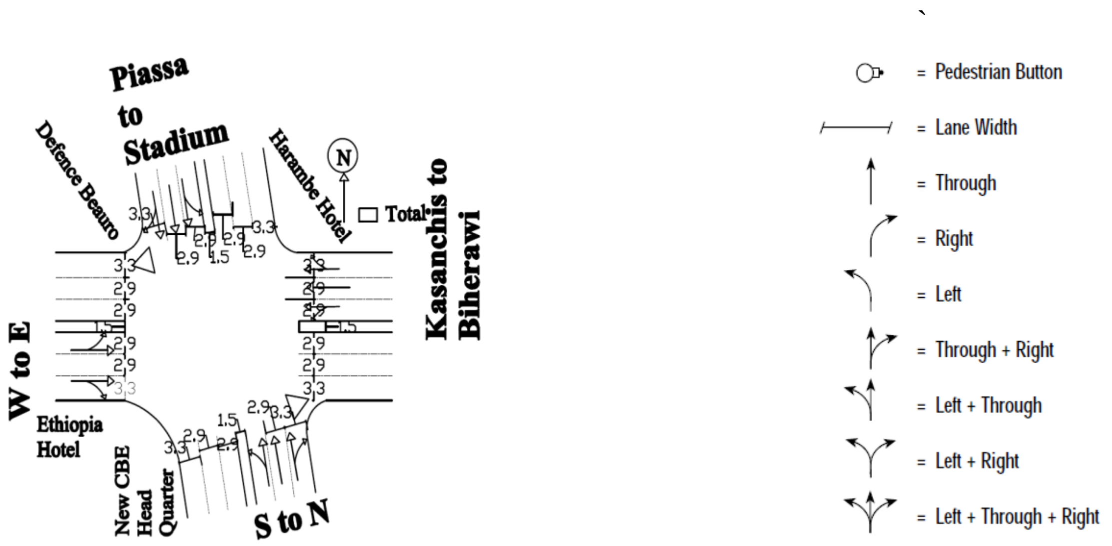
LEVEL OF SERVICE FOR SIGNALIZED INTERSECTION

VOLUME ADJUSTMENT AND SATURATION FLOW WORKSHEET												
General Information												
Project Description												
Volume Adjustment												
	EB			WB			NB			SB		
	LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT
Volume, V (veh/h)	350	2354	120	251	1512	135	238	1367	118	204	1402	103
Proportion of LT or RT, (P_{LT} OR P_{RT})	0.125		0.043	0.133		0.072	1		1	1		1
Saturation Flow Rate												
Lane group												
Base saturation flow, s_o (pc/h/ln)		1407			1442			1484			1496	
Number of lanes, N		3			3			3			3	
Lane width adjustment factor, f_w		0.937			0.937			0.937			0.937	
Area type adjustment factor, f_a		1			1			1			1	
Lane utilization adjustment factor, f_{LU}		1			1			1			1	
Left-turn adjustment factor, f_{LT}		0.994			0.9934			0.952			0.952	

Right-turn adjustment factor, f_{RT}		0.994			0.989			0.85			0.85	
Left-turn ped/bic adjustment factor, f_{Lpb}		0.938			0.934			0.93			0.946	
Right-turn ped/bic adjustment factor, fRpb		0.979			0.964			0.966			0.973	
Saturation flow, s (veh/h) $s=s_oNf_wf_{LU}f_af_{LT}f_{RT}f_{Lpb}f_{Rpb}$		3620			3743			3268			3290	
Notes												
p_{LT}= 1 for exclusive left-turn and p_{RT}=1 for exclusive right-turn otherwise they are equal to the proportions of turning volume in the lane group.												

B1: Input worksheet

INPUT WORKSHEET			
General Information	**Site Information**		
Analyst : Tebebu Abera	Intersection Harambe hotel		
Agency/Company: MSc. Thesis	Area Type	CBD	Others ✓
Date performed: 7/15/2017	Jurisdiction: Jimma University		
Analysis time period: 6:30-9:00 AM & 4:30-7:00 PM	Analysis Year 2017		
Intersection Geometry			



Volume

	EB			WB			NB			SB		
	LT	TR	RT	LT	TR	RT	LT	TR	RT	LT	TR	RT
Volume, V (veh/h)	350	2354	120	251	1512	135	238	1367	118	204	1402	103
Arrival Type, AT	3			3			3			3		
Approach pedestrian volume, V_{ped} (p/h)	200			200			200			200		
Approach bicycle volume, V_{bic} (bicycles/h)	3			3			4			3		
Parking Maneuvers, N_m (maneuvers/h)	0			0			0			0		

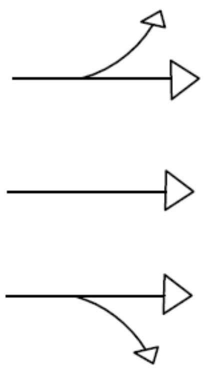
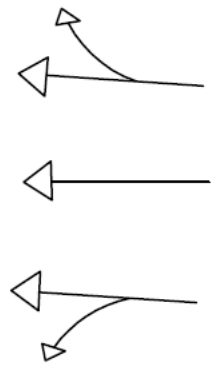
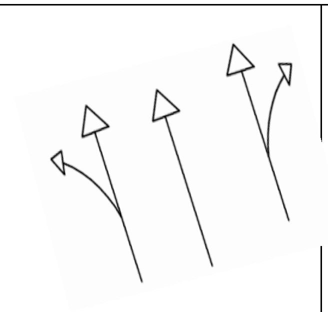
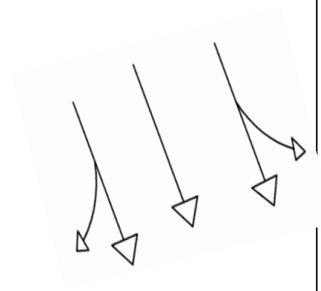
Bus Stopping, N_g (buses/h)	0		0		0		0	
Signal Timing								
DIAGRAM								
Timing	Green= 36 Yellow=3		Green=36 Yellow=3		Green=36 Yellow=3		Green=40 Yellow=3	
Pre-timed or Actuated	P	P	P	P	P	P	P	P
Protected turns		Permitted turns Pedestrians		Lost time/phase 4 s		Cycle length 175 s		Lost time/cycle 16 s
	EB	WB		NB		SB		
Minimum timing for ped. G_p	20.34	20.34		20.34		20.34		

Chart IV Input worksheet

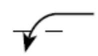
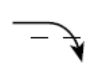
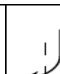
B2: Volume adjustment and saturation flow worksheet

Chart V Volume adjustment and saturation flow worksheet

B3: Supplemental worksheet

SUPPLEMENTAL WORKSHEET FOR PERMITTED LEFT TURNS OPPOSED BY A SINGLE LANE AND MULTILANE APPROACH				
General Information				
Project Description Final Thesis				
Input				
	EB	WB	NB	SB
Cycle length, C (s)	176			
Total effective green time for LT lane group, G (s)	36	36	36	40
Effective permitted green time for LT lane group, g (s)	36	36	36	40
Opposing effective green time, g_o (s)	36	36	36	40
Number of lanes in LT lane groups, N	3	3	3	3
Adjusted LT flow rate, v_{LT} (veh/h)	369	265	251	215
Proportion of LT volume in LT lane groups, p_{LT}	0.125	0.133	0.14	0.12
proportion of LT volume in opposing flow, p_{LTo}	0.133	0.125	0.12	0.14
Adjusted flow rate for opposing approach, v_o (veh/h)	1898	2824	1708	1722
Lost time for LT lane groups, t_L	4	4	4	4
Computation				
LT volume per cycle, $LTC=v_{LT}C/3600$ (veh/C)	17.94	12.88	12.20	10.45
Opposing flow per lane per cycle, $v_{olc}=v_oC/3600$ (veh/C/ln)	96.35	143.99	87.26	87.50

Opposing platoon ratio, R_{po}	1.33	1.33	1.33	1.33

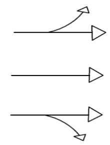
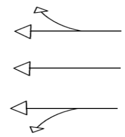
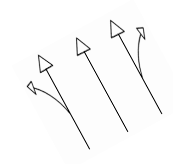
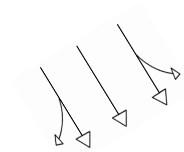
SUPPLIMENTAL WORKSHEET FOR PEDESTRIAN-BICYCLEEFFECTS ON PERMITTED LEFT TURNS AND RIGHT TURNUS				
General Information				
Project Description **Final Thesis**				
Permitted Left Turns				
	EB	WB	NB	SB
				
Effective pedestrian green time, g_p (s)	36	36	36	40
Conflicting pedestrian volume, v_{ped} (p/h)	200	200	200	200
$V_{pedg} = v_{ped}(C/g_p)$	972	972	972	875
$OCC_{pedg} = v_{pedg}/2000$, if ($v_{pedg} < 1000$)	0.486	0.486	0.486	0.438
Opposing queue clearing green, g_q (s)	110.99	152.18	102.63	98.20
Effective pedestrian green consumed by queue, g_q/g_p if $g_q > g_p$, then $f_{lpb}=1.0$	3.08	4.23	2.85	2.46
f_{lpb}, since $g_q > g_p$	1	1	1	1
Permitted Right Turns				
				
Effective pedestrian green time, g_p (s)	36	36	36	40
Conflicting pedestrian volume, v_{ped} (p/h)	200	200	200	200
Conflicting bicycle volume, v_{bic} (bic/h)	3	3	4	3

$V_{pedg}=v_{ped}(C/g)$	972	972	972	875
$OCC_{pedg}=v_{pedg}/2000$, if ($v_{pedg}>1000$)	0.486	0.486	0.486	0.438
Effective green, g (s)	36	36	36	40
$V_{bicg}=v_{bic}(C/g)$	10	10	15	9
$OCC_{bicg}= 0.02+v_{bicg}/2700$	0.024	0.024	0.026	0.023
$OCC_r= OCC_{pedg}+OCC_{bicg}-(OCC_{pedg}*OCC_{bicg})$	0.498	0.498	0.499	0.451
Number of cross street receiving lanes, N_{rec}	3	3	3	3
Number of turning lanes,N_{turn}	1	1	1	1
$A_{pbT}=1-0.6OCC_r$, if $N_{rec}>N_{turn}$	0.701	0.701	0.700	0.729
Proportion of right turns, P_{RT}	0.043	0.072	0.069	0.0605
Proportion of right turns using protected phase,P_{RTA}	0	0	0	0
$f_{Rpb}=1-P_{RT}(1-A_{pbT})(1-P_{RTA})$	0.987	0.978	0.979	0.984

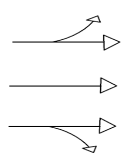
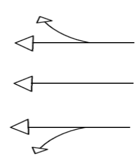
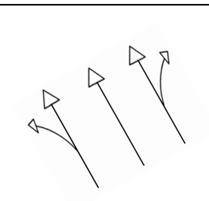
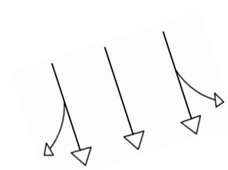
Chart VI Supplemental worksheet

B4: Capacity and LOS worksheet

CAPACITY AND LOS WORKSHEET				
General Information				
Project Description <u>Final Thesis</u>				
Capacity Analysis				
Phase Number	1	1	2	2

Lane group				
Adjusted flow rate, v (veh/h)	2824	1898	1722	1708
Saturation flow rate, s(veh/h)	3620	3743	3268	3290
Green ratio, g/C	0.206	0.206	0.206	0.229
Lane group capacity, c=s(g/C),(veh/h)	740	766	668	748
v/c ratio, X	3.81	2.48	2.58	2.28
Critical lane group /phase	√		√	
Flow ratio, v/s	0.78		0.53	
Sum of flow ratio for critical lane groups, Y_c Y_c=sum(critical lane groups, v/s)	1.31			
Critical flow ratio to capacity ratio, X_c $X_c=(Y_c)(C)/(C-L)$	1.44			

Control Delay and LOS Determination

	EB	WB	NB	SB
Lane group				
Adjusted flow rate, v (veh/h)	2824	1898	1722	1708
Lane group capacity, c (veh/h)	740	766	668	748
v/c ratio, X=v/c	3.81	2.48	2.58	2.28
Total green ratio, g/C	0.206	0.206	0.206	0.229

Uniform delay, d_1 $d_1 = \frac{0.50C\,[1-(g/C)]^2}{1-(g/C)[\mathrm{Min}(X, 1.0)]}$ (s/veh)	70	70	70	68
Incremental delay calibration, k	0.5	-	-	-
Incremental delay, d_2= $900T\,[(X-1)+\sqrt{(X-1)^2+\frac{8klX}{cT}}\,]$(s/veh)	198.71	198.69	198.79	198.71
Supplemental delay, d_3	0	0	0	0
Progression adjustment factor, PF	0.54	-	-	-
Delay, $d=d_1(PF)+d_2+d_3$ (s/veh)	236.51	198.69	198.79	198.71
LOS by lane group	F	F	F	F
Delay by approach, d_A=sum(d*v)/sum(v) (s/veh)	236.51	198.69	198.79	198.71
Approach flow rate, v_A (veh/h)	2824	1898	1722	1708
Intersection delay, d_I=sum(d_A*v_A)/sum(v_A) (s/veh)	211.82		F	

Chart VII Capacity and LOS worksheet

APPENDIX C

EVEL OF SERVICE FOR UN-SIGNALIZED INTERSECTION

C1: Three-legged un-signalized intersection

TWSC - UNSIGNALIZED INTERSECTIONS WORKSHEET Worksheet 1	
General Information	Site Information
Analyst Tebeu Abera	Intersection In front of Filwuha

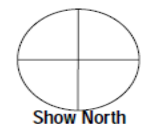
Agency or Company <u>Jimma University</u>

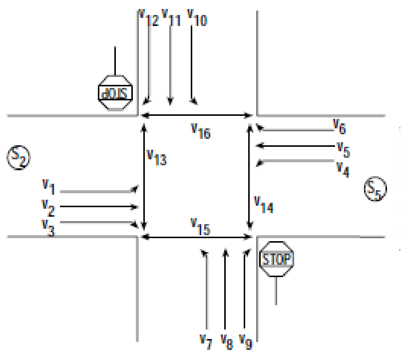
Jurisdiction

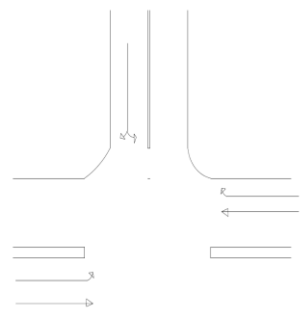
Date performed <u>7/28/2017</u>

Analysis Year <u>2017</u>

Geometrics and Movements







Length of study period= 0.25 h

Grade = 2% all approach

Worksheet 2

Vehicle Volumes and Adjustments

Movement	Vehicle Volumes and Adjustments											
	1	2	3	4	5	6	7	8	9	10	11	12
Volume (veh/h), V	17	76			68	23				19		50
Peak-hour factor, PHF	1	1			1	1				1		1
Hourly flow	17	76			68	23				19		50

rate, v (veh/h)												
Proportion of heavy vehicles, PHV	0	0.1			0.13	0.04				0		0.02

Pedestrian Volumes and Adjustments				
Movement	13	14	15	16
Flow, V_x (ped/h)	30	48		152
Lane width, w (m)	19.7	19.7		12
Walking speed[1], S_p (m/s)	1.2	1.2		1.2
Percent blockage, f_p	0.14	0.22		0.69
Notes Default walking speed = 1.2 m/s				

TWSC - UNSIGNALIZED INTERSECTIONS WORKSHEET Worksheet 3	
General Information	
Project Description	
Lane Designation	

movements	Lane 1	Lane 2	Lane 3	Grade, G	Right Turn Channelized?
1,2					X
5,6					X
10,12					X

TWSC - UNSIGNALIZED INTERSECTIONS WORKSHEET Worksheet 4			
General Information			
Project Description			
Critical Gap and Follow-Up Time			
$t_c = t_{c,base} + t_{c,HV} P_{HV} + t_{c,G} G - t_{c,T} - t_{3,LT}$			
Movement	Major LT	Minor RT	Minor LT
	1	12	10
$t_{c,base}$	4.1	6.2	7.1
$t_{c,HV}$	1.5	1.5	1.5
P_{HV} (from Worksheet 2)	0	0.02	0
$t_{c,G}$	-	0.1	0.2
G (from Worksheet 3)	0.02	0.02	0.02
$t_{3,LT}$	0	0	0.7

$t_{c,T}$, single stage	0	0	0
t_c	4.1	6.232	6.404
$t_f = t_{f,base} + t_{f,HV} P_{HV}$			
	Major LT	Minor RT	Minor LT
Movement	1	12	10
$t_{f,base}$	2.2	3.3	3.5
$t_{f,HV}$	0.95	0.95	0.95
P_{HV} (from Worksheet 2)	0	0.02	0
t_f	2.2	3.319	3.5

TWSC - UNSIGNALIZED INTERSECTIONS WORKSHEET Worksheet 6	
General Information	
Project Description	
Impedance and Capacity Calculation	
Step 1: RT from Minor Street	V_{12}
Conflicting flows	$v_{c,12}$ =68/2+0.5*23+30+152=228 veh/h
Potential capacity	$c_{p,12}$ =228*((e^(-228*6.2/3600)/(1-e^(228*3.3/3600)) =822 veh/h
Pedestrian impedance factor	$p_{p,12}$ =1-fpb=1-0.22=0.78

Movement capacity	$c_{m,12}$ = cp,v1/12 pp,12 =642 veh/h
Probability of queue free state	$p_{0,12}$ ==1-50/822=0.94
Step 2: LT from Major Street	V_1
Conflicting flows	$V_{c,1}=v_5+v_6+v_{16}=68+23+152=243$ veh/h
Potential capacity	$C_{p,1}$=243*((e^(-243*4.1/3600)/(1-e^(-243*2.2/3600))=1,335 veh/h
Pedestrian impedance factor	$P_{p,1}=1-f_{pb}=1-0.14=0.86$
Movement capacity	$C_{m,1}=c_{p,1}*p_{p,1}$=1,148 veh/h
Probability of queue free state	$P_{0,1}=1-v_1/c_{p,1}$=1-17/1,335=0.987
Major left shared lane probability of queue free state	-
Step 4: LT from Minor Street	V_{10}
Conflict flows	$V_{c,10}=2*v_4+v_5+0.5v_6+v_{16}=2*0+68+0.5*23+23=286$ veh/h
Potential capacity	$C_{p,10}$=286*((e^(-286*6.4/3600)/(1-e^(-268*3.5/3600))= 737veh/h
Pedestrian impedance factor	$P_{p,10}=1-f_{pb}=0.82$
Movement capacity	$C_{m,10}=c_{p,10}*p_{p,10}$= 605 veh/h
Probability of queue free state	$P_{0,10}=1-v_{10}/c_{p,10}$=1-19/103=0.816
Major left, minor through adjusted impedance factor	-

Capacity adjustment factor due to impeding movements	-

TWSC - UNSIGNALIZED INTERSECTIONS WORKSHEET Worksheet 8					
General Information					
Project Description					
Shared Lane Capacity					
$c_{SH} = \frac{\sum_y v_y}{\sum_y \left(\frac{v_y}{c_{m,y}}\right)}$					
	v (veh/h)		cm (veh/h)		c_{SH} (veh/h)
Lane	-	-	Movement 10	Movement 12	
1			32	642	
2			32	642	
	Movement 10	Movement 12	Movement 10	Movement 12	
1	19	50	32	642	103
2	19	50	32	642	103

APPENDIX D:

QUESTIONNAIRE

Population for questionnaire using Average Daily Traffic volume (ADT)

Assumptions

a. Public car frequency = 8 per day (4 before launch & 4 after launch)

b. Private car frequency = 4 per day (morning, for launch, after launch and night)

c. Consider only 2 approaches (EB & NB) since most of the time go and back

Time interval	Approaches				
	EB		NB		12 person/public car & 2 person/private car
	Public	Private	Public	Private	
6:30-7:30 AM	973	996	678	701	3325
7:30-8:30 AM	1172	1231	730	810	3873.5
8:30-9:30 AM	892	921	532	673	2933
9:30-10:30 AM	632	731	289	432	1963
10:30-11:30 AM	436	543	231	398	1471
11:30-12:30 PM	367	621	396	432	1671
12:30-1:30 PM	437	721	467	657	2045
1:30-2:30 PM	238	489	175	489	1108.5
2:30-3:30 PM	289	398	189	398	1115
3:30-4:30 PM	321	534	193	456	1266
4:30-5:30 PM	784	982	554	723	2859.5
5:30-6:30 PM	1410	1450	797	910	4490.5
Total population					**24,982**

Traffic police and Road user's perception were gathered through structured questionnaire as follows:

I. General

a. Questionnaire Date: ________________

Address:___________ Age:__________ Sex:_____ Educational status:____________

II. Questions

Please answer the following questions to your convenient perception

A. For road users (drivers and passengers): driver ☐ passenger ☐

1. How often do you use this corridor?

   a. Sometimes b. most of the time c. always

2. Do you think there is traffic congestion at this intersection? Yes ☐ no ☐
3. If ans. To ques. 1 is yes, what do you think the levels of traffic congestion at this intersection?

   a. Low b. medium c. high d. very high

4. What do you think the causes of traffic congestion on this intersection?
   a. traffic management problem b. poor road network c. Traffic volume
5. What do you think the effects of traffic congestion to yourself as well as Addis Ababa city?
   a. Social effect b. Economic effect c. Environmental effect
6. What do you recommend possible solutions of unsafe traffic movement at this intersection?

____

____

B. Traffic police

Address:___________ Age:__________ Sex:_____ Educational status:____________

1. Do you think there is traffic congestion at this intersection? Yes ☐ no ☐
2. If ans. To ques. 1 is yes, what do you think the levels of traffic congestion at this intersection?
   a. Low b. medium c. high d. very high
3. What do you think the causes of traffic congestion on this intersection?

____

____

4. What do you think the effects of traffic congestion to sub city as well as Addis Ababa city?

____

____

5. What do you think the possible solutions of traffic congestion at this intersection?

____

____