ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTEOF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

ESTIMATING TOTAL TRAFFIC CONGESTION COSTS FOR SELECTED ROAD OF ADDIS ABABA CITY

(A CASE STUDY: MEKANISA - JEMO ROAD)

A Thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfilment of the Degree of Masters of Science in Civil Engineering under Road and Transport Engineering

BY

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Declaration

I certify that this research work titled "Estimating Total Congestion Cost for selected Road of Addis Ababa city. (A case study Mekanisa – Jemo Road) " is my own work. The work has not been presented elsewhere for assessment and award of any degree or diploma. Where material has been used from other sources it has been properly acknowledged/ referred.

<u>**Netsanet Admasu**</u> ______________________ ____________

Name Signature Date

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ABSTRACT

For everyday travelers, the frustration of traffic congestion is obvious. Understanding the impact on cities and the economy, however, it is not as straightforward as many would like it to be. From an economic perspective, congestion's main impact is the lost productivity from more time spent traveling to work rather than working; delaying (or missing) meetings; foregoing interactions among individuals or personal activities due to long travel time; and spending more time to accomplish tasks than would otherwise be necessary if we could reliably plan for accomplishing the same things at free-flow speeds. And also Emissions may increase as vehicles spend more time in congestion, idling or crawling, and undergoing numerous acceleration and deceleration events.by this the environmental cost will be higher. In short, a region's economy does better when people spend more time working and doing things they find valuable and less time traveling to do them. We depend on our transportation system to provide access to people and places we want to go.

Following the economic and population growth in Addis Ababa, traffic congestion problem has emerged and the problem is even growing faster. In this study, the level of the traffic congestion for selected area of Addis Ababa city was quantified using travel time approach. Travel time, traffic volume, and travel speed data were collected at two intersections. Accordingly, the travel rate, the delay rate, total travel delay (veh.-min and per-min), were calculated. And also, the total congestion cost was estimated.

The result showed that on average the maximum delay of 826 veh – min and 616 veh. – Min. was lost during the morning and the evening peak period respectively at those approaches. The total cost of congestion for specific approaching distance was above Birr 210,805.87 per year during off peak time and Birr 343,597.99 per year during peak time. And the total loss due to congestion will be above Birr 132,792.12 per year on single selected approach.

Key word: - Traffic Congestion, Congestion costs, Delay

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List of Acronyms

AACRA: - Addis Ababa City Road Authority.

ACBSE: - Anbesa City Bus Service Enterprise.

BTRE: - Bureau of Transport and Regional Economics.

CO_2: - Carbon Dioxide.

HCM 2000:- High way Capacity Manual.

HPMS: - Highway Performance Monitoring System.

IRC: - Indian Road Congress.

L: Left Turning

LOS: Level of Service.

NCHRP: - National Cooperative Highway Research Program.

PCU: - Passenger Car Unit.

R: Right Turning.

SIDRA: Signalized (Un-signalized) Intersection Design And Research Aid.

TH: Through movement.

TRB: - Transportation Research Board.

TTI: - Texas Transportation Institute.

UMR: - Urban Mobility Report.

VOT: - Value of Time.

VOC: - Vehicle Operating Cost.

WHO: - World Health Organization

WIP: - Willingness-To-Pay.

CHAPTER - ONE

INTRODUCTION

Traffic congestion is a problem in many cities of the World, both in developed and developing countries and it is predicted that it will get worse in the future. Urban traffic congestion can be contributed by a number of factors including rapid increase in urban population, economic growth, increase in employment opportunities, increase in number of cars, and number of peoples using cars, low capacity of transport infrastructure, road lay out, under investment in road infrastructure, poor management, shortage of off-street parking, signal and equipment failure, non-adherence to traffic regulation, poor urban planning transport etc. (Institute of Transport Engineers, 1989).

As urban population expand and city roads become increasingly congested, policy makers and planners need to review urban development and transport policies in order to address future needs taking in to account anticipated social and demographic change. Addis Ababa is the capital city of Ethiopia with a population of 3,384,569 according to the 2015 year population census with annual growth rate of 3.8%. This number has been increased from the originally published 2,738,248 figure and appears to be still largely underestimated. Addis Ababa has the status of both a city and a state. It is where the African Union is and its predecessor the OAU was based. It also hosts the headquarters of the United Nations Economic Commission for Africa (ECA) and numerous other continental and international organizations. It is home to many embassies.

Congestions will generate many problems due to inefficiency. With congested roads, vehicle speed will be simultaneously up and down, and the average speed will be lower and hence the cost will increase. Therefore, road users will suffer from increasing vehicle operating costs and losing more time. In other words, transportation costs will increase due to congestions. Therefore proper quantification and measuring the extent or level of congestion is an important step for understanding the performance of the existing road network and for evaluation of proposed congestion mitigation measures.

NCHRP-398 states that congestion measures are needed to analysing and prioritizing system improvement options, to provide quantitative information for policy makers and the public, to determine how much delay and queue size formed, which area or region is.

1.1 Study Area.

The study area is situated in one of the areas of Addis Ababa city called MEKANISA and JEMO in NIFAS SILK LAFTO Sub city. Currently, this area has a large number of movements of peoples and vehicles. And among different intersections which are found, the one German and Jemo Michael intersection are playing a great role for the occurrence of traffic congestions. As many peoples and traffic police says that the traffic demand and the road capacity for using these intersections are not balanced. Especially, during morning and evening peak time, there are a high number of traffic volumes.

German intersection is a roundabout intersection with 60m diameter. It has four approaching legs. This intersection leads to the outer way of Addis Ababa to different places. Some of the vehicles which are operating are trucks which make the intersection to be congested.

Previously, the Jemo Michael intersection was a roundabout with 46m circular diameter. But, at the moment it is changed to a signalized intersection. According to the Addis Ababa City Road Authority (AACRA) data, the Mekanisa –Jemo- Sebeta Asphalt road project was funded by the Ethiopian government and administrated by AACRA. The project road is intended to enhance the mobility within the city through the provision of new access before reaching to concentration points. In addition, when the project road gets completed, it will have vast and significant share in reduction of rush hour traffic congestion that prevailed in the surroundings road networks. This time, the peoples who live in Jemo area are complaining about the current traffic congestion which starts from Jemo to Jemo Michael roundabout. The length of road stretch is about 2.5 km serving the heterogeneous traffic movement which include private car, mini bus, Bajaj, public bus, Medium bus and Trucks. Due to the design nature of Jemo Michael intersection which was previously a small round about and having a nature of slow traffic flow and also the design nature of Jemo road which has a large widening of median for Bus rapid Transit

(BRT) project and a small size width of traffic lane, drivers will always get traffic congestion during peak time and off- peak time.

The project road begins at Mekanisa and passes through Jemo and terminates at 16 km on Addis –Jimma Trunk road. It is completely new road way with limits of 40m.

The road way contains a dual carriage way having 7m width each, 5m pedestrian walk way along both sides and a reserved gravel surfaced median of 16m for a length of 4.4 km until it reaches the Jimma road Junction.

This road stretch is highly feasible for commercial activity because of its significance. These commercial activities held along the stretch mainly in urban area which tends to increase the traffic congestion. The study area was divided into two observation points, where the two of them are intersections. The topography of the proposed project road dominantly follows a flat terrain with insignificants portion of rolling terrain at the end of the project. Figure 1.1 below shows the photographic image of the study area.

Figure 1.1 Image for study area founded from google earth.

1.2 Statement of the Study

Addis Ababa city is one of the major cities that exhibit a higher amount of traffic congestion problem at different places of intersections and urban street of the road. Among different roads the one from “MEKANISA to JEMO” road section is the recently built residential and commercial area. Drivers and passengers on the study face congestion at peak and off- peak hours and the most commonly seen vehicles are private cars, mini buses, medium buses, public buses, and different trucks.

The main impacts of traffic congestion are:

- ✓ Makes people late to work;
- ✓ Can lead to drivers and passengers becoming frustrated and engaging in road rage;
- ✓ It stresses us out before we even get there;
- ✓ Deliveries can't arrive on time and to a certain extent; and
- ✓ Reduces productivity and finally reduce economic growth of a country.

This study is focused on recurrent peak Period congestion, which is, congestion associated with the regular, daily buildup of traffic during the morning and evening peak periods. Because there are too many vehicles straggling to use the road at the same time and during weekday morning and afternoon peak periods. As a result drivers and passengers always encounter traffic congestion when traveling to work and return home at around the same time. Due to these problems drivers have limited freedom to manoeuvre and poor quality of traffic flow.

1.3 Research Questions.

The presumed research questions are depicted in Table 1.1 below.

Table 1.1 Research Questions.

No.	Research Questions	Research Objectives
1.	What are the characteristics of the current traffic flow and causes for traffic congestion?	To analyse the overall impact of traffic lane design and intersections design on traffic congestion.
2.	Does traffic congestion prolongs travel time; affect fuel consumption and emission gas?	To identify the extent to which traffic congestion adversely will affect.

1.4 Objective of the Study

1.4.1 The General objective

- ✓ The main objective of this study is to estimate total traffic congestion costs for selected roads of Addis Ababa city in this case study the Mekanisa – Jemo Road and suggest possible counter measures to the problem.

1.4.2 The specific objective of the study

- ✓ To identify the cause for traffic congestion of the selected road.
- ✓ To identify the extent to which traffic congestion adversely will affect; and
- ✓ To analysis the level of service for those selected intersections.
- ✓ To estimate the total traffic congestion cost for selected intersection

1.5 Significance of the Study

The impact of traffic congestion cost for Addis Ababa city is a big issue which currently occurs in day- to- day activities. For this it will be important to estimate the congestion cost using best indicators and measures. As well as, giving estimations to associated impacts of congestion and their costs. Finally, it will be important for policy makers and planners to review urban development and transport policies which are essential by taking in to account the future social and demographic changes and also consider Countermeasures and forward recommendations.

1.6 Limitation of the Study

Firstly, there are two types of traffic congestion which are recurrent traffic congestion and non- recurrent traffic congestion. However, the first type of congestion was considered in this study which is observed many times of the day in Addis Ababa. In conducting this research, the researcher took only one day traffic count. Due to time limitation budget constraints, and there are different types of variables that are in estimating traffic congestion cost, However. The researcher took only three variables which were believed to be important in the analysis of congestion costs. For analysing the total congestion cost, due to the large carrying capacity of passengers. Vehicles those choose are light- duty vehicles such as mini buses - taxi, midi - buses and standard buses.

1.7 Organization of the Study

The thesis report is organized as follow:

Chapter 1 presents the introduction comprising of the study area, statement of the study, and organization of the study.

Chapter 2 provides a summary of different literature review in the area of traffic congestion, congestion indicator, and congestion cost analysis. Chapter 3 will covers different aspects of the methodology used during the research. It presents different options available to carry out the study and gives reasons why a particular method was selected at different stages of the project. As a lot of data collection was involved in the study, the way the collection was made can affect the outcome of the project. For this reason, the data collection method selected on the course of the project is discussed here. It covers different aspects of the methodology used during the research. Chapter 4 focuses on the analysis and results of the previous data used in chapter 3. The detail analysis of traffic congestion measurement and traffic congestion costs are stated. Chapter 5 conclusion from the study and recommendations forwarded.

CHAPTER -TWO

2.0 LITERATURE REVIEW

2.1 Introduction

It is an old saying, but true as ever: “Time is money.” A company that can produce quality products in less time than its competitors is likely to be more profitable and productive. An urban area where employees travel less time to get to work is likely to be more productive than one where travel times are longer, all things being equal. Productivity is a principal aim of economic policy. Productivity means greater economic growth, and greater job creation. Congestion Costs: This is why such serious attention is paid to the Texas Transportation Institute’s (TTI) Annual Mobility Report, which estimates the costs of traffic congestion, principally the value of lost time as well as excess fuel costs.

The problems of intra-urban traffic in Lagos Nigeria have been studied by (Bashir and Waziri 2008). The study found that 57% of commuters and motorists spend between 30 to 60 minutes on the road due to traffic congestion. They also found that the worst traffic congestion occurred on Mondays. Researchers listed the causes of traffic congestion in Lagos to include the following: Presence of pot holes/bad road, trading activities, on-street parking, loading and discharging of passengers, illegal bus stops, flooding/poor drainage, vehicle breakdown, narrow road sections, religious activities, high volume of traffic, and lack of parking space and lack of traffic light at some road intersections. Since it is a day to day occurrence to almost all road users, the concept of congestion as a serious problem of traffic flow is well known to the public or road users. However, many documents showed that there was no considerable effort to conceptually investigate congestion before 1990’s.

According to Cottrell (2001), the 1991 Intermodal Surface Transportation Efficiency Act and the subsequent Transportation Equity Acts mark a significant start for researches and investigations on congestion as part of Congestion Management System (CMS) in United States of America.

Since then, different research efforts to develop methods and parameters for measuring traffic congestion have been proposed by different researchers and manuals. One of such efforts was the research project funded by the National Cooperative Highway Research Program (NCHRP) titled “Quantifying Congestion”. Proper quantification and measuring the extent or level of congestion is an important step for understanding the performance of the existing road network and for evaluation of proposed congestion mitigation measures. NCHRP-398 states that congestion measures are needed to analyzing and prioritizing system improvement options, to provide quantitative information for policy makers and the public, to determine how much delay and queue size formed, which area or region is more congested . (Lomax, 1997)

2.2 Definition of Traffic Congestion

As the Transport Canada states , “Congestion is the inconvenience that travellers impose on each other while using their vehicles and attempting to use the road network at the same time, because of the relationship that exists between traffic density and speed (with due consideration of capacity). ”

Traffic streams are described by three variables: **DENSITY K** (vehicles per lane per kilometre), **SPEED V** (km/h) and **FLOW q** (veh./ln/hr). Traffic flow is the product of traffic density (vehicles/km) and speed (km/h), so these three variables are related by the equation $\mathbf{q = K * V}$. All things being equal, as more vehicles enter the same road, traffic density increases, travel speed falls and travel time increases. This is the fundamental traffic flow principle on which the engineering approach bases its definition of congestion. (Transport of Canada, 2006)

Report NCHRP-398 states that the clear definition of traffic congestion on road is shown in figure 2.1 below.

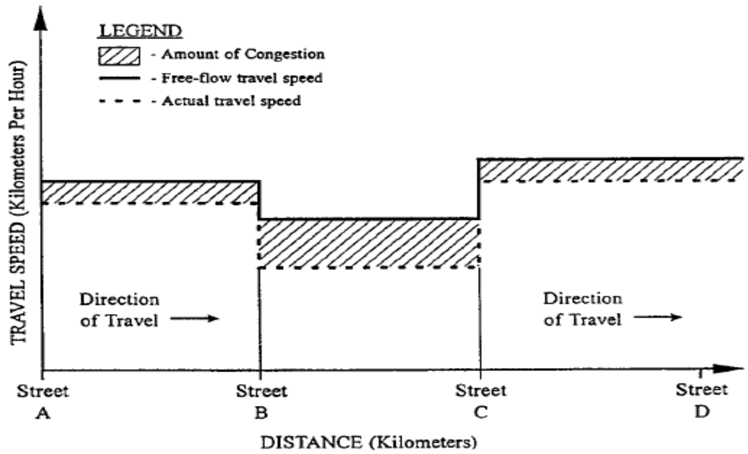


Figure: - 2.1 Definition of Congestion

The above figure tell us the travel time or excess delays are found to be higher while actual travel speed is much below than the free flow speed and by this the amount of congestion is different from place to places.

According to Lomax et al, 1997, definition of congestion and the congestion measures derived therefrom, should rely on concepts that are understood by the intended audience (road user) and one method that may be used to resolve this issue is to define two quantities, congestion and unacceptable congestion.

- ✓ Congestion is travel time or delay in excess of that normally incurred under light or free-flow travel conditions.(Figure 2.1)
- ✓ Unacceptable congestion is travel time or delay in excess of an agreed upon norm. The agreed upon norm may vary by type of transportation facility, travel mode, geographical location, and time of day.

As demand approaches the capacity of a road (or of the intersections along the road), extreme traffic congestion sets in. When vehicles are fully stopped for periods of time, this is known as a traffic jam or traffic snarl-up. Traffic congestion can lead to drivers becoming frustrated and engaging in road rage. Congestion makes people late to work. It stresses us out before we even get there. Deliveries can't arrive on time and to a certain extent. Traffic congestion occurs when a volume of traffic or modal split generates demand for space greater than the available road capacity; this point is commonly termed saturation.

2.3 Types of Congestion

The two types of congestion are outlined as **recurrent congestion** and **non-recurrent congestion.** These types are based upon the frequency and predictability of the congestion the factors which are capable to impact on driver behavior. The costs associated with each type of congestion are likely to be different. Non-recurrent congestion costs may be more difficult to quantify due to the inherent sparseness of adequate amounts of data needed. It may be argued that the costs could be higher as drivers have not been able to take the possibility of congestion into account in planning their journey or alternatively the costs not have come into play. Some routes are increasingly subject to non-recurrent congestion, for example with accident black spots. In these cases drivers may "learn" an expected cost in terms of likely delay and successful contingency routes. (Laird et al, 2006)

I. **Recurrent congestion**: - occurs mainly when there are too many vehicles wanting to use the road at the same time. Recurrent congestion typically occurs during weekday morning and afternoon peak periods, when most people go to work and return home at around the same time. In large urban areas, the peak periods can range from 7:00 to 9:30 a.m. and from 3:30 to 7:00 p.m. In smaller urban areas, the peaks may have a shorter duration (one or two hours). Of interest is the growing recurrent congestion that occurs during off-peak periods (i.e. during other weekday hours, and even on weekends). This reflects, in large part, a rapid growth in off-peak travel (off-peak travel is growing faster than peak-period travel in some areas).

II. **Non –recurrent congestion**: - is the other main source of traffic congestion. Non-recurrent congestion is associated with random conditions or special and unique events, such as traffic incidents, truck spills, accidents, work zones, unusual or disruptive manoeuvres by individual drivers, irregular facility maintenance operations (e.g., seasonal street cleaners), and adverse weather and special events. Because of the random nature of this type of congestion, non-recurrent congestion is more difficult to predict and address.

As the Transport Canada states, the impact of non-recurrent congestion is significant in that, the reliability and predictability of travel time is of utmost importance to the public, to the goods-generating industries and to the economy in general. Variability in travel time leads to costly uncertainty for commuters and, in particular, for goods transporters who must meet fixed delivery schedules. Low variability in travel times can be even more important to the public than the actual duration of the trip.

2.4 Congestion Indicator

One of the most critical needs in traffic engineering is a clear understanding of how much a given facility can accommodate and under what operating conditions.

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 transports system is operation at a given period of time; it is essential to define or have indicators of the presence of congestion in the system. For example, if the road is a multilane highway. It has its own characteristics.

According to HCM, a Multilane highway can be characterized by three performance measures:-

- ✓ density in terms of passenger cars per kilometre per lane,
- ✓ speed in terms of mean passenger car speed, and
- ✓ Volume to capacity ratio.

Each of these measures is an indication of how well traffic flow is being accommodated by the highway. Above all, travel time and speed is a common indicator of the occurrence of congestion that is when a given vehicle goes at a lower speed with forming queue and increasing of the average travel time. These two require more effort to measure than the traffic volume counts that currently provide the basis for most congestion estimation procedures.

2.5 Cause of Congestion

The proximate causes of congestion are numerous, e.g. too many vehicles for a given road's design or intersection capacity, dynamic changes in roadway capacity caused by lane-switching and car-following behaviour. They are also invariably linked to other indirect factors such as land-use patterns, employment patterns, income levels, car ownership trends, infrastructure investment, regional economic dynamics, etc.

However, we can identify two principal, broad categories of causal factors; micro-level factors (e.g. those that relate to traffic "on the road") and macro-level factors that relate to overall demand for road use. In this context, congestion is "triggered" at the "micro" level (e.g. on the road), and macro level. The most common example is the physical use of roads by vehicles. When traffic demand is great enough that, the interaction between vehicles are slow the speed of the traffic stream, this results in some congestion.

2.6 Consequence of Congestion

Increased travel time is the most direct consequence of road traffic congestion. But it is not the only cost. Congestion incurs both tangible and intangible costs to individual road users as well as our society. For example, apart from time wasted when people are caught in congestion, the low mobility adversely affects the business sectors. When goods or services cannot be delivered on time, the business sectors need to incur additional inventory costs and logistics costs. As a road reaches its capacity, each additional vehicle imposes more total delay on others than they bear, resulting in economically excessive traffic volumes. Congestion tends to increase travel time, decrease productivity, arrival unreliability, fuel consumption, pollution emissions and driver stress, and reduce life satisfaction.

2.7 Congestion Impact

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. As the European conference of ministry states congestion also has a range of indirect impacts including the marginal environmental and resource impacts of congestion, impacts on quality of life, stress, and safety as well as impacts on non-vehicular road space users such as the users of sidewalks and road frontage properties. Policy-makers should give serious attention on evaluation methodologies include an assessment of these impacts as well as take into account broader considerations such as the type of cities people want.

This study assesses about congestion, congestion cost, and their impact on different types of transportation. The costs of traffic congestion have received increasing attention in recent years.

2.8 Recommended Congestion Measure

The many ways of measuring congestion developed over the years, have been joined additional measures and indices defined and /or formulated as part of this research projects. While some of these are simple to comprehend and apply, others are complex. Travel time and delay should be the foundation for the primary system of congestion measurement.

As stated by Lomax et al, (1997) there are four components that interact in a congested roadway or system. These components are **duration**, **extent**, **intensity** and **reliability**. They vary among and within urban areas – smaller urban areas, for example, have shorter durations of congestion than larger areas.

- ✓ **Duration** – this is defined as the amount of time congestion affects the travel system.
- ✓ **Extent** – this is described by estimating the number of people or vehicles affected by congestion, and by the geographic distribution of congestion.

- ✓ **Intensity** – this is the severity of the congestion that affects travel. It is typically used to differentiate between levels of congestion on transportation systems and to define the total amount of congestion.
- ✓ **Reliability** – this component of congestion estimation is described as the variation in the other three elements. Reliability is the impact of non-recurrent congestion on the transportation system.

There are several different ways to define and measure the level of congestion on roadways. Some of the techniques are consistent with the definition and use of congestion thresholds, including the following:

- ✓ A congestion index related to the rate of travel that is being advanced in a number of research projects at the Texas Transportation Institute (TTI);
- ✓ An excess delay measure for urban areas that is tied to the amount of time spent at an intersection or along a roadway segment operating below a certain level of service (LOS); and
- ✓ The percentage of time at a given point on a highway system, the average speed drops below some threshold value.(NCHRP no. 463)

Many literatures including the NCHRP report 398 “Quantifying Congestion” provide different measures for congestions based on travel time approach. Most of the measures explain only one or two of the dimension of congestion and hence it is necessary to use more than one congestion measure to explain the level of congestion at a road section. Accordingly, there are quite a number of congestion measures suggested in different literatures for each congestion dimension.

However, the following congestion measures are taken & summarized mainly from NCHRP 398: Quantifying Congestion by Lomax (1997) and NCHRP 618 by Jenks et al (2008). Table 2.1 below presents the different types of congestions measures:

Table: -2.1 Different Types Congestion Measures.

Travel Rate (minutes per mile)	$= \frac{Travel\ Time\ (minutes)}{Segment\ Length\ (miles)} = \frac{60}{Average\ Speed\ (mph)}$
Delay Rate (minutes per mile)	= Actual Travel Rate (minutes per mile) _ Acceptable Travel Rate (minutes per mile)
Total Segment Delay	= [Actual Travel Time (minute) _ Acceptable Travel Time (minute)] * Vehicle volume (vehicles)
Relative Delay Rate	$= \frac{Delay\ Rate}{Acceptable\ Travel\ Rate}$
Delay Ratio	$= \frac{Delay\ Rate}{Actual\ Travel\ Rate}$
Congested Travel	$= \sum$ Congested segment length (miles) * Traffic Volume (vehicles)

2.8.1 Level of Service Measure (LOS)

It is essential to define or have indicators of the presence of congestion in the system. According to Cottrell (2001) and 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.

The assigned primary performance measure which is used to provide an estimate of level of service is density. The three measures of speed, density, and flow or volume are interrelated. When values for two of these measures are known, a value for the remaining measure can be computed. Level of Service (LOS) is a qualitative measure describing operational conditions with in a traffic stream, generally in terms of such service measures as speed and travel time, and comfort and convenience. 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.

According to HCM 2000 say "The capacity of a facility is the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions".

Congestion occurs when the road capacity does not meet traffic demand at an adequate speed, traffic controls are improperly used, or there is an incident on the road such as an accident or disabled vehicle. Congestion can occur during any time of the day and along any type of roadway. Table 2.2 below presents the level of service criteria for two types of flow.

Table 2.2 Level of Service Criteria for Different Types of Flow (HCM 2000)

Type of flow	Type of facility	Measure of effectiveness
Uninterrupted flow	Free way	Density (pc/mi/ln)
	Basic section	Density (pc/mi/ln)
	Weaving areas	Density (pc/mi/ln)
	Rump Junctions	Density (pc/mi/ln)
	Multilane highway	Density (pc/mi/ln)
	Two lane highway	Average travel speed (mi/h)
		Percent time spent following (%)
Interrupted flow	Signalized Intersections	Control Delay (s/veh)
	Un signalized Intersections	Control Delay (s/veh)
	Urban Street	Average travel speed (mi/h)
	Transit	Service frequency (veh/day)
		Service headway (min)
		Passenger/seat
	Pedestrian	Space (ft^2/ped)
	Bicycles	Frequency of(conflicting)(evnt/h)

Table 2.3 presents the level of service criteria for multilane highways. And Table 2.4 presents level of services for different types of intersections.

Table 2.3 Level of Service Criteria for Multilane Highway (Source: HCM 2000)

		LOS				
Free Flow Speed	**Criteria**	A	B	C	D	E
100 km/h	Max density (pc/km/ln) Average speed (km/ln) Max v/c Max service flow rate (pc/hr/ln)	7 100.0 0.33 700	11 100.0 0.50 1100	16 98.4 0.72 1575	22 91.5 0.94 2015	22 88.0 1.0 2200
90 km/h	Max density (pc/km/ln) Average speed (km/ln) Max v/c Max service flow rate (pc/hr/ln)	7 90 0.31 630	11 90 0.47 990	16 89.8 0.68 1435	22 84.7 0.89 1860	26 80.8 1.00 2100
80 km/h	Max density (pc/km/ln) Average speed (km/ln) Max v/c Max service flow rate (pc/hr/ln)	7 80.0 0.30 560	11 80.0 0.44 880	16 80.0 0.64 1280	22 77.6 0.85 1705	27 74.1 1.00 2000
70 km/h	Max density (pc/km/ln) Average speed (km/ln) Max v/c Max service flow rate (pc/hr/ln)	7 70.0 0.28 490	11 70.0 0.41 770	16 70.0 0.59 1120	22 69.6 0.81 1530	28 67.9 1.00 1900

Note: pc = passenger cars, ln= lane

Table: 2.4 Levels of Service Criteria for Different Type of Intersections. (HCM 2000)

	Signalized Intersection	Unsignalized Intersection
Level of Service	Average Control Delay (s/veh.)	
A	≤ 10	0 – 10
B	>10 – 20	>10 – 15
C	>20 – 35	>15 – 25
D	>35 – 55	> 25 – 35
E	>55 – 80	>35 – 50
F	>80	>50

2.9 Definition of Traffic Congestion Cost

Traffic Congestion Cost:- are defined as the external interference costs imposed by each road user on the rest of society, including travel delay, increased vehicle operating costs, pollution, and driver stress and etc. Congestion costs increase more than proportionally, particularly when facilities are highly saturated. (Zegras and Littman, 1997)

The most common measure of the cost of congestion estimates is the cost of travel relative to a free-flow base case. This is normally represented as the travel times involved in making the trip in question in the early hours of the morning. This is consistent with a definition of congestion that includes any interaction between vehicles (the economists' definition).

While some authors reject the use of free flow as the base for calculating the cost of congestion, a study by the Australian Bureau of Transport and Communications Economics (BTCE 2000) says:

"The definition has the merit of having as its reference point a relatively well-defined state of zero congestion. However, it is important to note that there is no implication that zero congestion is a possible or desirable goal for policy."

In this respect, the 'cost of congestion' must be carefully distinguished from the 'cost of doing nothing about congestion'.

To measure the costs of congestion, we first have to agree on a suitable definition of congestion. Three choices are identified in the literature:

(i) Most economists implicitly treat anything less than free flow as congested, so the economists' definition of congestion is the presence of interactions between vehicles on the road. Practically, all major roads are thus 'congested' which does not seem a very useful definition;

(ii) Users perceive roads to be congested when speeds fall below an acceptable level (which may differ by location and over time), we will call this perceived congestion;

(iii) Engineers classify a road as congested when more vehicles are attempting to use the road than it has capacity to carry.

The latter situation is defined by economists as hyper-congestion and corresponds to the lower branch of the speed-flow curve.

The cost of congestion is the difference between the observed travel time and the travel time when the road is operating at capacity plus schedule delay costs, reliability costs and other applicable social and environmental costs. Since with this definition elimination of congestion is achievable, the cost of congestion measure has a practical meaning. It is a cost that can be avoided. It also can be justified on efficiency grounds: it is comparing the cost of the current network with the cost if the network was operating at maximum efficiency, i.e. with roads operating at their maximum capacity. Congestion can be seen as the situation where there is so much traffic that the network cannot operate efficiently. (Wallis and Lupton, 2013)

Congestion has a substantial detrimental impact on today's society, affecting social and economic well-being as well as the environment. The effects are diverse but can be expressed in monetary terms. Figures collected from European and American literatures estimate a range of congestion-related costs per capita of between $200 and $800 per year.

That the reports in Table 2.5 are not exactly the same is not surprising: apart from the differences in area, year of observation and local congestion levels, the calculations require a large number of assumptions as input, for example about the definition of congestion, the valuation by travelers of lost time and whether and how to include fuel wastage. However measured or valued, it is clear that congestion is a significant drain on the economy. In Western Europe, the estimated congestion costs are at least 1% of GDP (UNITE, 2003), and expected to grow. For example, at the UK national level traffic is expected to increase by 22% in 2015 compared to 2003 levels and congestion even more. (Tom Van Vuren & Neil Hurts, 2008).

Table 2.5 Congestion Costs per person with various sources.

Location	Congestion cost per person per year	Sources
UK	£ 350	Confederation of British Industry (CBI)
UK	£ 220	UNITE (2003)
US	$ 600	NJIT (2000)
US	$ 710	Schrank and Lomax (2007)
CANADA	$ 200	Transport Canada (2006)

2.10 Different Approaches in Estimating Congestion Costs.

The Texas Transportation Institute (TTI) publishes an annual urban mobility report (UMR) (Lomax, et al 2010) covering some 100 cities and municipalities in the USA. The procedures used in the report have been developed over a number of years and as a result of several research projects. The congestion estimates for all study years were recalculated in 2010 to provide a consistent data trend as the methodology had been amended.

The TTI study measures congestion relative to a free-flow base case, represented by the travel times involved in making the trip in question in the early hours of the morning.

The UMR provides estimates of mobility at the area-wide level. The approach used describes congestion in consistent ways allowing for comparisons across urban areas or groups of urban areas. The calculation uses a dataset of traffic speeds from a private company (INRIX) that provides travel time information to a variety of customers; and volume and roadway inventory data from the Federal Highway Administration Highway Performance Monitoring System (HPMS).

Most of the basic performance measures presented in the UMR were developed as part of the process of calculating travel delay. The amount of extra time spent travelling due to congestion.

The INRIX speed data reflects the effects of both recurring (or usual) delay and incident delay (crashes, vehicle breakdowns, etc.). The delay calculations are performed at the individual roadway section level for each hour of the week.

But, all this methodology is done based on “free flow speed” which means with the state of zero congestion. However, it is important to note that there is no implication that zero congestion is a possible or desirable goal for policy.

The Transport Canada research adapted a region-wide perspective for each area.

Lindsey (2007) provides an example of a cost of congestion calculation using ‘acceptable’ levels of congestion as the comparison. He quotes statistics that had recently been compiled by Transport Canada quantifying the costs of travel delay, additional fuel consumption, and greenhouse gas emissions for the nine largest urban areas of Canada. Rather than taking free-flow conditions as the baseline, the study adopted a percentage of the speed limit as a threshold below which congestion could be considered ‘unacceptable’. Since this threshold varies across municipalities and road networks, the study undertook calculations with thresholds of 50%, 60% and 70% of the speed limit.

The costs of congestion for the nine urban areas estimated with the 60% threshold were about CAN$3 billion. The cities of Montreal and Toronto accounted for 70% of the total. In per capita terms, the annual cost ranged from CAN$17 per person for Hamilton to CAN$270 per person for Toronto.

The Cost of Urban Congestion in Canada study concentrated on three components:

- ✓ delay costs (time lost during congestion);
- ✓ Fuel costs (fuel wasted due to congested conditions); and
- ✓ An imputed cost for greenhouse gas (GHG) emissions due to traffic congestion.

All the costs were calculated on the basis of personal passenger vehicle use. The focus on these three components was a function of the study purpose and of the availability of consistent and reliable information for all nine urban areas. A unit price value was determined for each of the three main components of congestion.

Therefore, in order to estimate the total traffic congestion cost for selected road the researcher decided to take the base line speed is the off peak average traveling speed. And also, the cost of total congestion will consist of the travel time cost, fuel consumption cost and associated CO_2 emission cost due to excess fuel consumption.

2.10.1Travel Time Cost

Travel time is one of the largest categories of transport costs, and time savings are often the greatest expected benefit of transport improvement projects. Factors such as traveler comfort and travel reliability can be quantified by adjusting travel time cost values. On average people devote 60-90 minutes a day to travel. Travel time costs are the product of time spent traveling multiplied by unit costs (e.g., cents per minute or dollars per hour). Travel time unit costs vary depending on type of trip, travel conditions, and traveler preferences. For example, time spent relaxing on a comfortable seat tends to impose less cost than the same amount of time spent driving in congestion or standing on a crowded bus. (Victoria Transport policy institute, 2017).

The most widely used approach to estimate the associated cost is to impose the Value of Time (VOT) on the calculated delay due to congestion. By definition, VOT is the monetary value that a person will be ready to pay for a unit travel time reduction or it is the estimates of hours lost due to congestion in monetary terms, usually determined from „willingness-to-pay‟ (WTP) surveys.

It certainly depends on many factors, i.e. socio-economic condition of the traveler, trip purpose, condition of travel or the mode types, time of travel and there are lots of estimates available in literature regarding VOT depending on the various factors that affect VOT. Along with the travel time losses, there is another important cost arising from the unreliability or unpredictability of the journey times (mostly at peak periods of the day). This adds to the actual value of VOT. Table 2.6 presents the value of time for different countries.

Table: - 2.6 Value Travel time Comparisons between modes for different country.

(US.$/hr.)

Serial number	Country	Car	Pickup	Bus	Truck
1	India	1.00	0.44	1.80	1.04
2	Kenya	0.51	0.65	0.98	1.73
3	China	0.33	0.12	0.33	0.33
4	Bangladesh	0.91	0.91	0.35	-

(Sources: - Estimation of Value of Time for a Congested Network – cases study of the National Highway, Karachi) and this table can tell us

A among different country, the researcher took the one which is close to our country in any aspect. Therefore the value of time of Kenya will be chosen.

$$TTC = Tih \times Oi \times VOTi \times L$$

Where: - TTC = Travel Time Cost (birr)

T_{ih} =Average Travel Time at peak and off- peak (min/km)

O_i = Vehicle Occupancy

VOT_i =Value of Travel Time of the passenger (birr/min)

L= Vehicle distance traveled (km).

2.10.2 Excess Fuel Consumptions cost

Fuel consumption is simply the "total quantity of fuel consumed by a vehicle in a road network in a specified area and time period. In metric system, this volume of fuel is generally expressed in liters.

Fuel consumption per kilometer is also known as "specific fuel consumption" refers to liters consumed per 100 kilometers traveled as "fuel consumption rate", in some studies that compare alternative fuel sources, fuel consumption rate is measured in mega joules per kilometer traveled. (Haworth and Symons, 2001)

Some researchers stated that fuel consumption rate of a vehicle per unit distance exhibited a convex function with respect to cruise speed. Specifically, the fuel consumption rate decreased from the highest rate, at the lowest speed (10 km/hr.), reaching its minimum at a speed of approximately 80 km/hr. and then increasing again with an increase in the cruise speed. (Rakha, H., and Ding, Y.2003)

Traffic congestion leads to excess fuel usage due to two effects: time spent idling in gridlock, and the start-and-stop nature of travel in congested conditions, as travel at a steady speed uses fuel at a lower rate. Fuel consumption is a significant component of VOC and is one component that is directly affected by driving conditions. Traffic congestion, road condition and alignment influence fuel consumption, so it is sensitive to road investment decisions. Figure 2.2 illustrate the framework for fuel consumption cost.

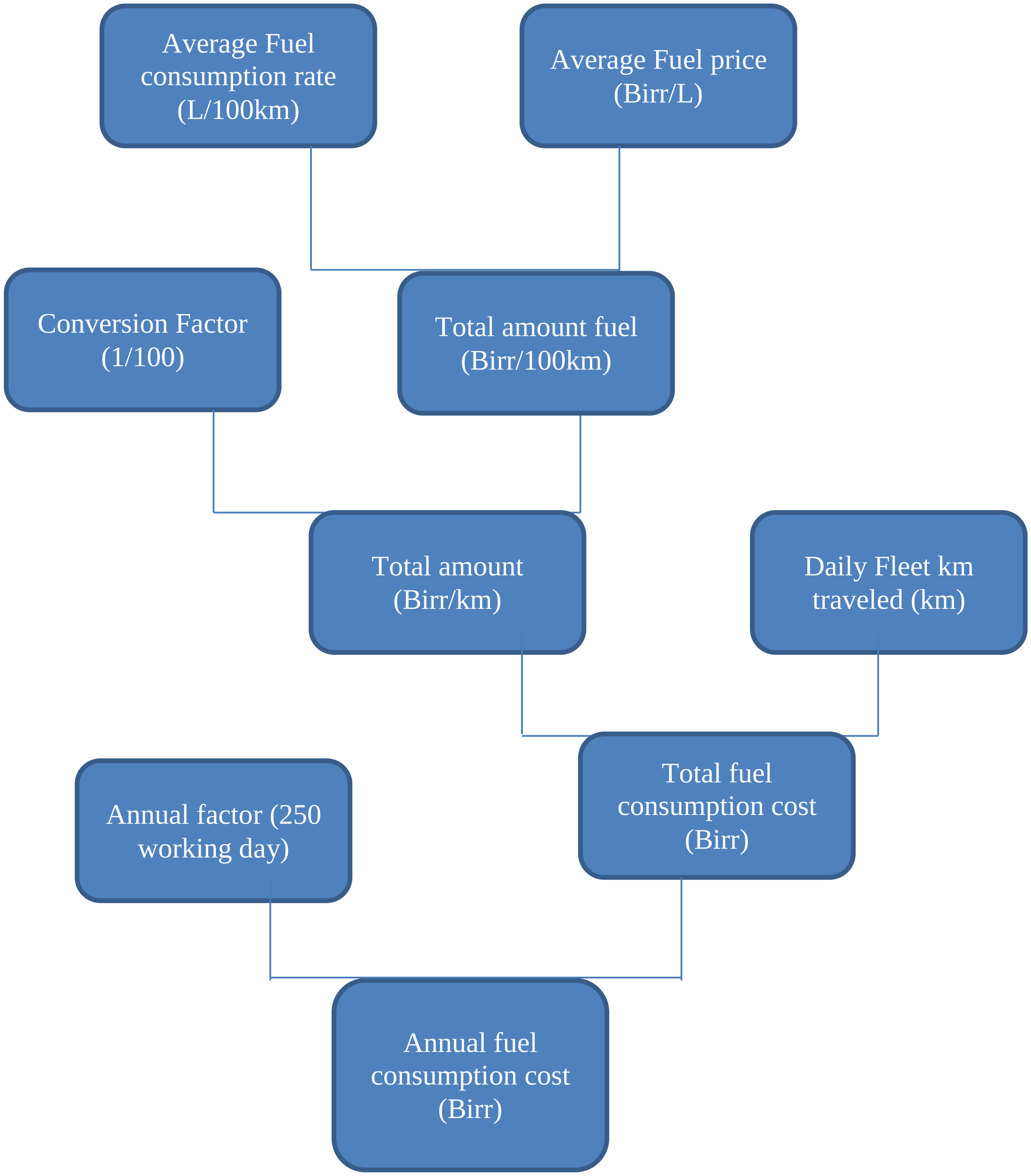


Figure:- 2.2: Framework for fuel consumption cost.

2.10.3 Associated CO_2 Emission Cost Due to Excess Fuel Consumption

Vehicles emit various chemical compounds as a direct result of the combustion process. The type and quantity of these emissions depends on a variety of factors including the tuning of the engine, fuel type and driving conditions. When dealing with vehicle emissions, these are the following substances; hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO2), oxides of nitrogen (NOx), Sulphur dioxide (SO2), lead (Pb) and particulate matter (PM). These compounds are considered to not only form the majority of the emissions, but also form the most damaging to the natural environment and human health. (Greenwood, 2003)

Emissions may increase as vehicles spend more time in congestion, idling or crawling, and undergoing numerous acceleration and deceleration events. A number of studies, in developed and developing countries, apportioning the sources of air pollution put the transport sector atop both from direct exhaust and indirect road dust. Increasing fuel consumption on the road mean emissions increase, air quality will only get worse. Given the following standard emission rates for diverse vehicular modes, and among different emission substances, the researcher mainly focused on the CO2 emission caused by excess fuel consumption due to congestion as estimated per year. Vehicles are the dominant sources of many air pollutant emissions in urban areas than country area. (TRB, 2002) Congestion has the potential to significantly worsen ambient air quality, particularly near major roadways. Impacts due to vehicle emissions have been receiving increasing attention, and recent epidemiological studies show elevated risks of non-allergic respiratory morbidity, cardiovascular morbidity, cancer, allergic illnesses, adverse pregnancy and birth outcomes, and diminished male fertility for drivers, commuters and individuals living near roadways (WHO, 2005).

Dr.Eng. Demiss Alemu Amibe, (2004) estimated that the vehicle population in Ethiopia has exceeded 350,000 and is growing at about 8% annually. Among this 250,000 are light duty vehicles which emit about 1.9 million ton of CO_2 per annum. And Most of the light duty vehicles are older than 15 years and beyond their useful service life. As a result, high fuel consumption, emission of pollutants and road accident prevail.

The total number of passenger car is expected to increase the carbon dioxide emission due to the strong urbanization.

Based on engineering judgment the researcher believes Most of the light duty vehicles in Ethiopia are older than 15 years and beyond their useful service life.

Energy and activity based approaches were used to calculate carbon dioxide emission of the automobiles. Energy based approach is used because, data regarding energy use of the vehicles were obtained and standard emission factor is used to convert values to carbon dioxide emissions. Activity based approach on the other hand, is used to manually calculate the emission level. Combination of the two approaches helps to minimize the shortcoming of the approaches and to be benefited from their synergy. The following formula is sourced from carbon calculator model in order to compute carbon dioxide emission level of motor vehicles. As provided by the Institute of Environmental Management and Analysis corporate, (2013)

$$CO2\ Emssions\ (tones) = \left(\left(\frac{\text{Mile Drives}}{Fuel\ Efficiency} \times 19.36\ \frac{lbs\ CO2}{Gallon}\right)\right) \div 2204.6$$

To make the calculation compatible with the data gathered, miles were substituted by kilometers. The emission factor is 19.36 lbs. CO2/gallon is divided by 2204.6 to convert the pounds of CO2 emissions to metric tons. 19.36 lbs. of CO2/gallon is equivalent to 19.36 lbs. CO2/3.78541 liters or 5.115 lbs. of CO2/liter. This is also equivalent with 2.32012kg CO2/liter. Vehicle’s emission factor is computed based on the averaged details of: vehicle numbers; annual mileage travelled; fuel specifications; road distribution by type of road; average vehicle speed; and temperature and humidity (Hao, Andrew, and Michael, 2013). The vehicle’s emission factor for any diesel and gasoline car in Ethiopia is 2.68kg CO2/liter and 2.4kg CO2/liter respectively.

In due course, the above formula was modified and the following formula was finally used to compute carbon dioxide emissions of automobiles and results are described in terms of grams of carbon dioxide per kilometer, since international standard of carbon dioxide emissions of cars is expressed in grams of carbon dioxide per kilometer.

$$CO2\ emissions\ (grams) for\ Diesel\ Gas = \frac{Kilometers\ Driven}{Fuel\ Efficiency} \times 2680 \frac{grams\ of\ CO2}{liters}$$

$$CO2\ emissions\ (grams) for\ Gasoli\ Gas = \frac{Kilometers\ Drivens}{Fuel\ Efficiency} \times 2400 \frac{grams\ of\ CO2}{liters}$$

Diesel vehicles emit most of the harmful air pollutants, as much as 80‐90% in some countries. Although the technology is improving, diesel still generates more harmful pollutants than gasoline. In addition, the combustion of one liter of diesel causes more CO2 emissions than the combustion of one liter of gasoline. In many countries, the majority of new cars entering the market are diesel. One reason is that many countries provide tax incentives to purchase diesel cars. Switzerland, the United Kingdom and the United states are the only countries where taxes on diesel are higher than on gasoline. Figure 2.3 presents the framework for CO_2 emission cost.

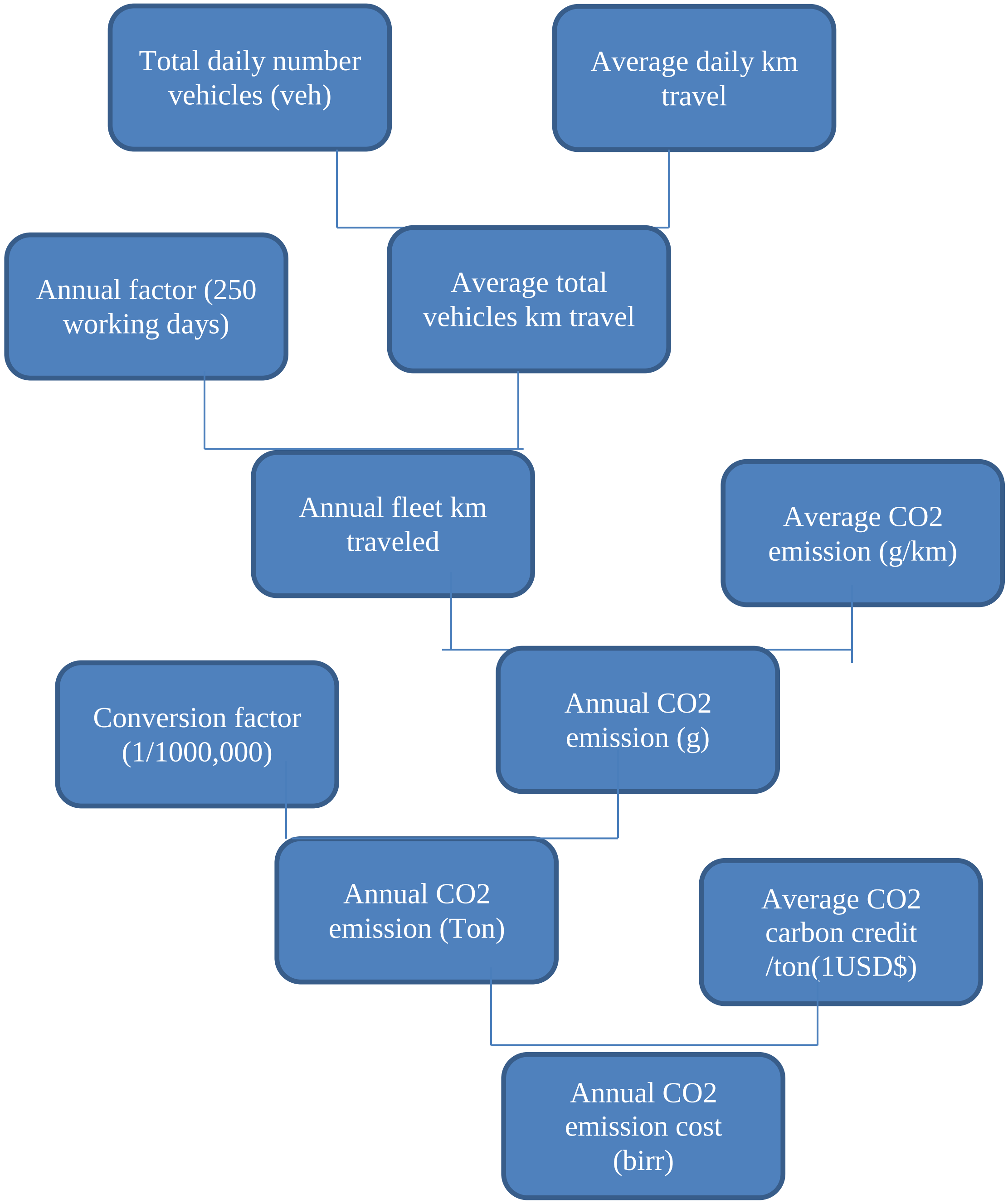


Figure2.3: Framework for CO_2 emission cost.

In Ethiopia, particularly in the city of Addis Ababa there are different types of public transport vehicles which give service to the residents, the main ones are Anbesa bus, Midi- bus and Mini bus.

According to, Eshetie Berhan, (June 2013). The Anbesa City Bus Servise Enterprice (ACBSE) makes more than 5000 trips daily, with a fleet size of more than 759 operational buses out of which only about 534 of the buses are used for regular service s and cover an area with a radius of 45 km from the city center. It serves more than 640,000 passengers daily and travels an average of about 78,000 kilometers per day throughout the city. The high mobility of passengers in the city of Addis is mainly because of the concentration of economic activities, educational and social facilities in few city centers.

Currently ACBSE has new brands of Bishoftu buses which are single and articulated types that are about 460 in numbers. As shown in Table 2.7, the total number of buses currently available at ACBSE is more than 975, including non-operational ones. The Enterprise currently operates in 110 routes (as of the end of 2012) with an average length of 14.6 kilo meters, most of which are radial routes to the central business and commercial areas of the city. The Enterprise fixes the bus capacities larger than the international standard. For example from Table 2.7 Mercedes bus with seat capacity of 30 is considered to transport 100 passengers; with a mean. Standing capacity of 70 passengers, which is higher than the international standards. Under the column of standing in the table, the numbers given in bracket are allowable standing capacity based on the international standard. In order to cope with commuters' demand, the government has made interventions to introduce midi-buses (495 China made Higer buses with a seat capacity of 25 passengers) and encourage private owners to participate in the public transportation. But this could not address fully the high demand rather created high congestion in the mixed traffic system. In the case of the remaining private modes of public transport such as minibus and taxi, services are provided on selected and heavily populated routes at a higher price than that of ACBSE.

Table:-2.7 Available buses and their respective capacity

Bus type	Buses		Capacity		
	Total	operational	Seats	Standing	Total
Mercedes	55	27	30	70 (30)	100
DAF	461	320	30	70 (30)	100
Single	350	315	30	70 (30)	100
Articulated	109	97	50	100 (40)	150
Total	975	759	140	310	450

The other productivity indicator parameter is the fuel consumed in 100Kms covered. As The finding shows that ACBSE consumes an average of 58.36 litters of fuel for every 100Kms. It also exhibits fluctuations from month to month. The overall performance indicates that low range of Kilometers have been covered with high fuel consumption per 100Kms. This may happen due to the large number of old buses that cover short range of kilometers and consume too much fuel. (Eshetie Berhan, 2013).

Demelash Abate (2007), states in his analysing public transport performance using efficiency measures and spatial analysis, the case of Addis Ababa Ethiopia. In his study, he stated that the fuel consumption of Anbesa city bus is 47.62 L/100 km. however, as the data which was gave from the ACBSE the current fuel consumption of buses are approximately founded 69.10 L/100 km. when we compare this fuel consumption value from the previews; it is increasing due to the age of vehicles and different factors. The fuel consumption of the other vehicles is founded by doing some interview to the drivers and owner of the vehicles.

The mixed traffic system used in the country (poor utilization of the road infrastructure) causes high traffic jams; resulting in long service time, which is one of the factors that affect the quality of the service. This contributes adversely to the high traffic congestion and environmental pollution. It is also mainly because of 80% of the nationally registered fleet are located in Addis Ababa. (Africa-Trans, April 2010).

CHAPTER – THREE

3.0 METHODOLOGY

3.1 General

The methodology employed for a research work is the critical aspect for ensuring the proper result which aligns with the objective or the research question, rose. Hence, this part of the thesis discusses the methodology used and the reason for the selection of the methods in order to address the research problem stated earlier in Chapters 1and 2.

3.2 Research Approach

Among different research designs, both qualitative and quantitative descriptive research design were used for the purpose of this study which enable the research to interpret the finding adequately and accurately. Consequently, this paper quantitatively described the existing vehicle traffic flow, road characteristics, and congestion costs. In addition, describing the relationship of vehicles kilometers running per litter with in a normal and congested traffic conditions, amount of fuel consumption, its impact on travel time (delay) and also associated CO_2 emission due to excess fuel consumption.

Qualitative data is considered to be particularly suitable for gaining an in-depth understanding of the underlying reasons and motivations. It provides insights into the setting of a problem. At the same time, it frequently generates ideas and hypotheses for later quantitative research. The main source is primary data which is acquired through questionnaires and interviews of different people and traffic polices. Journals and related books were also used to determine whether the congestion in selected road considerable or not and to assess other related parameters. That is acquired through secondary data collection.

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 intersections and road sections.

It is impossible to assess the traffic congestion at all intersections and road sections in the city, with this understanding, a case study of selected intersections were considered in the study.

In this research, the intersections and road sections considered were at the South-West corridor, specifically in NIFAS SILK LAFTO Sub-city specifically the MEKANISA - JEMO section; which is connecting the highly populated residential area and is on the road SEBETA.

Quantitative data is considered quantification and analysis of the data. This allows generalizations of results from a sample to an entire population of interest and the measurement of the incidence of various views and opinions in a given sample. The main source of quantitative data is primary data which is collected from different relevant bodies, such as Addis Ababa Road Transport Branch Office, and Addis Ababa City Roads Authority and NIFAS SILK LAFTO sub-city traffic police office so as to assess the road network like observation, and field measurements of different parameters. The main use of this data and analysis are in order to determine the level of service of intersections, as well as to estimate the total congestion cost.

In this thesis, the methods followed were designed in such a way that the key questions of the Research be answered properly. In order to assess whether the intersections or the road sections are congested or not; a key question "does traffic congestion exists at this location?" Was raised and answered first using congestion indicator parameters? The congestion indicator parameters used in this research were level of service (LOS) and Travel time and travel speed measure. The LOS criterion was according to HCM-2000 and determined using the widely used SIDRA software.

For the road intersections identified as "congested" further analysis for the level of the congestion was done using travel time approach. In doing so, the performance measure parameters were used to measure the intensity, extent and duration of the congestion. As travel time approach is easy to understand and interpret by every people and it is easy to convert to other index parameters. The performance measurement parameters used in this research were based on travel time approach.

3.3 Description of Study Area

Addis Ababa is the capital city of Ethiopia and is located at about 2,440m above sea level at 9.02°00’16.68” N 38044’49.39” E. the population was 3,384,569 according to the 2007 population census with annual growth rate of 3.8%. This number has been increased from the originally published 2,738,248 figure and appears to be still largely underestimated. Addis Ababa has the status of both a city and a state, it has 10 sub cities and it is the quarter the African Union is and its predecessor the OAU is based. It also hosts the headquarters of the United Nations Economic Commission for Africa (ECA) and numerous other continental and international organizations and home to many embassies. The selected study area is located at South West corridor, which is in NIFAS SILK LAFTO sub city. Figure 3.1 below shows the Addis Ababa administrative units.

Figure: 3.1 Addis Ababa City Administrations

In selected area, there are different types of intersections; among them the two intersections in study are getting worse and worse condition by traffic congestion. From the data that we get at AACRA and different media also talk about the current situation of this area, Due to the above stated reason this study area is chosen.

The names of the intersections to be studied are:-

- ✓ German roundabout.
- ✓ Jemo Michael signalized Intersection.

3.3.1 Description of German Intersection

This intersection is the first congested area of among the area. It is roundabout with four legs namely, MEKANISA approach, JEMO MICHAEL approach, HANA MARIAM approach and GOFA approach. The intersection is shown below in figure3.2.

Figure: 3.2 German roundabout.

3.3.2 Description of Jemo Michael Intersection

This intersection is the second congested intersection of the surrounding area. It had a 46m radius of small roundabout with four legs namely, AYER TENA approach, LIDETA approach, GERMAN approach and JEMO approach. This roundabout has been recently changed to portable traffic signalized.

Figure 3.3 Jemo Michael signalized intersection.

3.4 Vehicle Ownership

According to T.Wendessen in his MSc paper, the vehicle ownership per capita of Ethiopia is the lowest in the world, with one per 1000 people. But, now days, it has a slight change in number. A vehicle ownership per capita data of about 192 countries for the year 2004 – 2014 is given on Wikipedia and the data is summarized below to help comparison of the Ethiopia's vehicle ownership with other developed and Sub- Saharan countries.

Table:-3.1 List of Counties with vehicle ownership.

Country	Vehicles per 1000 peoples	Country	Vehicle per 1000 peoples	Country	Vehicles per 1000 peoples
San Marino	1263	Libya	290	Sudan	27
Monaco	899	South Africa	165	Cameron	14
USA	797	Tunisia	125	Uganda	3
Liechtenstein	750	Egypt	45	Somalia	8
Iceland	745	Nigeria	31	**Ethiopia**	**3**
Luxembourg	739	Djibouti	28	Sao tome and Principe & Togo	2

(Source: - (https://en.wikipedia.org/wik/list of country by vehicle per capital.)

3.5 Data Collection and Equipment

The preliminary stage involved a reconnaissance visit to the study area for on-the-spot evaluation of the selected traffic congestion areas in the city. And after this in order to get the objectives of this study, both data has to take properly. Finally recommended techniques and steps have been followed to minimize errors.

The primary data were collected using the following techniques:-

- ✓ Questionnaires;
- ✓ Manual traffic counts;
- ✓ Manual travel time and travel speed measure; and
- ✓ Field measures.

Questionnaires were developed based on a sample frame, best type of sampling which is Stratified sampling and was determined because Stratified sampling is a sample obtained by dividing the populations in to sub-group, called strata, according to various homogenous characteristics and then selecting members from each stratum for the sample.

The Advantages of this sampling method are: -

- ✓ It ensures representation of all populations sub groups that are important to the study;
- ✓ If there is a clear and small number of variables, dividing a given populations to representative sub group is understandable and important.
- ✓ Only use information on the population’s composition is known or can be obtained through additional observation or data collection. (Estelle .cum laude, 1992).

Therefore, the one and clear variable is the occurrence of congestion and data was gathered based on information on the perception of the road users about the traffic congestion on selected area of the city. Similarly, to check the traffic congestion at that area is either real or not. Finally, other types of data which is important to describe about the congestion were also collected.

There are five types of road users that frequently utilize the prescribed road intersections these are:

(i) Taxi drivers.

(ii) Private car drivers.

(iii)Passenger, who use Public transport.

(iv)Passenger, who use taxi transport.

(v) Traffic police.

The fact that most of the basic analyses in this research are based on the quantitative data described before and the data on the questionnaire are a supplement for the result.

Before identifying the sample frame, an observation made to estimate the total volume of Passengers that travel along the road per hour. The researcher decided to allocate according to what have been observed. The carrying capacity of different modes of motor vehicles is assessed during the two travel times, morning and evening.

On average 1,227 vehicles are passing along the street per hour in both directions carrying total passengers of more than 10,000 on average.

Sample size determination was based on the Krejcie and Morgan (Kothari, 2004) developed table.

Sample size for infinite population size is: -

$$\mathbf{S} = \frac{\mathbf{Z^2}\ \boldsymbol{P}\ (\mathbf{1} - \boldsymbol{P})}{\mathbf{M^2}}$$

Where: - S – Sample size.

Z - Statistical Z from student z-distribution for specific confidence level. (95%)

P- Population proportion (expressed as decimal) assumed to be 0.5 % (50%).

M – Margin of error (10%). And it is expressed as a proportion of (0.1).

$$\mathbf{S} = \frac{\mathbf{1.960^2} * \mathbf{0.5}(\mathbf{1} - \mathbf{0.5})}{\mathbf{0.1^2}}$$

$$\mathbf{S} = 96\ samples.$$

Therefore, 96 representative sample elements were drawn According to their average traffic flow with in the days. 37 (40%) from all passenger who use taxi (minibus) transport system, 28 (30%) passenger who use public transport, 18 (20%), private car drivers, 9 (10%) taxi drivers and the remaining 4 the maximum number of traffic police.

Manually traffic volumes were counted at15-minute intervals for hours of peak period and off peak period to obtain the traffic volume data. The traffic volume count was made for specific hours of **Video Recording** at each peak period and off peak time starting in the **Morning peak time 7:30AM – 9:30AM**, **Midday off- peak time 11:00 AM -2:00 PM and the Evening peak time 4:30 PM – 7:30 PM** at **15 minutes interval**. The vehicles were counted in the category of ERA vehicles classifications as **Small car (**passenger cars, minibuses up to 24 passenger seats taxis, pick –ups & Land cruiser ,Land rover etc.), **Bus** (medium and large size buses above 24 passenger seats), **Medium Truck** (small and medium sized trucks including tankers up to 7 tons load). According to the Traffic volume count guide, Traffic count during Monday and Friday may show exceptionally high volumes and are not normally used in the analysis, therefore, counts are usually conducted on Tuesday, Wednesday and Thursday. By this case the researches took traffic volume count on Tuesday was considered for analysis.

Manual Travel Time will be on collecting travel time data using pen and paper, including discussion, equipment and personnel requirements, necessary procedures, and associated costs. Audio tape recorders and portable computers were introduced to improve the quality and efficiency of the pen and paper techniques. However, discussions were mainly used with pen and paper.

Travel speed of vehicles is measured by using specified marked length of distance of two known places starting and ending point and by recording the vehicles starting time in order to pass that marked point and final destination time interval. Finally, travel speeds were calculated by the relationship of distance and travel time data which if calculated with manual travel time data (pen and paper method).

A field measures were done to gather data on the geometrical features of intersection and road way for the determination of the level of services of the intersections. These include number of lanes, lane width, configurations of lanes, grade, width of median, and movement policy.

The secondary data were data from NIFAS SILK LAFTO sub city recorded data on traffic accident data which were collected during the previous year.

3.5.1 Traffic Volume Data

Traffic volume count data are very important to determine and understand the flow pattern in the facility, to determine the peak flow rates and peak periods, to assess the relationship between traffic volume and congestion. Furthermore, it is extremely required to analyze the level of service of a facility and quantify the congestion intensity. Hence, acquiring traffic volume data at selected road sections and intersections in the study corridor were mandatory and luckily enough,

The traffic volume count was made for 2 hours by video Recording of each peak period of time starting in the morning peak time 7:00AM – 9:30AM, midday off-peak time 11:00 AM -2:00 PM and the evening peak time 5:00 PM – 7:00 PM at 15 minutes interval.

The vehicles were counted by type "passengers Car" and "goods vehicles". The passengers cars category includes vehicle types namely; cars and taxis, 4WD, minibus taxi, mid-bus and standard bus, whereas the goods vehicles category include vehicle types of pickups, light, medium and heavy commercial vehicles.

For the analysis of Level of Service, traffic volume has been counted on each intersection. This is done by considering different types of vehicles and movement mechanism (TH, L and R). To get accurate result, it is important to count at least for 7 days but due to economic and time constraint, the count was done only for one day. These days were selected on the basis of information collected from the traffic polices.

According to the traffic polices information, with in the week almost there is a high traffic volume. But, the first three days of the week have the highest number of traffic volume. And the researcher took the second day of the week. Because as it stated early the traffic volume count guide say that, taking traffic volume count at Monday and Friday may show exceptionally high volumes and are not normally used in the analysis.

Table 3.2 Total Traffic Volume data for all approaches

German roundabout				
Date	**Mekanisa Approach**	**Gofa Approach**	**Hana Mariam Approach**	**St. Michael Approach**
13/12/2016	**9308**	**4705**	**11078**	**7428**

Jemo Michael signalized intersection				
Date	**Ayer Tena Approach**	**Lideta Approach**	**Jemo Approach**	**German Approach**
20/12/2016	**4133**	**5748**	**7701**	**6257**

3.5.2 Travel Time Data

Travel time is a widely used measure, applicable to a distinct starting and ending point, that highway users generally understand, with lower travel time generally interpreted as an indicator of less congestion. It is considered by many to be the best measure of system congestion. Travel time is inversely related to speed. (NCHRP- 463)

Travel time data was the most important data for the congestion analysis. In order to collect the travel time data at the selected locations, the procedures described on travel time data collection handbook (1998) were followed. Travel time is a simple concept understood and communicated by a wide variety of audiences, including transportation engineers and planners, business persons, commuters, media representatives, administrators, and consumers. Engineers and planners have used travel time and delay studies since the late 1920s to evaluate transportation facilities and plan improvements. Travel time is broadly defined as “the time necessary to traverse a route between any two points of interest.” Travel time can be directly measured by traversing the route(s) that connects any two or more points of interest. Travel time is composed of running time, or time in which the mode of transport is in motion, and stopped delay time, or time in which the mode of transport is stopped (or moving sufficiently slow as to be stopped). Accordingly, video with manual transcription was taken and data collected using this technique.

This method was chosen because;

- ✓ The video data provides a permanent, easy -review record of traffic condition;
- ✓ Helps to capture as much as data required or helps to capture large sample size data;
- ✓ Different types of data other than travel time can be extracted if required;
- ✓ Provide a better accuracy than manual count; and
- ✓ Requires lesser number of peoples but much expensive equipment.

There are different methods for the determination of travel time. With the method, collecting travel time data was done using pen and paper technique. This technique requires a driver and a recorder, one or two stopwatches, data collection forms, and a test vehicle. The test vehicle is driven along the study route throughout the time period of interest, using set headways (typically 30 minutes) if desired.

The recorder starts the first stopwatch as the driver passes the first checkpoint, recording the cumulative elapsed time at subsequent checkpoints on the field sheet.

A second stopwatch may be used to record the amount of delay time incurred by the test vehicle when slowed or stopped (0 to 8 km/h, or 0 to 5 mph), also noting the cause of the delay.

In this research, travel time has been measured manually by using Video record, before the actual video capturing owners of the buildings where we plan to set up the video were requested for permission and then a trial run was made to identify best locations and possible problems to be happened and get ready for that. Once all preparations are completed, capturing video was started at the location with specific heights accordingly, a specified hours of traffic flow video data was acquired for further manual transcription at on a computer.

The sample size has been determined using the following formula from travel time hand book (Turner et.al 1998).

Sample size for travel time $n = \left[\frac{z \times c.v}{e}\right]^2$

Where: Z = student z-distribution for specific confidence level.

C. V = Coefficient of variance.

e = Relative error.

The handbook using the above statistical equation provides a sample size for different traffic conditions and level of confidence. Accordingly, for congested traffic condition at 95% confidence interval and + 5% error, with coefficient of variance of 9% for traffic volume less than 15,000, according to travel time hand book Table 3.3 and Table 3.4 shows Illustrative test vehicle sample size on arterial street and freeways. The minimum sample size was calculated to be 8 for 30 min count.

By using prioritized sampling, the critical or most congested segments (approach) are fully sampled.

Factor which can be used for prioritizing data: -

- ✓ Perceived bottlenecks or congested locations;
- ✓ Percent change in congestion level (if available);
- ✓ Average daily traffic volume per lane and Average daily traffic volumes, and

The raw data for the travel time of each approach is summarized below.

During travel time data collection period, it was decided by fixing the length of the road which will be seen by video camera. Therefore, at a specified height of the buildings researcher took the travel time data were taken for two intersections.

Table 3.3 Travel Time Data in Seconds.

Travel Time (Sec)										
	German Intersection				Average	Jemo Michael Intersection				Average
Time	Hana Mariam Approach Length=110m				Travel Time	Jemo Approach. Length =160m				Travel Tim
7:30-7:45AM	96.4	113.5	112.5	106	107.1	65.9	66.9	75.2	60.3	67.1
7:45-8:00AM	92.9	110.5	103.1	99	101.3	62.1	72.1	64.2	62.1	65.1
8:00-8:15AM	88.0	116.2	100.6	100.1	101.2	60.5	59.3	71.8	62.6	63.5
8:15-8:30AM	96.5	94.5	95.7	100.4	96.7	55.3	60.6	63.9	63.4	60.8
8:30-8:45AM	89.4	91.6	93.4	68.7	85.7	60.1	54.9	63.8	57.5	59.1
8:45-9:00AM	92.8	96.2	94.7	96.5	95.0	59.2	56.4	55.5	59.4	57.62
9:00-9:15AM	90.3	94.3	90.8	90.2	91.4	46.1	42.1	49	45.5	45.67
9:15-9:30AM	90	98.2	90.1	90.6	92.2	36.1	40.3	50.1	50.9	44.3
11:00-11:15AM	72.4	75.3	78.6	75.7	75.5	38.5	49.6	38.3	55.2	45.4
11:15-11:30AM	78.4	77	72	71	74.6	50.8	52.5	50.4	55.7	52.3
11:30-11:45AM	65.5	66.2	61.9	69.1	65.6	56.9	46.7	43.3	33.9	45.2
11:45-12:00AM	60.1	68.7	63.2	66.1	64.5	31.3	39.2	42.1	45.5	39.5
12:00-12:15AM	64	65	60.1	63.9	63.2	36.5	34	35.7	36	35.5
12:15-12:30AM	59.6	57.3	60.2	60.9	59.5	45.6	37.6	32.6	32.3	37.1
12:30-12:45AM	55.3	50.2	52.4	57.2	53.7	31	28.7	31.3	25.6	29.1
12:45-1:00 PM	48.9	47.2	55.9	58.7	52.6	36.2	31.5	30.7	34.6	33.2
1:00-1:15PM	50.1	53.6	45.9	47.9	49.3	45.9	33.7	34.3	29.1	35.7
1:15-1:30PM	40.1	45.1	42.8	39.3	41.8	30.1	29.6	30	38	31.9
1:30-1:45PM	42.1	42.6	40.1	48.2	43.2	29.1	27.5	31.2	30.9	29.6
1:45-2:00PM	40.4	35.5	36.2	44.7	39.2	30.8	20.2	31.6	32	28.6
4:30-4:45PM	79.6	78.4	77.3	75.4	77.6	31.2	29.1	35.2	37.7	33.3
4:45-5:00PM	86.4	75.9	75.2	80.1	79.4	45.6	47.8	44	50.9	47.1
5:00-5:15PM	88.9	85.3	73.6	82.1	82.4	54.3	55.9	51.7	59	55.2
5:15-5:30PM	90.1	75.9	85.4	84.3	83.9	60.3	59.6	70.6	60.1	62.6
5:30-5:45PM	89.2	79.6	85.2	86.4	85.1	56.7	52.8	75.4	64.4	62.3
5:45-6:00PM	102.5	112.3	106.6	100.7	105.5	49.7	45.6	40.5	46.9	45.6
6:00-6:15PM	93.5	90.4	89.2	85.5	89.6	43.8	51.2	47.3	49	47.8
6:15-6:30PM	75.4	65.2	60.3	57.7	64.6	40.3	44.7	42.1	45.2	43.1
6:30-6:45PM	57.3	50.9	52.1	45.5	51.4	49.2	43.7	47.4	41.4	45.4
6:45-7:00PM	45.7	43.2	37.2	32.2	39.5	39.3	30	33.1	30.2	33.1
7:00-7:15PM	40.2	42.1	40.6	42.5	41.3	36	35.2	30.9	32.5	33.6
7:15-7:30PM	38.6	44.5	40.1	40.5	40.9	30.1	32.2	30.7	31.6	31.1

3.5.3 Passenger Car Unit (PCU)

In developing Countries like Ethiopia, road traffic is heterogeneous in nature. One of the methods used to convert heterogeneous traffic in to equivalent homogeneous one is by using PCU factor. Present roadway and traffic conditions at both intersections were observed and analyzed. Using the present traffic data, by adopting Time Headway Approach, new PCU values were developed. The term Passenger Car Equivalent (PCE) was first introduced in the 1965 Highway Capacity Manual. Today, the definition remains relatively unchanged as “The number of passenger cars that are displaced by a single heavy vehicle of a particular type under prevailing roadway, traffic, and control conditions”.

Urban roads are characterized by mixed traffic conditions, resulting in complex interaction between various kinds of vehicles. To cater to this, it is usual to express the capacity of urban roads in terms of common unit. The unit generally employed is the ‘passenger car unit (PCU), and each vehicle type is converted into equivalent PCUs based on their relative interference value (IRC 106/1990)

According to Umama Ahmed, (2009) several approaches to estimate PCU values have been used. The most commonly applied approaches are the constant volume-to-capacity ratio approach and the headway approach. The constant volume-to-capacity ratio approach was developed based on the output of a multilane freeway simulation model developed at the Midwest Research Institute. PCU values were based on mixed traffic volumes that consumed the same proportion of roadway capacity (produced the same volume-to- capacity ratio) as PC-only volumes. The constant volume-to-capacity ratio approach was appropriate for calculating PCUs when LOS was a consideration for PCU calculation. But it is not applicable to the current procedure, which estimates PCU only under a steady-state condition, which is why headway approaches is used for the determination of PCU for this research. The Researcher utilized the Headway method for its simplicity and easy application. The basic formula of PCE using the headway approach is as follows:-

$$\mathrm{PCUi} = \frac{\mathrm{Hi}}{\mathrm{Hc}}$$

Where, PCU_i = passenger car unit of vehicle type i.

H_i = Average headway of vehicle type i, (sec).

H_c = Average headway of passenger car, (sec).

Therefore, headways have been collected for each type of vehicles considering three cases; morning peak period, midday off-peak period and evening peak period and the sample size taken was the same as travel time sample size shown in travel time section. Table 3.4 below shows the PCU values for different types of vehicles.

Table 3.4 PCU, calculation based on headway.

PCU Factor ,Headway (Sec)									
	Bajaj	Car & Taxi	Mini bus Taxi	4WD	Mini/Medium bus	Std. Bus	Small Trucks	Medium Trucks	Large Trucks
1	2.3	3.8	4.6	3.8	4.5	6.4	4.6	4.4	6.3
2	3.1	3.3	4.7	3.7	4.4	5.6	4.2	4.7	5.9
3	3	3.7	5.1	4.2	4.3	7.9	3.5	5.7	5.9
4	2.9	3.2	5	4	4.8	5	5.5	5.6	5.8
5	3	4.1	4.5	4.1	4.9	5.6		4.4	5.5
6	3.2	4	4.6	3.9	4.2	8		5.6	6.1
7	3.1	3.9	5.2	3.8	3.7	6		4.4	5.9
8	3.1	3.4	4.8	4	4.5	7.2		6.8	7
Average h,	2.9	3.6	4.8	3.9	4.4	6.4	4.4	5.2	6.1
PCU=hi/hcar	0.8	1	1.3	1.1	1.2	1.7	1.2	1.4	1.6
1	3.3	3.4	3.8	3.6	4.2	6.8	5	5.4	6.5
2	2.1	3.7	3.6	3.5	4.1	6.6	4.2	5.7	6.9
3	3.2	3.5	3.7	4	4.9	7.9	3.5	5.7	7.1
4	2.7	3.2	3.8	3.8	5.2	7.5	4.5	5.6	7
5	3.1	3	4.1	3.6	4	7	4.1	6.2	6.5
6	3	4	4.2	3.9	4.2	8		5.6	6.1
7	3.3	3.1	4.1	3.8	4.6	7.9		6	6.2
8	3.1	3	3.9	3.1	4.5	7.2		6.8	7
Average h,	2.9	3.3	3.9	3.6	4.4	7.4	4.3	5.8	6.6
PCU=hi/hcar	0.8	1	1.2	1.1	1.3	2.2	1.3	1.7	1.9
1	3.5	3.5	3.6	3.6	4.6	7	4.5	5.5	7.5
2	3.1	3.7	3.6	3.5	4.4	7.2	4.2	5.9	6.5
3	3.2	2.9	3.2	3.9	4.9	7.9	3.5	5.7	7.1
4	2.9	3.2	3.1	3.8	5.2	7.5	4.7	6	7.5
5	3.1	3	4.1	3.6	3.9	7	4.1	6.2	6.5
6	3.5	3.2	3	3.5	4.2	7.5		5.6	6.3
7	3.3	3.1	3	3.8	4.6	7.9		6.1	6.2
8	3.1	3	3.1	3.1	4.5	7.2		6.8	7
Average h,	3.2	3.2	3.3	3.6	4.5	7.4	4.2	5.9	6.8
PCU=hi/hcar	1.0	1	1.1	1.1	1.4	2.3	1.3	1.8	2.1
Average PCU	0.8	1	1.1	1.1	1.3	2.1	1.2	1.6	1.9
	0.8	1	1.1	1.1	1.3	2.1	1.3	1.7	1.9

3.5.4 Field Measurement

The field measurements were conducted on the geometric feature of the intersections selected. Intersection layout is primarily composed of the alignment of the legs, width of traffic lanes, crosswalks, sidewalks on each approach, number of lanes, median, street side elements and the method of treating and channelization of turning movements.

The design of an intersection's layout requires a balance between the needs of pedestrians, vehicles, freight and transit in the available right of way. Beyond intersection layout, the practitioner needs to work with a multidisciplinary team to address accessibility, traffic control and placement of equipment, traffic operations, lighting (safety and pedestrian scaled), landscaping and urban design.

During field measurement, alignment of the legs, width of traffic lanes, crosswalks, number of lanes, median and the method of treating and channelization of turning movements were measured on each approach for the selected intersection.

The width of traffic lane and median measurement were done manually using tape meter. The same method was for the roundabout. The rest of the data were collected by visual observation. The collected data are summarized and presented below as Table (a) and (b) for the selected intersection.

Table 3.5 Field data for intersections.

German Intersection					
Approach	No of lane	Lane width (m)	Median width(m	Lane type	Cross walk
Mekanisa	3	3.5	1	Normal & Give way	Yes
Gofa	3	3.5	1	Normal & Give way	Yes
Hana Mariam	3	3.5	3	Normal & Give way	Yes
St. Michael	3	3.5	3	Normal & Give way	Yes
Circulating lane		3			
Circulating width		10			
Island diameter		60			

(a) German roundabout

Jemo Michael Intersection				
Approach Name	No. of Lane	Lane width(m)	Median Width(m)	Cross Walk
Ayer Tena	3	3.5	3	Yes
Lideta	3	3	1	Yes
Jemo	2	3	14	Yes
Germen	3	3.5	3	Yes

(b) Jemo Michael signalized intersection.

3.5.5 Secondary Data

Traffic accident data has been collected from NIFAS SILK LAFTO Sub city traffic police administration. The office provided five years accident data. The accident data for those two intersections are shown below in Table 3.6.

Table 3.6 Total Traffic Accident at intersections.

Month	Number of accident at German roundabout	Number of accident at Jemo Michael signal Intersection
July,2007	4	5
Augest,2007	11	4
Pagume, 2007	2	3
September,2008	5	2
October,2008	6	5
November,2008	6	3
December,2008	14	7
January,2008	13	8
February,2008	12	6
March,2008	26	7
April,2008	8	10
May,2008	9	8
June,2008	11	11

German roundabout				
	Type of Accident			
Month	Car - Car	Car - Pedestrian	Car - property	Total
July,2007	4	0	0	4
Augest,2007	11	0	0	11
Pagume, 2007	2	0	0	2
September,2008	4	0	1	5
October,2008	6	0	0	6
November,2008	6	0	0	6
December,2008	13	1	0	14
January,2008	13	0	0	13
February,2008	12	0	0	12
March,2008	25	0	1	26
April,2008	8	0	0	8
May,2008	9	0	0	9
June,2008	11	0	0	11

Jemo Michael signalized				
	Type of Accident			
Month	Car - Car	Car – Pedestrian	Car – property	Total
July,2007	5	0	0	5
Augest,2007	4	0	0	4
Pagume, 2007	3	0	0	3
September,2008	1	0	1	2
October,2008	3	1	1	5
November,2008	3	0	0	3
December,2008	6	1	0	7
January,2008	7	0	1	8
February,2008	6	0	0	6
March,2008	7	0	0	7
April,2008	8	1	1	10
May,2008	6	0	2	8
June,2008	11	0	0	11

CHAPTER - FOUR

4.0 RESULTS AND DISCUSSIONS

The analysis of this paper was done on the selected intersections using quantitative and qualitative data to look in to the trend of the traffic flow were done the day and identify the peak period and peak hour volumes. The collected data following the proper and best methodology and the results are presented in the following sections.

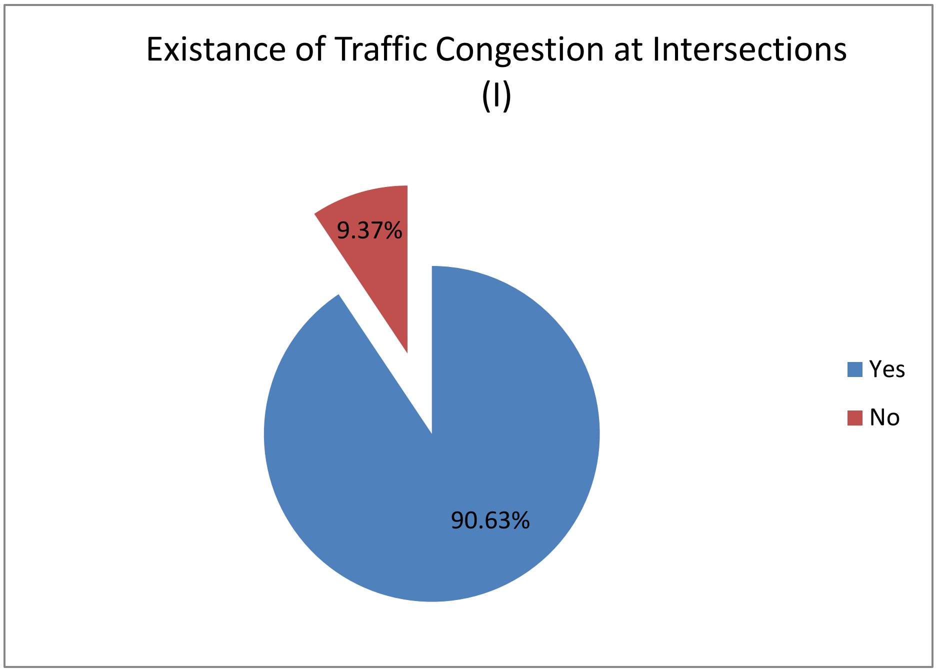
4.1 Questionnaires Responses

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

According to the definition by Lomax (1997), congestion is a travel delay in excess of the acceptable travel time. Hence, according to this definition the road users' elements should be included to define the demarcation between congested and uncongested intersections. Hence, the structured questionnaires were distributed based on stratified sampling for road users (Taxi drivers, passengers who use taxi, passengers who use public bus, private car drivers, and Traffic polices). Table 4.1 below presents questionnaires respondent at figure 4.1 (I) and (II) illustrate level of traffic congestion at the intersections.

Table 4.1 Questionnaires Respondents

		Number	Percentage
Questionnaires	Distributed	96	100%
	Returned	96	100%
Sex	Female	45	47%
	Male	51	53%
	Total	96	100%
Group	Passenger (taxi)	37	39%
Distribution	Passenger (public)	28	29%
	Drivers(private)	18	19%
	Drivers(Taxi)	9	9%
	Traffic Polices	4	4%
	Total	96	100%



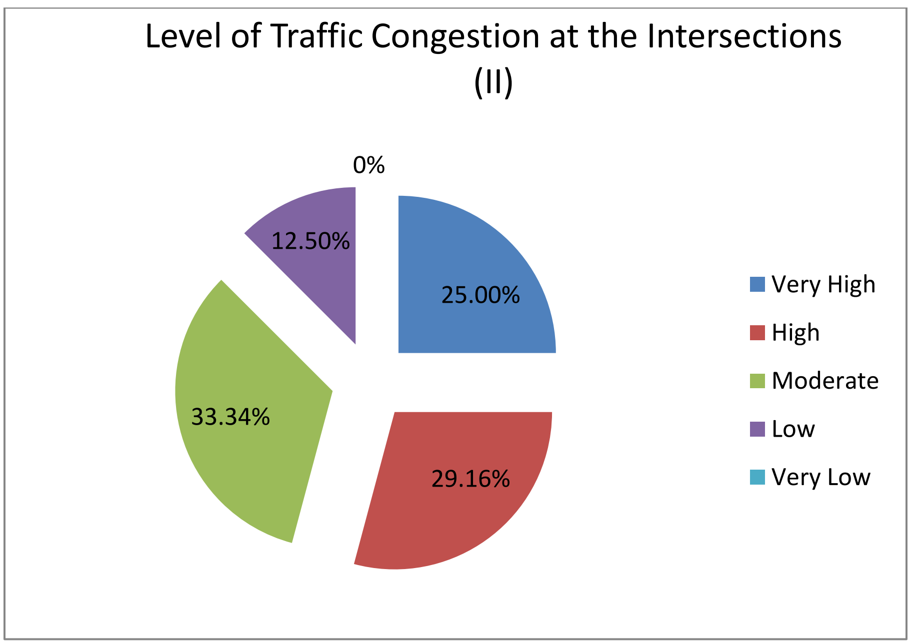


Figure 4.1: Respondent's Perceptions about:

I. Existence of Traffic Congestion.
II. Level of Traffic Congestion at the Intersection.

4.2. Traffic Volume Analysis

A directional traffic volume analysis was conducted on a traffic volume data, which is counted at 15 minute interval. The traffic count was done for a specific hours of a day starting from the early morning to the late afternoon and evening. Therefore, traffic volume analysis is done for all approaches of the two intersections.

4.2.1 Passenger Car Unit Analysis

Different vehicle types occupy different spaces on the road, move at different speeds, and start at different accelerations. Furthermore, the behavior of drivers of the different types of vehicles may also vary considerably. This poses a problem for designing as well as planning of roads, intersections, and traffic signals. A uniform measure of vehicles is thus necessary to estimate traffic volume and capacity of roads under mixed traffic flow. This is rather difficult to achieve unless the different vehicle types are stated in terms of a common standard vehicle unit. For these reasons, the concept of Passenger Car Unit (PCU) or Passenger Car Equivalent (PCE) was developed and it became a common practice to convert the other vehicle types into PCUs. It is generally expressed as PCU per hour, PCU per lane per hour, or PCU per kilometer length of lane. (Rana and Mohit, 2016).

4.2.2 Traffic volume at German Roundabout

German intersection is a roundabout intersection which has four approaches. The traffic count was conducted for three hours of each peak time and off-peak period of time of the whole day by considering all turning movement. As shown in Figure 4.2 the distribution of total traffic volume at German intersection, among four approaches, Hana Mariam Approach has the highest traffic volume during peak time. Next to this approach the Mekanisa Approach has the second highest traffic volume at peak hour. The St. Michael and Gofa Approaches have a relatively moderate traffic volume during peak times. Figure 4.3 presents vehicle composition at German intersection.

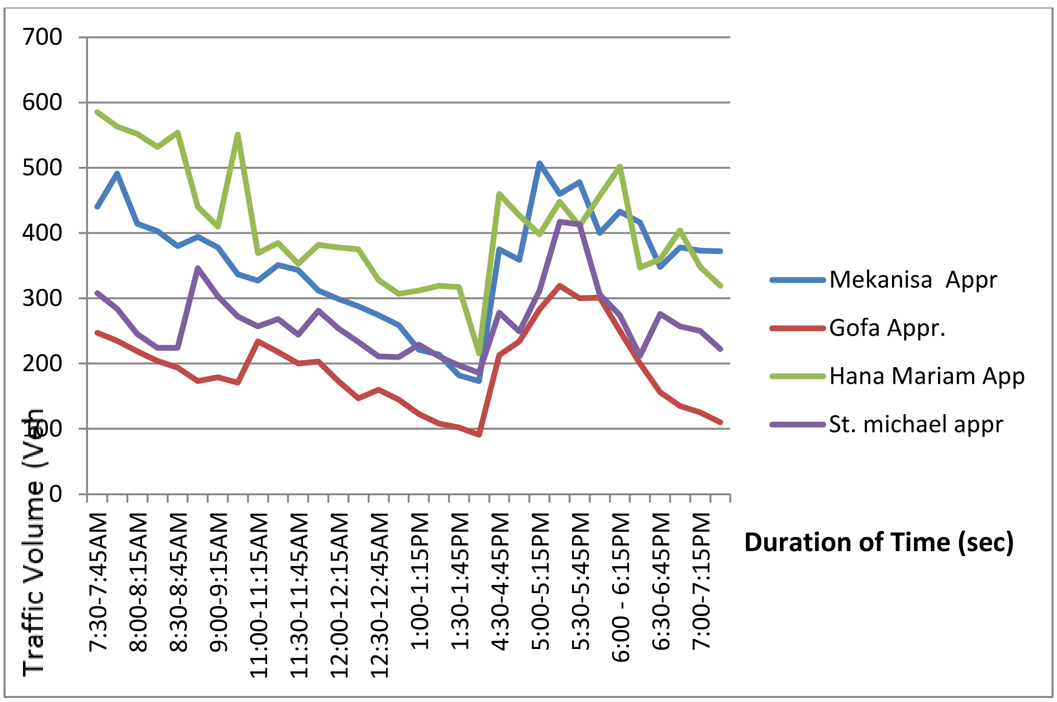


Figure: 4.2. Total Traffic Volumes Count Data for German Intersection.

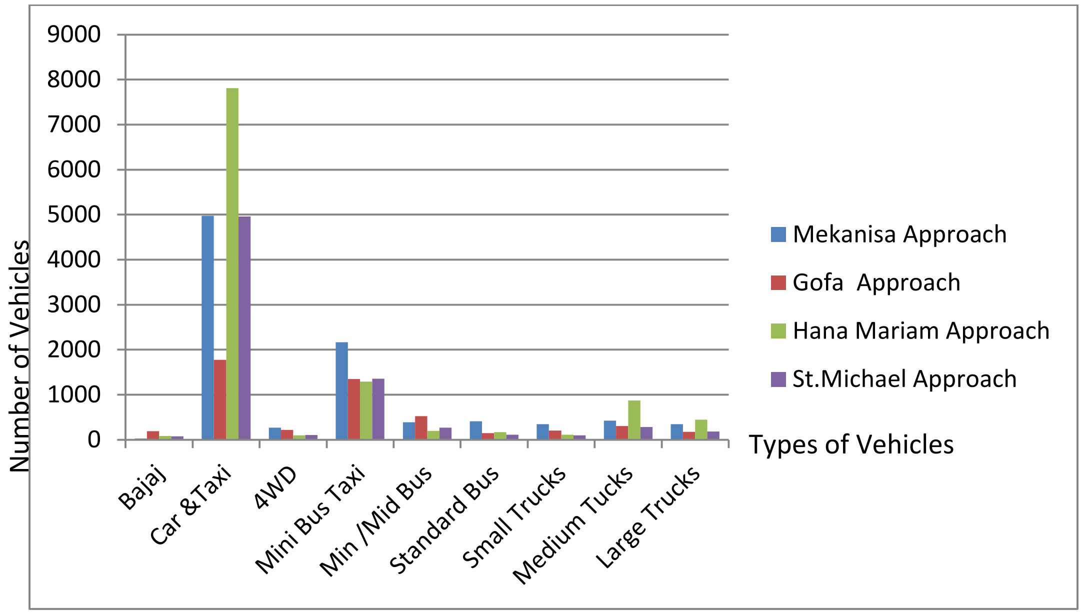


Figure 4.3 Total Vehicle Compositions at German Intersection

As we see from the above Figure 4.3, there are different types of vehicle compositions at German intersection. Cars and taxis have large percentage compositions and next to this mini bus taxi, medium trucks and large trucks are also the second largest percentage composition of vehicles in this intersection. Among the four approaches, the Hana Mariam approach has a high volume of car and taxi vehicles compositions. The Mekanisa approach has the largest composition regarding mini bus taxi.

4.2.3 Traffic Volume at Jemo Michael intersection

Previously, this intersection was a roundabout with a small width of diameter. Due to this nature vehicles got congestion in day-to-day movements. Recently it has been changed to traffic signal. But the occurrence of traffic congestion still does exist due to the geometric design of the intersection. The road users' demand is not balanced with current road capacity. From figure 4.4 the total traffic volume for Jemo approach has the highest traffic volume during peak times, and the second higher approach is the German approach. The rest of the approaches have a relatively lower traffic volume.

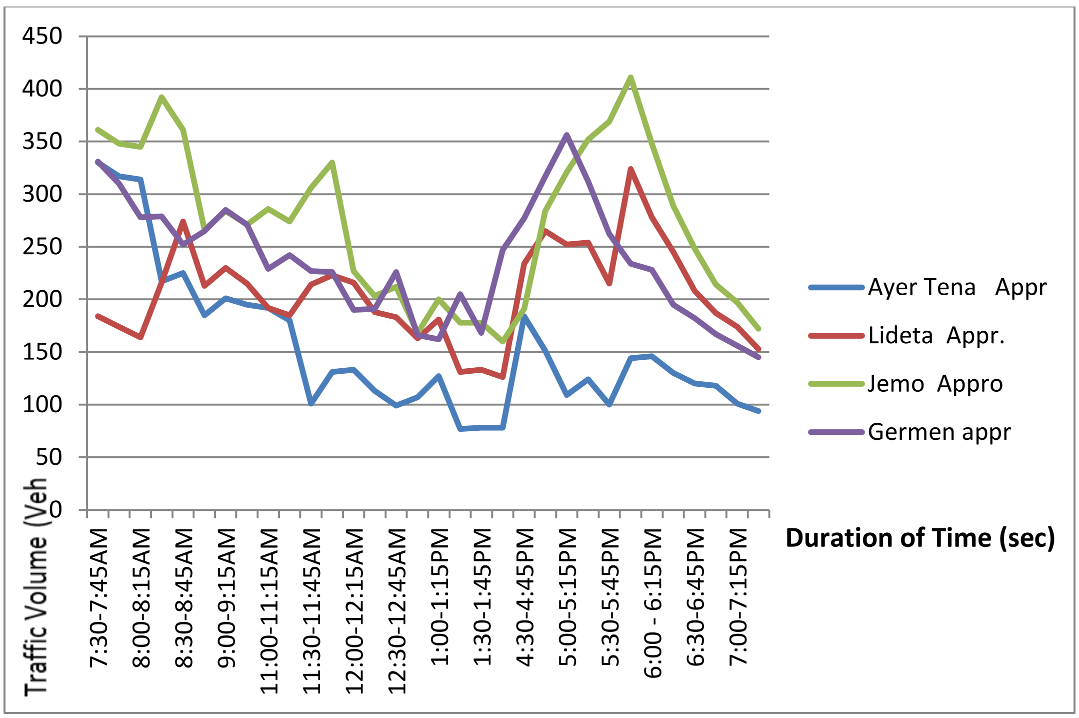


Figure: 4.4 Total Traffic Volume Count Data for Jemo Michael Intersection.

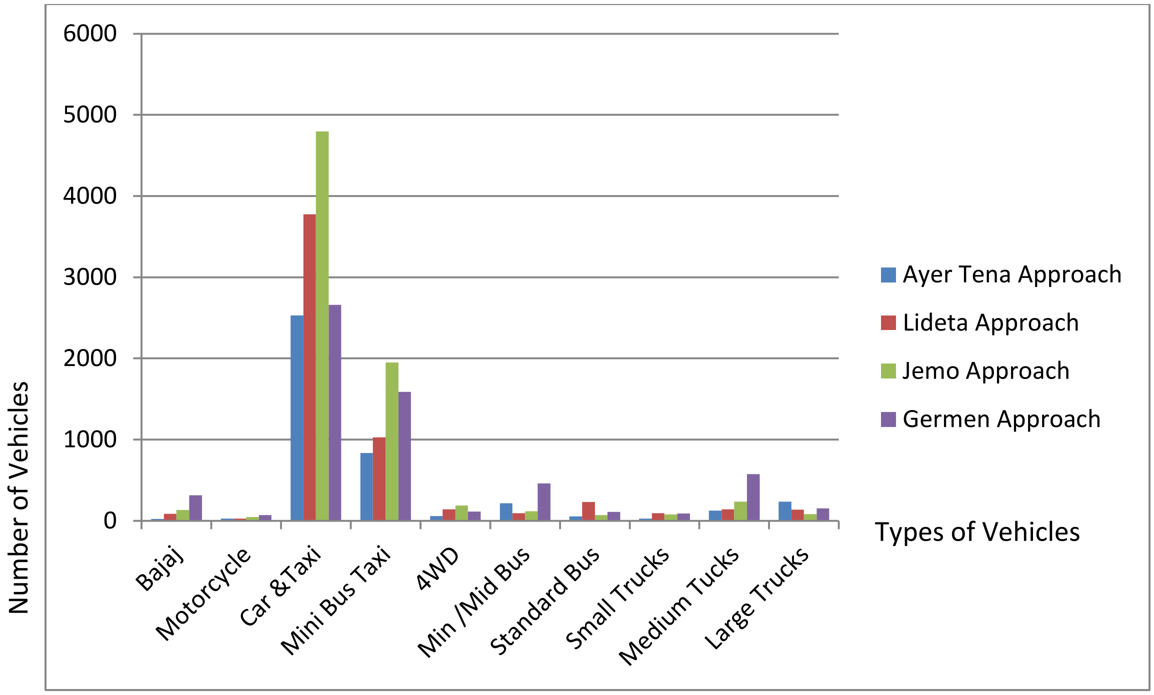


Figure 4.5 Total Vehicles Composition at Jemo Michael Intersection.

Figure 4.5 above show the total vehicles composition at Jemo Michael intersection. Among the different kind of vehicles composition, car and taxi have the highest number of composition in all four approaches. Mini bus taxi, medium trucks and min/medium buses are also the next higher composition value in this intersection. The maximum numbers of car and taxi vehicles are found from Jemo approach.

4.3 Intersection Level of Service Analysis

In order to check whether the intersections are congested or not, analysis was made using SIDRA program. So, to analyze the LOS using the program, installation was made with the options right-hand driving rule and HCM 2000 metric version which represent the driving rule of Ethiopia. The HCM 2000 metric version was chosen because it is widely accepted with the Highway Capacity Manual throughout the world with only minor modifications and calibration. The Level of Service (LOS) will be determined for an indicative result leaving the other out puts of the program; Calibration was not taken as an issue for the purpose.

In order to conduct the analysis the geometric and directional hourly traffic volume data were prepared as an input data for LOS analysis are summarized below in the Table 4.2. And also table 4.3 shows the output data from los analysis. However, recommended and default values were taken for other input data; for instance critical gap, saturated flow.

Table 4.2 Input Data for LOS Analysis.

Intersections	Approach Leg	Number of Entry lane	Number of Exit lane	Lane Width(m)	Median Width (m)	Total Traffic Volume (veh)			Peak hour factor (%)			Heavy vehicle factor (%)		
						TH	RT	LT	TH	RT	LT	TH	RT	LT
German	Mekanisa	3	3	3.5	1	699	725	304	96.2	98	96	12.86	10.98	16.8
	Gofa	3	3	3.0	1	250	200	150	80.1	80	80	1.2	2.1	1.5
	Hana Mariam	3	3	3.5	3	865	281	845	97.8	95	94	13.31	13.28	13.6
	St, Michael	3	3	3.5	3	412	622	822	96.8	98	98	14	15.6	14
Jemo Michael	Ayer Tena	3	3	3.5	3	765	411	315	98.9	98	84	16.95	15.99	3.1
	German	3	3	3.5	3	650	598	567	98.9	99	99	16.1	15.1	14.2
	Lideta	3	3	3.0	1	745	400	580	97.1	99	93	14.9	15.1	8.6
	Jemo	3	2	3.0	14	918	499	204	97	93	88	5.29	15.1	5.85

Table 4.3 Output Data for LOS analysis.

		Delays(sec)			LOS		
Intersection	Approach Leg	LT	TH	RT	LT	TH	RT
German	Mekanisa	126.4	120	183.2	F	F	F
	Gofa	66.5	76.9	11.6	E	F	B
	Hana Mariam	303.7	300.5	300.3	F	F	F
	St. Michael	111.4	62.5	153.3	F	E	F
Jemo Michael	Ayer Tena	85.3	101.7	33.5	F	F	C
	Lideta	120.5	65.2	25.7	F	E	C
	Jemo	155.4	128.8	36.6	F	F	D
	German	121.7	52.9	52.6	F	D	D

4.4 Congestion Analysis

From different types of congestion analysis approach, the researcher chooses Travel time approach with best advantages which was mentioned in Chapter Three. The following congestion measures were analysed, and these are; Average travel time, Average speed, Travel rate, Delay rate, Delay ratio, Total segment delay. Accordingly, the discussions of each parameter are shown in the subsequent sections.

4.4.1 Travel time

As we can see below in Figure 4.6, there is Average travel time at 15 min. interval for the segment selection. The result shows that during morning and evening time the highest travel time and the lowest travel time were recorded during midday off-peak time. When compared each other the German approach has the highest peak travel time during the morning and evening time. And also the Jemo approach has the next highest travel time.

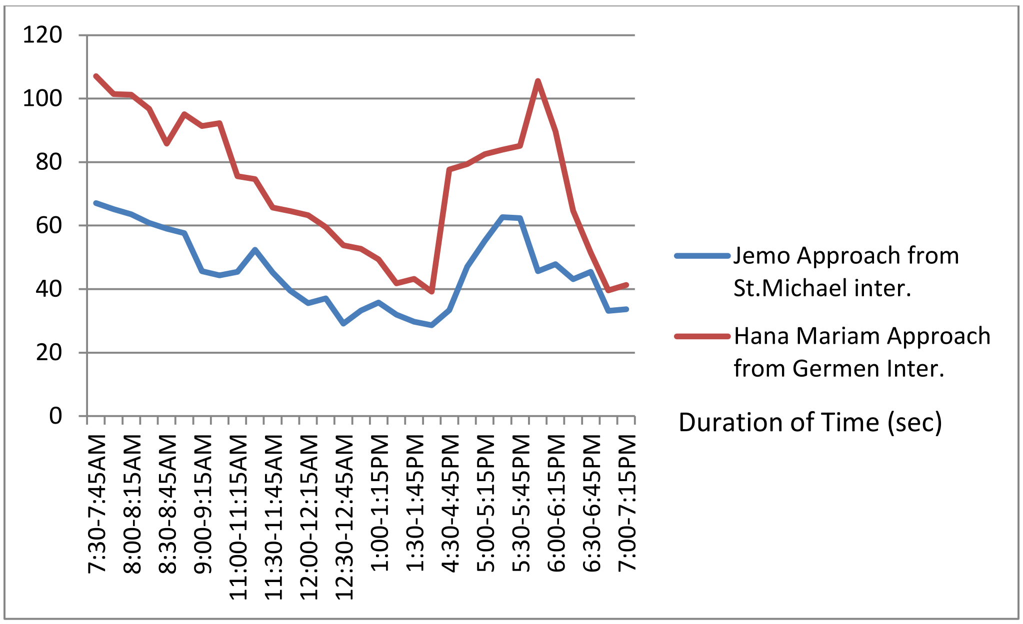


Figure: 4.6 Travel Time for Selected Approaches (Sec).

4.4.2 Average Speed and Travel rate

The average speed calculated at the congested road sections considered in this study is shown below. The result shows that during the morning period travel speeds at the sections are almost below 5 km/hr. and below 10 km/hr. up to midday. However, during midday the travel speed increased to the maximum value. During the midday, the Jemo approach shows the highest travel speed of 20 km/hr.

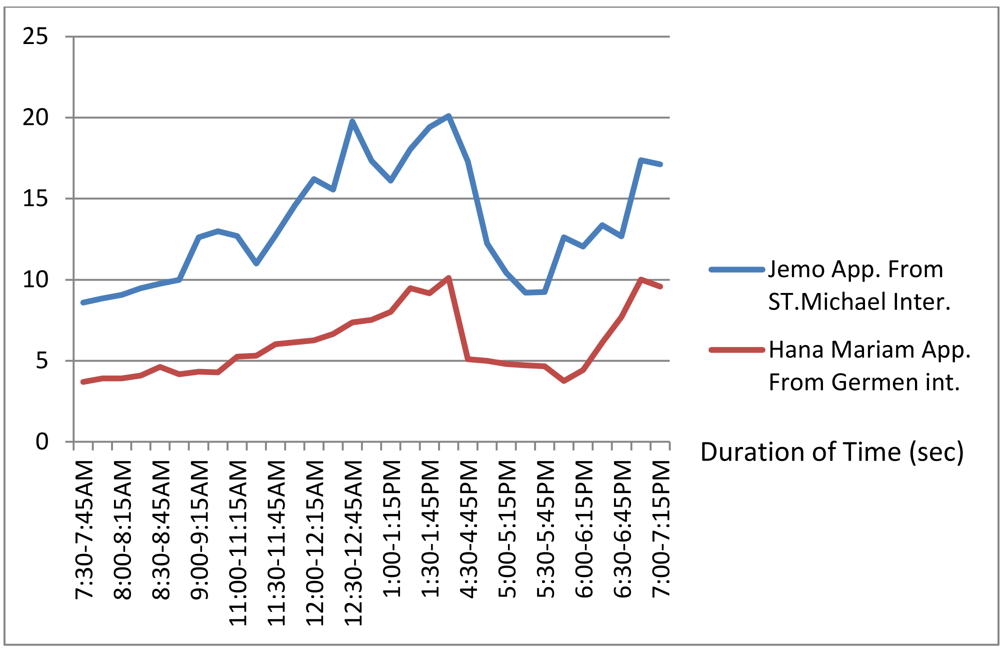


Figure: 4.7 Average Travel Speed for Selected Approaches (km/hr.)

The travel rate which is the inverse of travel speed and the very important parameter in congestion analysis is calculated and presented below in Figure 4.8. The figure shows that the travel rate during the morning and evening peak period is higher than the midday off- peak period.

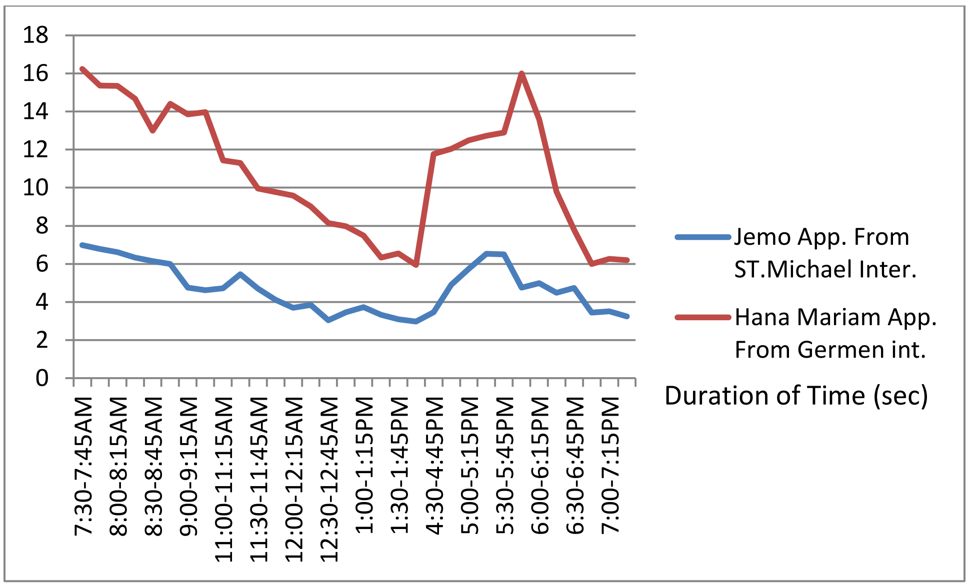


Figure: 4.8 Travel Rate for Selected Approaches (min/km).

4.4.3 Delay rate, Delay ratio, Delay

Delay is one of the important parameter in congestion measure analysis. For the analysis of delay rate, delay ratio and delay the posted approaching speed at the intersection is used as a reference. Delay is the amount of extra time spent in congestion compared to the time it would take under ideal or free-flow conditions.

Delay rate is the rate of time loss for vehicle operating in congested conditions, expressed in minute per kilometer for a specified roadway segment. It is calculated as the difference between the actual travel rate and the acceptable travel rate. The quantity can be used to estimate the difference between system performance and the expectation for those system elements, which can be used to prioritize alternative improvement.

Delay ratio is a dimensionless measure that can be used to compare or combine the relative congestion level of facilities with different operating characteristics like freeways, arterial streets and transit routes. It is calculated as the delay rate divided by the actual travel rate. The delay ratio identifies the magnitude of mobility problem in relation to actual condition.

Therefore, the result of Delay rate, Delay ratio and Delay are listed in Figure 4.9, 4.10 and 4.11 below.

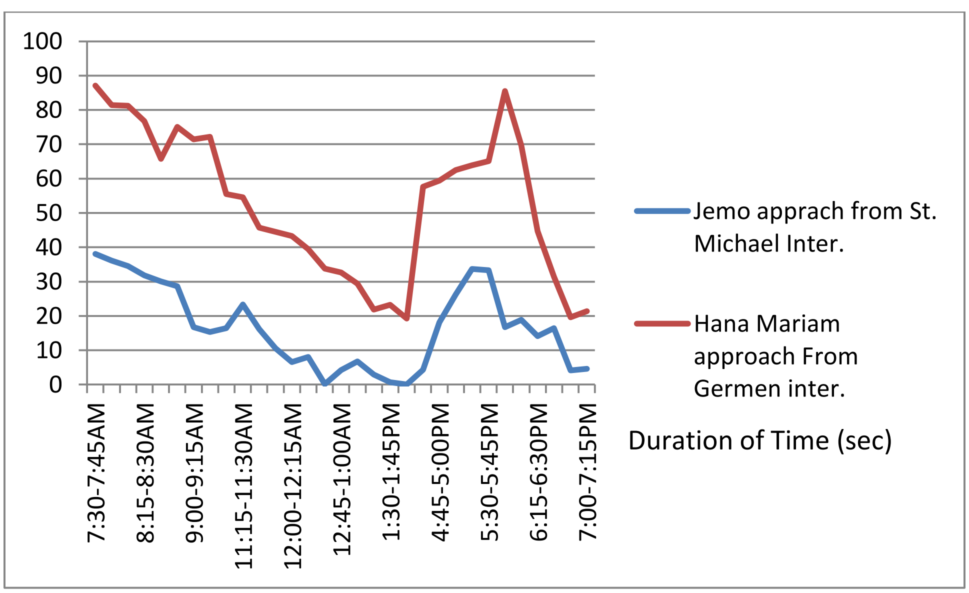


Figure: 4.9 Delay for two Intersections (sec).

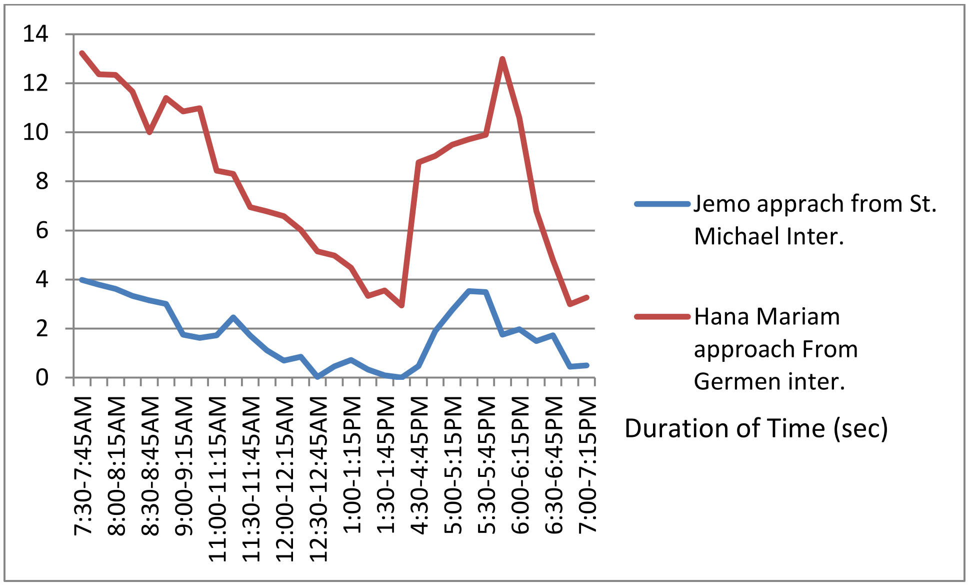


Figure: 4.10 Delay Rate for two Intersections (min/Km).

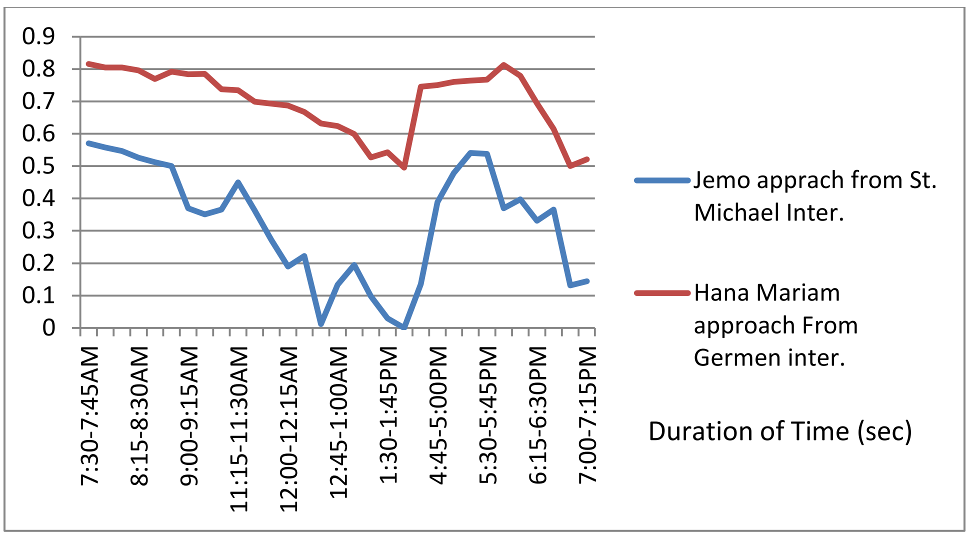


Figure: 4.11. Delay Ratio for two Intersections.

Regarding delay analysis, from German intersection, the Hana Mariam approach has the highest delay at both morning and evening peak time with 87.1 second and 85.5 second respectively. Figure 4.11 shows the delay ratio which is the ratio of delay rate to actual travel rate for all the legs studied. Accordingly, though the delay rate amount is different for the morning and the evening peaks; and the delay ratio are also different from time to time. The delay ratio for two intersections of two selected approaches are from 0.58 to 0.83 was observed.

4.4.4 Total Segment delay

Total segment delay measured in Vehicle-min and or Person-hour is the measure of congestion intensity. It shows how the congestion is serious and indicates the extent of the congestion that how much people are being affected with the congestion. Figure 4.12 below shows the total segment delay in Vehicle-Min for the leg length considered. The total segment delay shown in this Figure is calculated for the selected approach based on their lengths which are not equal. Hence, the result should not be compared instead it should be read for a single leg only at once.

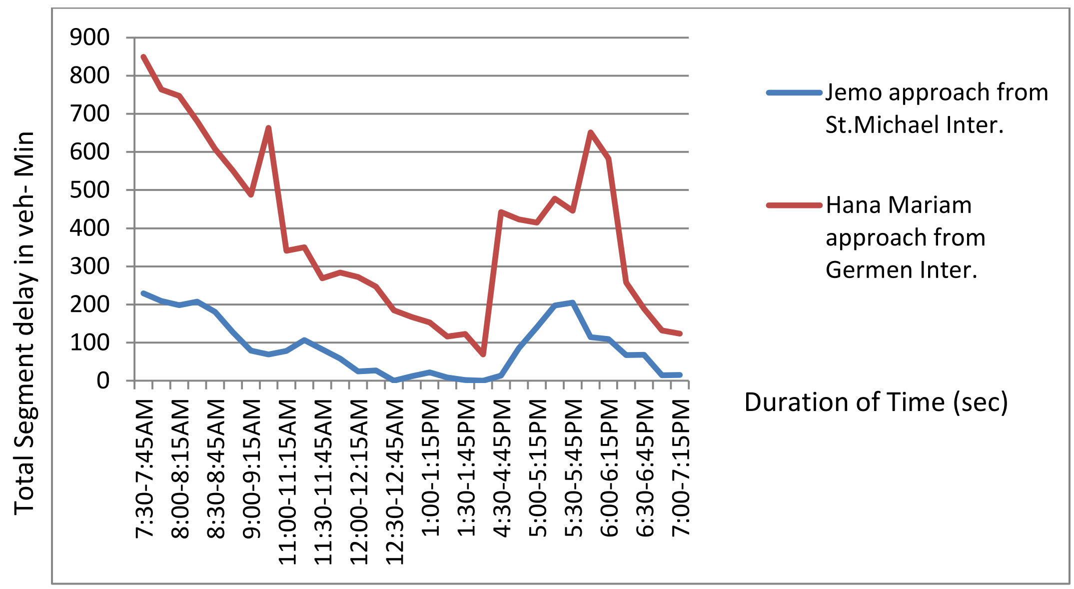


Figure: 4.12 Total Segment Delay for two Intersections (veh-min/meter)

Next, in order to compare the two approaches, the total delay was divided by the length of the segment and the delay was converted to a unit length delay. Accordingly, Figure 4.13 below shows that during the morning peak period, the congestion severity at Hana Maria approach is the highest and it is nearly three times that of the Jemo approach. The highest congestion severity at Hana Mariam approach starts early at 7:30 AM and goes on until the midday. Then, after late lunch time, the congestion again starts and reaches peak by 6:00 PM. In general, the comparison shows that the German intersection of Hana Mariam approach has the highest congestion severity than Jemo approach.

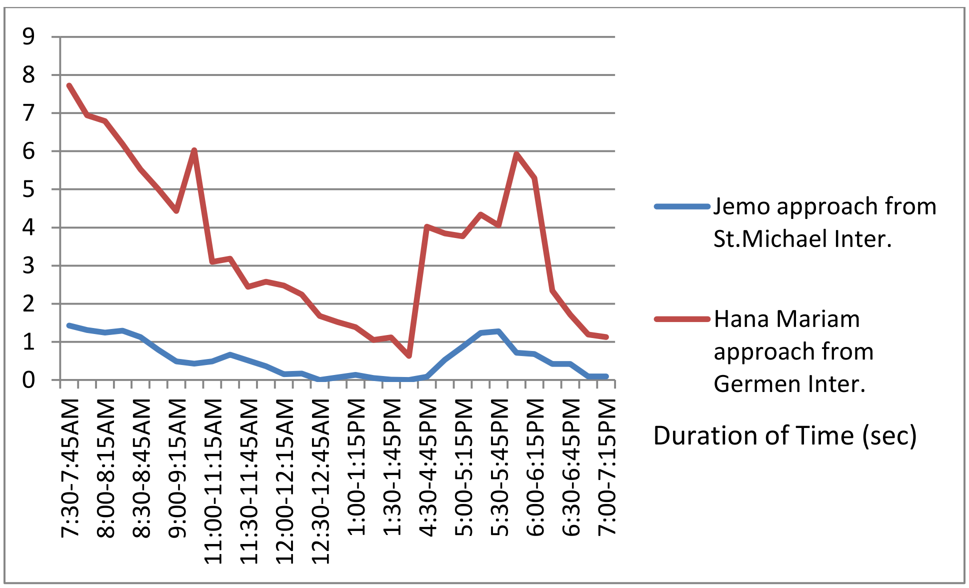


Figure: 4.13 Unit Length Delay

4.5 Causes of Congestion

Traffic congestion is one of the major problems facing the Addis Ababa City and it is attributed by a number of factors including rapid population increase, inadequate and poor road infrastructure, city structure, rapid increase in number of cars and lack of physical plan to control city development.

According to the results, based on the traffic volume count study analysis the cause of German intersection is due to higher number of road users during the morning and evening peak hours and the existence of large trucks. And the cause of Jemo Michael intersection is due to lower signal timing, absence of posted seconds count down and behavior of drivers which is being eager to pass the intersection will aggravate the increase of traffic congestions. Accordingly, the results showed that in the United States of America the cause and their percentage share are; bottleneck (40%), traffic incidents (25%), work zone (10%), bad weather (15%), poor signal timing (5%) and special events contribute 5% of the traffic congestion.

As Haregewoin, (2010) stated in his research, in order to identify causes of traffic congestion in Addis Ababa along Total-Ayer Tena road as; limited road capacity, road parking, un-integrated urban planning, and lack of mass transit, accident, poor vehicle condition, and road side illegal trade.

Therefore, the common feature of traffic congestion in developing countries shows that the root causes emanate from lack of proper planning, improper use of limited road network and bottleneck problem.

4.6 Traffic Congestion and Traffic Accidents

According to the data which was collected from NIFAS SILK LAFTO sub city Traffic Police Administration, Figure 4.14 shows that the distribution of traffic accidents in the sub city from 2004 E.C to 2008 E.C.

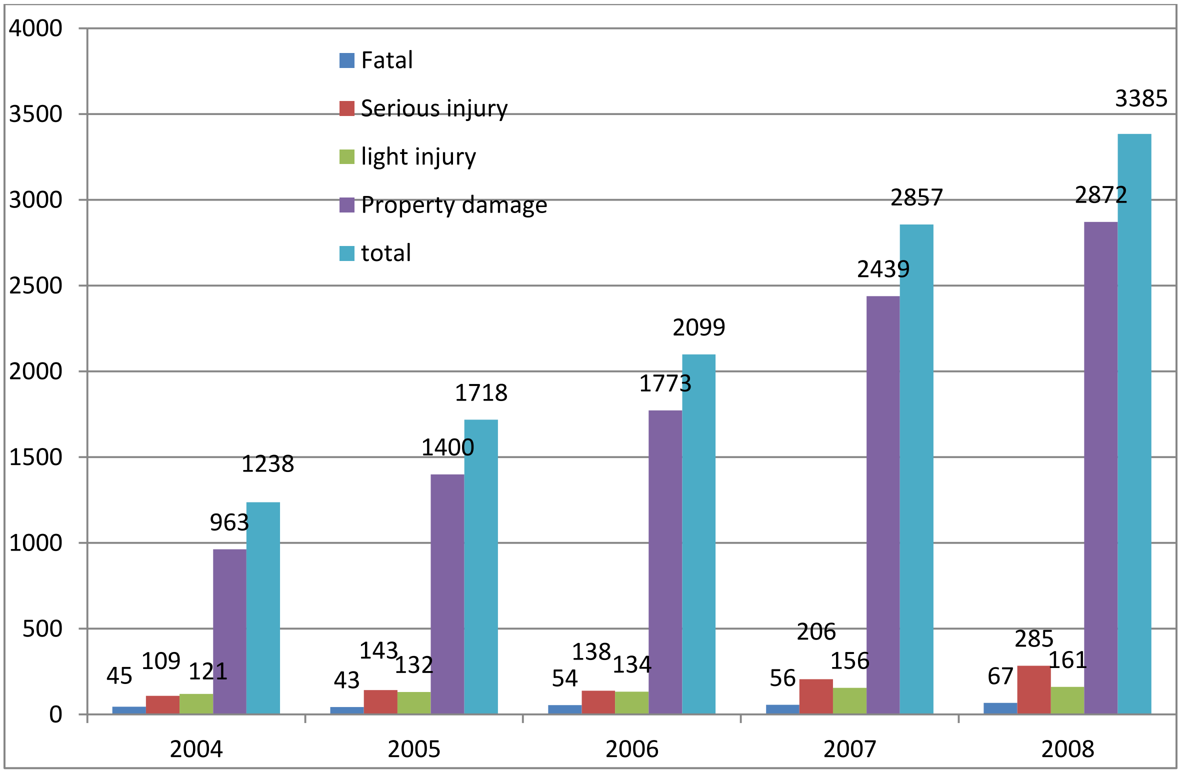


Figure: 4.14 Traffic Accident Data for Nifas Silk Lafto Sub city.

As shown below in Figure 4.15, the type of traffic accidents which occurred at two selected intersections is mostly vehicles to vehicles accident. Which is due to the occurrence of traffic congestion at selected intersection and the behavior of drivers are being eager to pass those intersections finally, traffic accident will happen. From the two intersections, the German intersection has larger number of traffic accidents than Jemo Michael intersection.

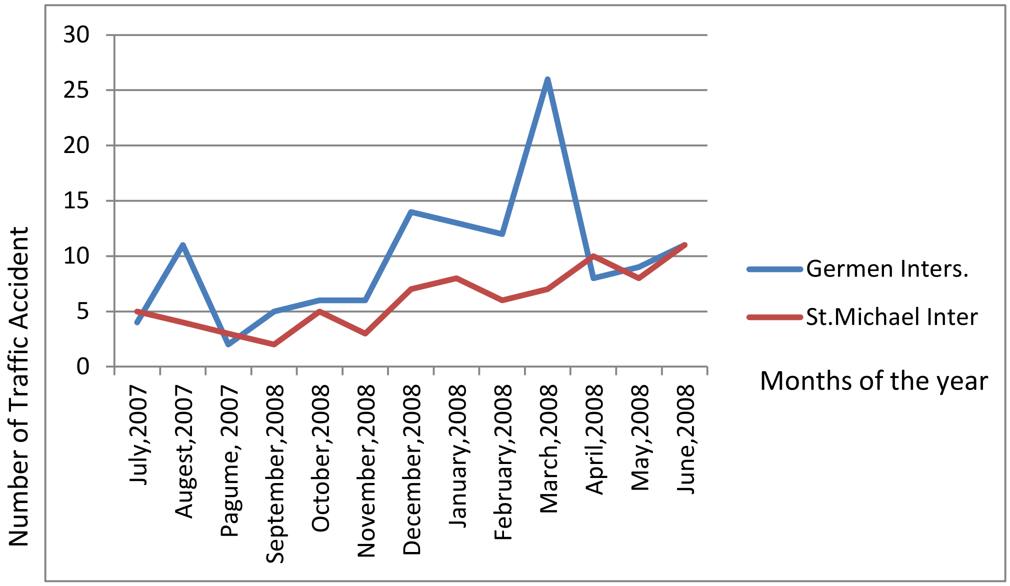


Figure 4.15 Traffic Accident Data for Selected Intersections.

4.7 Traffic Congestion Reduction Measures

The most serious cause of congestion at those selected intersection is the reduction in highway capacity, for the increase in traffic volume. To improve the capacity of the highway, there are two possible solutions: increase the capacity of the highway or decrease the traffic volume by shifting heavy vehicles to other roads.

As we can see from the vehicles composition of German intersection, the heavy trucks are moving they cover large distance than other vehicles. So, shifting those trucks to other road will reduce the traffic congestion. Secondly, the geometric design of Jemo Michael intersection is not wide enough to carry the current traffic volume. Therefore, the capacity of this intersection should be increased, like changing this signal intersection to well-constructed interchange.

4.8 Total Costs of Traffic Congestion

As shown in the previous chapter, the three main costs of traffic congestion are clearly stated as: travel time cost, fuel consumption cost and associated CO_2 emission cost due excess fuel consumptions. By this, the researcher assumes different values:-

The fuel consumption data under congested condition, it has to be collected using instrumental devices but, due to the nature of unavailability of those devices for this the research made some assumption were regarding the value of fuel consumption under congested state that it will increased by 50% of the value at steady state condition.

As we can see in the previous chapter, the travel time value at congested condition is higher than the uncongested one, which is almost double at off-peak time.

According to Errampalli, et al (2014), as the travel time increases, the travel speed fuel consumption of the vehicles are highly dependent on the vehicles operating speed and also the road geometry characteristics namely roughness, rise and fall etc.

The following assumptions are made by the researcher:-

- ✓ The peak time fuel consumption is higher than the off-peak time, by 50% incremental value because of higher in travel time and lower in average travel speed.
- ✓ The Value of travel time is equal for three different modes at peak time and off-peak time;
- ✓ The Annual working day is 250 days;
- ✓ The vehicles occupancy is the current Average number of peoples who can be seen in different modes of transportation of Addis Ababa city;
- ✓ The approaching distance for intersections is taken as 500m.

Table 4.4 below presents total travel time costs.

Table 4.4 Total Travel Time Cost

Travel Time Cost			
	Vehicles type		
Off-Peak time	Mini – Bus	Midi - Bus(Higer)	Large Bus (Anbesa)
Average Travel Time (min/km)	0.719	0.788	0.894
Vehicle Occupancy	13	50	150
Value of Travel Time (birr/min)	0.375	0.375	0.375
Average Daily km travel(Approach L)	0.5	0.5	0.5
Number of vehicles	300	70	20
Daily Fleet km Traveled	150	35	10
Annual Fleet km traveled (250)	37500	8750	2500
Total Annual Travel time cost(Birr)	26962.5	6895	2235
Total	36092.5		
Peak time			
Average Travel Time (min/km)	1.56	1.64	1.81
Vehicle Occupancy	12	60	200
Value of Travel Time (birr/min)	0.375	0.375	0.375
Average Daily km travel(Approach L)	0.5	0.5	0.5
Number of vehicles	200	90	30
Daily Fleet km Traveled	100	45	15
Annual Fleet km traveled (250)	25000	11250	3750
Total Annual Travel time cost(Birr)	39000	18450	6787.5
Total	64237.5		

Sources: Research results.

Table 4.5: Total Fuel Consumption Cost

Fuel Consumption cost			
Off peak time	Vehicles Type		
	Mini- Bus	Midi- Bus (Higer)	Large Bus (Anbesa)
Average Fuel economy(L/100km)	12.20	50.55	69.10
Average Fuel price(Birr/L)	15.75	16.60	16.60
Total Amount (Birr/km)	192.15	839.13	1147.06
Conversion Factor	100	100	100
Amount in Birr per km	1.92	8.39	11.47
Number of working days in year	250	250	250
Average Daily km travel (Approach L)	0.50	0.50	0.50
Number of vehicle (fuel type)	300	70	20
Daily Fleet km traveled	150	35	10
Annual vehicle km traveled(250)	37500	8750	2500
Total Annual Fuel consumption cost(Birr)	72,056.25	73,423.88	28,676.50
Total	174,156.63		
Peak time			
Average Fuel economy(L/100km)	18.30	75.83	103.65
Average Fuel price(Birr/L)	15.75	16.60	16.60
Total Amount (Birr/km)	288.22	1258.77	1720.59
Conversion Factor	100	100	100
Amount in Birr per km	2.88	12.58	17.20
Number of working days in year	250	250	250
Average Daily km travel (Approach L)	0.50	0.50	0.50
Number of vehicle (fuel type)	200	90	30
Daily Fleet km traveled	100	45	15
Annual vehicle km traveled(250)	25000	11250	3750
Total Annual Fuel consumption cost(birr)	72,056.25	141,612.52	64,522.12
Total	278,190.9		

Sources: Research results.

Table: - 4.6 CO_2 Emission, (g/km) for Different Modes.

CO2 Emission for different modes						
Off peak time						
Vehicle type	Average km traveled/day	Fuel type	Fuel efficiency (km/l)	Emission factor (g/km)	Total CO2 emission(g)	CO2 Emission (g/km)
Mini- Bus	0.5	Diesel	8.2	2680	163.41	326.82
Midi- Bus	0.5	Diesel	2	2680	670	1340
Large Bus	0.5	Diesel	1.45	2680	924.13	1848.27
Peak time						
Mini Bus	0.5	Diesel	5.4	2680	284.14	568.28
Midi-Bus	0.5	Diesel	1.32	2680	1015.15	2030.30
Large Bus	0.5	Diesel	1	2680	1340	2680

Table 4.7 Total CO_2 Emission Cost

CO2 Emission Cost			
	Vehicles Type		
Off-peak time	Min-i Bus	Midi- Bus	Large Bus
Average CO2 carbon credit per ton USD	1	1	1
Exchange rate (1USD$to Birr)	22.71	22.71	22.71
Average CO2 emission g CO2/km	326.82	1340	1848.27
Total Vehicle	200	70	20
Average Daily km Traveled (Approach L)	0.5	0.5	0.5
Daily Fleet km traveled	100	35	10
Annual Fleet working day km traveled(250)	25000	8750	2500
Average Annual g CO2 Emitted	8170500	11725000	4620689.65
Conversion factor (1/1000,000)	8.17	11.72	4.62
Annual CO2 emission cost(Birr)	185.55	266.27	104.93
Total cost	556.76		
Peak time			
Average CO2 carbon credit per ton USD	1	1	1
Exchange rate (1USD$to Birr)	22.71	22.71	22.71
Average CO2 emission g CO2/km	496.29	2030.30	2680
Total Vehicle	300	90	30
Average Daily km Traveled (Approach L)	0.5	0.5	0.5
Daily Fleet km traveled	150	45	15
Annual Fleet working day km traveled(250)	37500	11250	3750
Average Annual g CO2 Emitted	18610875	22840909.09	10050000
Conversion factor (1/1000,000)	18.61	22.84	10.05
Annual CO2 emission cost(Birr)	422.65	518.71	228.23
Total Cost	1169.60		

Table: - 4.8 Total Cost Congestion.

Off-peak time					
Vehicles Type	Travel Time Cost (Birr)	Fuel Consumption Cost (Birr)	Co2 Emission Cost (Birr)	Total Cost of Congestion (Birr)	Loss due to Congestion (Birr)
Mini- Bus	26962.5	72056.25	185.55	99204.3	
Midi- Bus	6895	73423.87	266.27	80585.14	
Large Bus	2235	28676.5	104.93	31016.43	
Total	36092.5	174156.62	556.75	**210805.87**	
Peak time					
Vehicles Type					
Mini- Bus	39000	72,056.25	422.65	111478.9	
Midi- Bus	18450	141,612.52	518.71	92392.59	
Large Bus	6787.5	64,522.12	228.23	35692.23	
Total	64237.5	278190.9	1169.59	**343597.99**	**132792.12**

As shown in the above tables, the researcher trying to estimate the total cost of congestion at peak time and off peak time. Among three variables cost the annual fuel consumption cost for a specific approaching distance is higher than two other variable cost. And also the total cost of congestion at peak time is more than 1.6 times higher than the off peak total cost of congestion. The main reason to this is due to the occurrence of travel time delay and the incremental of fuel consumptions.

CHAPTER - FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on the findings of the analysis in this study, the following points are concluded.

- ✓ According to the Total traffic volume distribution, the two intersections have the morning and evening peak period with congested nature. And also the off peak time is on the midday time which relatively uncongested.
- ✓ The Level of Service data has shown that the intersections are performing above their capacity, specifically, the German intersection with the LOS F almost for all approaches.
- ✓ The two intersections at selected approach, the average and total segment delays have the morning and evening peak periods. The delay ratio for two intersections of two selected approaches of Hana Mariam and Jemo Approach are from 0.58 to 0.83 as observed respectively.
- ✓ Regarding the average traffic congestion intensity in those selected intersections expressed in terms of Veh.-min. the result shows that on average the maximum delay of 826 veh – min and 616 Veh- min was lost during the morning and the evening peak period respectively.
- ✓ Assuming, travel time cost, fuel consumption cost and CO_2 emission cost, and in average the total cost of congestion for specific approaching distance is Birr 210,805.87 per year during off peak time and Birr 343,597.99 per year during peak time. And the total loss due to congestion will be Birr 132792.12 per year on single selected approach.
- ✓ Based on the observation, the main cause for the occurrence of traffic congestion at those selected area is due to the performance of over capacity. The LOS analysis shows almost all approaches at the intersections are serving above their capacities.
- ✓ As we see from the Total cost of congestion analysis, during peak times total travel time, fuel consumption and CO_2 emission all increased.

- ✓ It can be observed that as the traffic flow increases, travel time cost increases as the coefficient in the equation is always positive for all vehicles. Further, it was found evident that the increase in traffic flow largely affects the private vehicles and buses.
- ✓ It was observed that, traffic accidents are mostly observed at the over -congested areas of German roundabout. Therefore, we can conclude that traffic congestion will increase traffic accidents.

5.2 Recommendation

The following recommendation forwarded for possible use by pertinent policy makers:

- ✓ In this study the traffic volume count was done for one day, due to time and budget limitations. Therefore, it is recommended to count at least for seven days. Similarly, during collecting travel speed and travel time, automatic data collection method is better to minimize error.
- ✓ The three variables for estimating total congestion costs were travel time cost, fuel consumption cost and CO_2 emission cost. However, it was found very difficult to estimate those costs at peak periods and so assumptions were for some values. Therefore, for better results, it is recommended to add other variables other than this and estimate their costs using technology devices.
- ✓ In order to estimate the travel time cost it is recommended to take best data collection by using either revealed-preferences or stated- preferences data.
- ✓ The analysis results, is show that the intersections are serving above their capacity. Therefore, the city administration should consider this issue and formulate capacity improvement methods. And also, removing or shifting those heavy trucks to other directions will decrease traffic congestion.
- ✓ According to the analysis, the cost of congestion for midi-bus and large bus is higher than mini bus, due to the ages and poor fuel efficiency of the vehicles. So, it is to recommend that the policy maker should give the required a serious attention by vehicles type plus fuel efficiency, In order to minimize traffic congestion costs.

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APPENDIXES

Appendix –A: Traffic Volume and PCU Analysis

Table 1: Traffic Volume at German Intersection.

German Intersection				Traffic Volume Count			13/12/2016					
	Mekanisa Approach			Gofa Approach			Hana Mariam Approach			Jemo Michael Approach		
Time	R	TH	L	R	TH	L	R	TH	L	R	TH	L
7:30-7:45AM	155	152	62	61	83	49	63	221	211	93	43	132
7:45-8:00AM	153	146	60	56	74	51	61	214	201	86	39	122
8:00-8:15AM	147	140	58	48	62	43	56	209	200	76	36	106
8:15-8:30AM	143	136	56	44	51	42	58	199	194	71	32	99
8:30-8:45AM	135	129	53	49	55	45	61	204	198	71	32	99
8:45-9:00AM	135	130	54	39	54	43	48	158	165	104	48	148
9:00-9:15AM	133	126	53	34	61	46	43	154	150	92	44	135
9:15-9:30AM	135	100	42	32	54	49	59	210	198	86	38	124
11:00-11:15AM	114	109	46	47	45	70	41	139	131	78	34	111
11:15-11:30AM	122	117	49	39	40	70	41	144	140	81	37	115
11:30-11:45AM	120	114	48	33	38	70	37	135	127	76	32	105
11:45-12:00AM	108	103	43	44	35	62	40	144	139	83	42	114
12:00-12:15AM	104	99	42	35	30	51	40	142	137	76	37	107
12:15-12:30AM	100	95	40	16	41	49	40	140	136	71	30	100
12:30-12:45AM	95	91	39	26	39	43	35	132	120	64	31	90
12:45-1:00AM	91	87	37	38	40	35	33	124	114	63	33	86
1:00-1:15PM	79	75	31	33	33	29	35	125	115	68	35	89
1:15-1:30PM	77	66	30	32	30	21	36	122	118	60	36	86
1:30-1:45PM	66	60	24	31	25	21	39	121	113	58	30	83
1:45-2:00PM	63	57	22	29	22	17	35	117	28	55	28	79
4:30-4:45PM	131	125	52	36	74	60	49	173	166	84	39	119
4:45-5:00PM	125	120	50	35	81	67	44	162	154	76	35	110
5:00-5:15PM	175	167	68	39	102	84	43	149	144	92	51	124
5:15-5:30PM	158	151	62	42	116	94	51	161	156	126	57	179
5:30-5:45PM	164	157	64	44	104	89	43	153	148	126	57	176
5:45-6:00PM	137	130	54	47	105	87	49	172	164	92	43	130
6:00 - 6:15PM	151	144	59	35	91	75	56	182	176	84	38	116
6:15-6:30PM	145	138	57	28	76	61	37	132	125	87	44	115
6:30-6:45PM	130	117	52	20	64	50	42	133	128	84	39	114
6:45-7:00PM	140	130	50	18	54	43	45	145	140	77	32	113
7:00-7:15PM	135	127	47	17	48	42	40	127	126	75	32	108
7:15-7:30PM	130	125	45	13	43	37	31	122	120	67	29	99

Table 2:- Traffic volume at Jemo Michael intersection.

Jemo Michael Intersection				Traffic Volume Count						20/12/2016		
	Ayer Tena Approach			Lideta Approach			Jemo Approach			German Approach		
Time	R	TH	L	R	TH	L	R	TH	L	R	TH	L
7:30-7:45AM	23	175	79	20	110	52	86	205	31	59	81	125
7:45-8:00AM	21	172	75	16	100	51	81	200	29	55	81	113
8:00-8:15AM	19	172	74	14	95	49	80	200	26	53	77	108
8:15-8:30AM	22	121	40	23	90	76	105	210	34	47	72	105
8:30-8:45AM	20	137	32	33	103	102	92	205	24	44	57	101
8:45-9:00AM	23	113	19	15	97	75	61	152	24	44	69	100
9:00-9:15AM	17	124	27	20	101	78	64	157	29	44	80	103
9:15-9:30AM	22	120	21	20	93	75	62	152	25	43	72	102
11:00-11:15AM	11	105	44	11	76	82	71	161	21	31	71	81
11:15-11:30AM	21	112	18	12	93	70	61	169	15	37	76	79
11:30-11:45AM	9	59	18	15	90	77	71	171	33	35	70	77
11:45-12:00AM	21	73	16	12	85	94	64	122	18	35	70	76
12:00-12:15AM	13	87	12	11	80	96	48	116	36	19	64	70
12:15-12:30AM	17	62	17	6	75	71	41	103	38	17	68	68
12:30-12:45AM	14	59	11	9	70	70	39	130	21	25	88	67
12:45-1:00AM	13	63	14	9	68	57	36	94	20	15	55	63
1:00-1:15PM	16	68	22	12	65	71	53	92	32	20	51	58
1:15-1:30PM	13	39	11	6	60	43	48	90	19	33	56	78
1:30-1:45PM	14	39	12	6	58	43	48	90	19	23	47	68
1:45-2:00PM	13	37	14	6	55	39	46	79	18	45	55	97
4:30-4:45PM	23	95	36	8	150	46	60	89	20	53	65	105
4:45-5:00PM	15	86	26	24	159	48	64	144	43	58	91	105
5:00-5:15PM	8	65	18	17	166	37	69	179	38	66	94	123
5:15-5:30PM	11	69	24	10	166	47	78	193	41	59	84	108
5:30-5:45PM	11	54	18	10	142	38	86	200	41	45	76	94
5:45-6:00PM	24	63	32	12	200	69	95	212	51	39	69	87
6:00 - 6:15PM	28	62	31	14	162	65	79	186	47	36	69	84
6:15-6:30PM	22	61	26	13	144	55	65	158	36	26	59	75
6:30-6:45PM	19	59	23	8	128	46	60	139	28	24	56	70
6:45-7:00PM	19	57	25	8	114	42	53	116	24	18	50	69
7:00-7:15PM	15	55	17	8	103	41	49	109	23	16	50	62
7:15-7:30PM	12	50	19	5	95	37	47	93	19	17	43	59

Table: 3 PCU Factor Analyses.

PCU Factor ,Headway (Sec)									
	Bajaj	Car & Taxi	Mini bus Taxi	4WD	Mini/Medium bus	Std. Bus	Small Trucks	Medium Trucks	Large Trucks
1	2.3	3.8	4.6	3.8	4.5	6.4	4.6	4.4	6.3
2	3.1	3.3	4.7	3.7	4.4	5.6	4.2	4.7	5.9
3	3	3.7	5.1	4.2	4.3	7.9	3.5	5.7	5.9
4	2.9	3.2	5	4	4.8	5	5.5	5.6	5.8
5	3	4.1	4.5	4.1	4.9	5.6		4.4	5.5
6	3.2	4	4.6	3.9	4.2	8		5.6	6.1
7	3.1	3.9	5.2	3.8	3.7	6		4.4	5.9
8	3.1	3.4	4.8	4	4.5	7.2		6.8	7
Average h,	2.96	3.67	4.81	3.93	4.41	6.46	4.45	5.2	6.05
PCU=hi/hcar	0.81	1	1.30	1.07	1.20	1.75	1.21	1.41	1.64
1	3.3	3.4	3.8	3.6	4.2	6.8	5	5.4	6.5
2	2.1	3.7	3.6	3.5	4.1	6.6	4.2	5.7	6.9
3	3.2	3.5	3.7	4	4.9	7.9	3.5	5.7	7.1
4	2.7	3.2	3.8	3.8	5.2	7.5	4.5	5.6	7
5	3.1	3	4.1	3.6	4	7	4.1	6.2	6.5
6	3	4	4.2	3.9	4.2	8		5.6	6.1
7	3.3	3.1	4.1	3.8	4.6	7.9		6	6.2
8	3.1	3	3.9	3.1	4.5	7.2		6.8	7
Average h,	2.97	3.36	3.9	3.66	4.46	7.36	4.26	5.87	6.66
PCU=hi/hcar	0.88	1	1.15	1.08	1.32	2.18	1.26	1.74	1.98
1	3.5	3.5	3.6	3.6	4.6	7	4.5	5.5	7.5
2	3.1	3.7	3.6	3.5	4.4	7.2	4.2	5.9	6.5
3	3.2	2.9	3.2	3.9	4.9	7.9	3.5	5.7	7.1
4	2.9	3.2	3.1	3.8	5.2	7.5	4.7	6	7.5
5	3.1	3	4.1	3.6	3.9	7	4.1	6.2	6.5
6	3.5	3.2	3	3.5	4.2	7.5		5.6	6.3
7	3.3	3.1	3	3.8	4.6	7.9		6.1	6.2
8	3.1	3	3.1	3.1	4.5	7.2		6.8	7
Average h,	3.21	3.2	3.33	3.6	4.53	7.4	4.22	5.97	6.82
PCU=hi/hcar	1.00	1	1.04	1.12	1.41	2.31	1.32	1.86	2.13
Average PCU	0.89	1	1.17	1.09	1.31	2.08	1.26	1.67	1.92
	0.89	1	1.17	1.09	1.3	2.08	1.26	1.67	1.92
	1	1	1.25	1	1.5	2	1.25	2	2.25

Appendix- B: Congestion Measure Analysis.

Table: - 4 Congestion Measure Analysis for German Intersection.

Intersection:	German								
Approach:	Hana Mariam								
Length:	110m								
Duration	Average Travel Time(Sec)	Delay (Sec)	Average Travel Speed (Km/h)	Travel Rate (min/Km)	Delay Rate (min/Km)	Travel Time Index	Traffic Volume (Veh)	Total Segment Delay (Veh-Min)	Delay Ratio
7:30-7:45AM	107.1	87.1	3.69	16.22	13.22	5.40	585	849.2	0.81
7:45-8:00AM	101.37	81.3	3.90	15.35	12.36	5.11	563	763.6	0.80
8:00-8:15AM	101.22	81.2	3.91	15.33	12.337	5.11	552	747.3	0.80
8:15-8:30AM	96.77	76.7	4.09	14.66	11.66	4.88	532	680.7	0.79
8:30-8:45AM	85.77	65.7	4.61	12.99	9.99	4.33	554	607.3	0.76
8:45-9:00AM	95.05	75.0	4.16	14.40	11.40	4.80	440	550.4	0.79
9:00-9:15AM	91.4	71.4	4.33	13.84	10.84	4.61	410	487.9	0.78
9:15-9:30AM	92.22	72.2	4.29	13.97	10.97	4.65	551	663.3	0.78
11:00-11:15AM	75.5	55.5	5.24	11.43	8.43	3.81	369	341.3	0.73
11:15-11:30AM	74.6	54.6	5.30	11.30	8.30	3.76	385	350.4	0.73
11:30-11:45AM	65.67	45.6	6.02	9.95	6.95	3.31	353	268.7	0.69
11:45-12:00AM	64.52	44.5	6.13	9.77	6.77	3.25	382	283.5	0.69
12:00-12:15AM	63.25	43.2	6.26	9.58	6.58	3.19	378	272.5	0.68
12:15-12:30AM	59.5	39.5	6.65	9.01	6.01	3.00	375	246.9	0.66
12:30-12:45AM	53.77	33.7	7.36	8.14	5.14	2.71	328	184.6	0.63
12:45-1:00AM	52.67	32.6	7.51	7.98	4.98	2.66	307	167.2	0.62
1:00-1:15PM	49.37	29.3	8.02	7.48	4.48	2.49	312	152.8	0.59
1:15-1:30PM	41.82	21.8	9.46	6.33	3.33	2.11	319	116	0.52
1:30-1:45PM	43.25	23.2	9.15	6.55	3.55	2.18	317	122.8	0.54
1:45-2:00PM	39.2	19.2	10.10	5.93	2.93	1.97	216	69.12	0.49
4:30-4:45PM	77.67	57.6	5.09	11.76	8.76	3.92	460	442.2	0.74
4:45-5:00PM	79.4	59.4	4.98	12.03	9.03	4.01	427	422.7	0.75
5:00-5:15PM	82.47	62.4	4.80	12.49	9.49	4.16	398	414.4	0.75
5:15-5:30PM	83.92	63.9	4.71	12.71	9.71	4.23	448	477.3	0.76
5:30-5:45PM	85.1	65.1	4.65	12.89	9.89	4.29	411	445.9	0.76
5:45-6:00PM	105.52	85.5	3.75	15.98	12.98	5.32	457	651.4	0.81
6:00-6:15PM	89.65	69.6	4.41	13.58	10.58	4.52	502	582.7	0.77
6:15-6:30PM	64.65	44.6	6.12	9.79	6.795	3.26	347	258.2	0.69
6:30-6:45PM	51.45	31.4	7.69	7.79	4.79	2.59	360	188.7	0.61

6:45-7:00PM	39.57	19.5	10.00	5.99	2.99	1.99	404	131.8	0.49
7:00-7:15PM	41.35	21.3	9.57	6.26	3.26	2.08	348	123.8	0.52
7:15-7:30PM	40.92	20.9	9.67	6.20	3.20	2.06	319	111.3	0.51

Table: - 5 Congestion Measure Analysis for Jemo Michael Intersection.

Intersection:	Jemo Michael								
Approach:	Jemo								
Length:	160m								
Duration	Average Travel Time(Sec)	Delay (Sec)	Average Travel Speed (Km/h)	Travel Rate (min/Km)	Delay Rate (min/Km)	Travel Time Index	Traffic Volume (Veh)	Total Segment Delay (Veh-Min)	Delay Ratio
7:30-7:45AM	67.08	38.08	8.58	6.98	3.98	2.32	361	229.11	0.57
7:45-8:00AM	65.13	36.13	8.84	6.78	3.78	2.26	348	209.55	0.55
8:00-8:15AM	63.55	34.55	9.06	6.61	3.6	2.20	345	198.66	0.54
8:15-8:30AM	60.8	31.8	9.47	6.33	3.33	2.111	392	207.76	0.52
8:30-8:45AM	59.08	30.08	9.75	6.15	3.15	2.05	361	180.98	0.51
8:45-9:00AM	57.63	28.63	9.99	6.00	3.00	2.001	266	126.93	0.50
9:00-9:15AM	45.68	16.68	12.61	4.75	1.75	1.58	284	78.95	0.36
9:15-9:30AM	44.35	15.35	12.99	4.61	1.61	1.53	271	69.33	0.35
11:00-11:15AM	45.4	16.4	12.69	4.72	1.72	1.57	286	78.17	0.36
11:15-11:30AM	52.35	23.35	11	5.45	2.45	1.81	274	106.63	0.44
11:30-11:45AM	45.2	16.2	12.74	4.70	1.70	1.56	306	82.62	0.36
11:45-12:00AM	39.53	10.53	14.57	4.11	1.11	1.37	330	57.91	0.27
12:00-12:15AM	35.55	6.55	16.2	3.70	0.70	1.23	227	24.78	0.18
12:15-12:30AM	37.03	8.02	15.56	3.85	0.85	1.28	203	27.16	0.22
12:30-12:45AM	29.15	0.15	19.76	3.03	0.036	1.01	212	0.53	0.01
12:45-1:00AM	33.25	4.25	17.32	3.46	0.46	1.15	168	11.9	0.13
1:00-1:15PM	35.75	6.75	16.11	3.724	0.72	1.24	200	22.5	0.19
1:15-1:30PM	31.92	2.92	18.04	3.32	0.32	1.11	178	8.67	0.09
1:30-1:45PM	29.67	0.67	19.41	3.091	0.09	1.03	178	2.00	0.02
1:45-2:00PM	28.65	0	20.1	2.984	0	0.99	160	0	0
4:30-4:45PM	33.3	4.3	17.3	3.46	0.46	1.15	191	13.68	0.13
4:45-5:00PM	47.07	18.08	12.24	4.90	1.90	1.63	284	85.55	0.38
5:00-5:15PM	55.22	26.23	10.43	5.75	2.75	1.91	321	140.3	0.47
5:15-5:30PM	62.65	33.65	9.19	6.52	3.52	2.17	352	197.41	0.54
5:30-5:45PM	62.32	33.33	9.24	6.49	3.49	2.16	369	204.95	0.53
5:45-6:00PM	45.67	16.68	12.61	4.75	1.75	1.58	411	114.22	0.36
6:00-6:15PM	47.82	18.83	12.04	4.98	1.98	1.6	348	109.19	0.39

6:15-6:30PM	43.07	14.08	13.37	4.48	1.48	1.49	289	67.79	0.33
6:30-6:45PM	45.42	16.43	12.68	4.73	1.73	1.57	248	67.89	0.36
6:45-7:00PM	33.15	4.15	17.38	3.45	0.45	1.15	214	14.80	0.13
7:00-7:15PM	33.65	4.65	17.12	3.50	0.50	1.16	197	15.26	0.14
7:15-7:30PM	31.15	2.15	18.49	3.24	0.24	1.08	172	6.163	0.075

Appendix - C: Level of Service Analysis Input and Output of SIDRA Intersection

Table: 6 In Put data for LOS Analysis at German Intersection.

Intersection Parameters	
Title	Germen Intersection
Intersection ID	Germen
Unit Time (for volumes)	60 minutes
Peak Flow Period (for performance)	15 minutes

Geometry - Approach Data

Location	Name	Type	No. of App. Lanes	No. of Exit Lanes	Median Width m	Extra Bunching %
South	Hana Mariam	Two-way	3	3	3.00	0.0
East	Gofa	Two-way	3	3	1.00	0.0
North	Mekanisa	Two-way	3	3	1.00	0.0
West	St.Michael	Two-way	3	3	3.00	0.0

Geometry - Roundabout Data

Location	Name	Island Diameter m	Circ. Width m	Circ. Lanes	Entry Radius m	Entry Angle degrees	Env. Factor	Entry/Circ. Flow Adjust.
South	Hana Mariam	60.00	10.00	3	20.0	30.0	1.2000	Medium
East	Gofa	60.00	10.00	3	20.0	30.0	1.2000	Medium
North	Mekanisa	60.00	10.00	3	20.0	30.0	1.2000	Medium
West	St.Michael	60.00	10.00	3	20.0	30.0	1.2000	Medium

Geometry - Approach Lane Data

Lane Number	Lane Type	Lane Discip.	Basic Satn Flow tcu/h	Utilisation Ratio %	Saturation Speed km/h	Capacity Adjustment %
South Hana Mariam						
App. Lane 1	Slip (Giveway/Yield)	LT	1900	–	–	0.0
App. Lane 2	Normal	T	1900	–	–	0.0
App. Lane 3	Slip (Giveway/Yield)	TR	1900	–	–	0.0
East Gofa						
App. Lane 1	Slip (Giveway/Yield)	LT	1900	–	–	0.0
App. Lane 2	Normal	T	1900	–	–	0.0
App. Lane 3	Slip (Giveway/Yield)	R	1900	–	–	0.0
North Mekanisa						
App. Lane 1	Slip (Giveway/Yield)	LT	1900	–	–	0.0
App. Lane 2	Normal	T	1900	–	–	0.0
App. Lane 3	Normal	TR	1900	–	–	0.0
West St.Michael						
App. Lane 1	Slip (Giveway/Yield)	LT	1900	–	–	0.0
App. Lane 2	Normal	T	1900	–	–	0.0
App. Lane 3	Slip (Giveway/Yield)	TR	1900	–	–	0.0

Geometry - Approach & Exit Lane Data

Lane Number	Lane Width m	Lane Length m	Grade %	SL Type
South Hana Mariam				
App. Lane 1	3.50	300.0	0.00	–
App. Lane 2	3.50	300.0	0.00	–
App. Lane 3	3.50	300.0	0.00	–
Exit Lane 1	3.50	300.0	0.00	–
Exit Lane 2	3.50	300.0	0.00	–
Exit Lane 3	3.50	300.0	0.00	–
East Gofa				
App. Lane 1	3.00	300.0	0.00	–
App. Lane 2	3.00	300.0	0.00	–
App. Lane 3	3.00	300.0	0.00	–
Exit Lane 1	3.00	300.0	0.00	–
Exit Lane 2	3.00	300.0	0.00	–
Exit Lane 3	3.00	300.0	0.00	–
North Mekanisa				
App. Lane 1	3.50	300.0	0.00	–
App. Lane 2	3.50	300.0	0.00	–
App. Lane 3	3.50	300.0	0.00	–
Exit Lane 1	3.50	300.0	0.00	–
Exit Lane 2	3.50	300.0	0.00	–
Exit Lane 3	3.50	300.0	0.00	–
West St.Michael				
App. Lane 1	3.50	300.0	0.00	–
App. Lane 2	3.50	300.0	0.00	–
App. Lane 3	3.50	300.0	0.00	–
Exit Lane 1	3.50	300.0	0.00	–
Exit Lane 2	3.50	300.0	0.00	–
Exit Lane 3	3.50	300.0	0.00	–

Lanes are numbered from left to right in the direction of travel.

Volumes							
To Approach		Total veh	HV %	Peak Flow Factor %	Vehicle Occupancy pers/veh	Flow Scale %	Growth Rate %/year
From: South	Hana Mariam						
West		845.0	13.61	93.9	1.20	100.00	2.00
North		865.0	13.31	97.8	1.20	100.00	2.00
East		281.0	13.28	95.3	1.20	100.00	2.00
From: East	Gofa						
South		200.0	2.10	35.0	1.20	100.00	2.00
West		250.0	1.20	30.0	1.20	100.00	2.00
North		100.0	1.50	30.0	1.20	100.00	2.00
From: North	Mekanisa						
East		304.0	16.78	96.2	1.20	100.00	2.00
South		699.0	12.86	96.2	1.20	100.00	2.00
West		725.0	10.98	98.4	1.20	100.00	2.00
From: West	St.Michael						
North		822.0	14.00	98.0	1.20	100.00	2.00
East		412.0	14.00	96.0	1.20	100.00	2.00
South		622.0	15.60	98.0	1.20	100.00	2.00

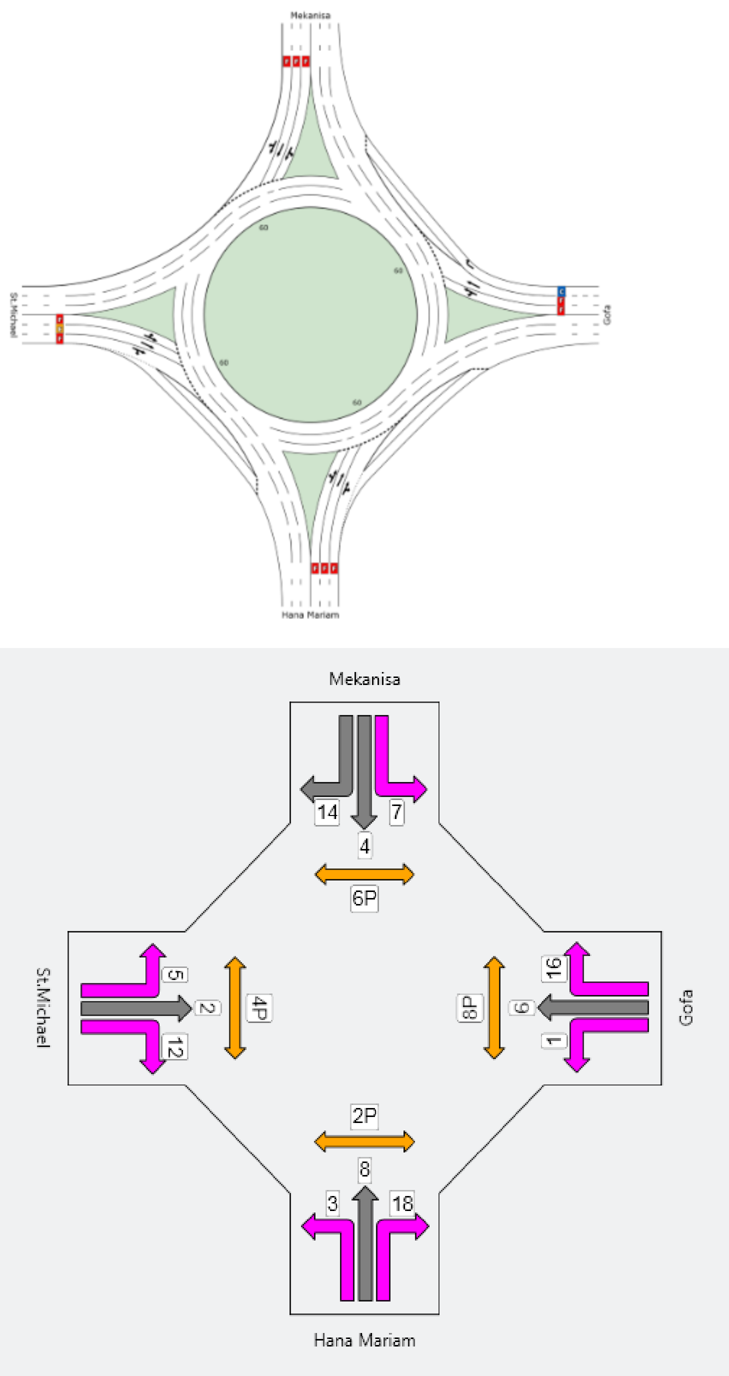

Figure: - 1 Layout and Intersection Movement ID for German Intersection.

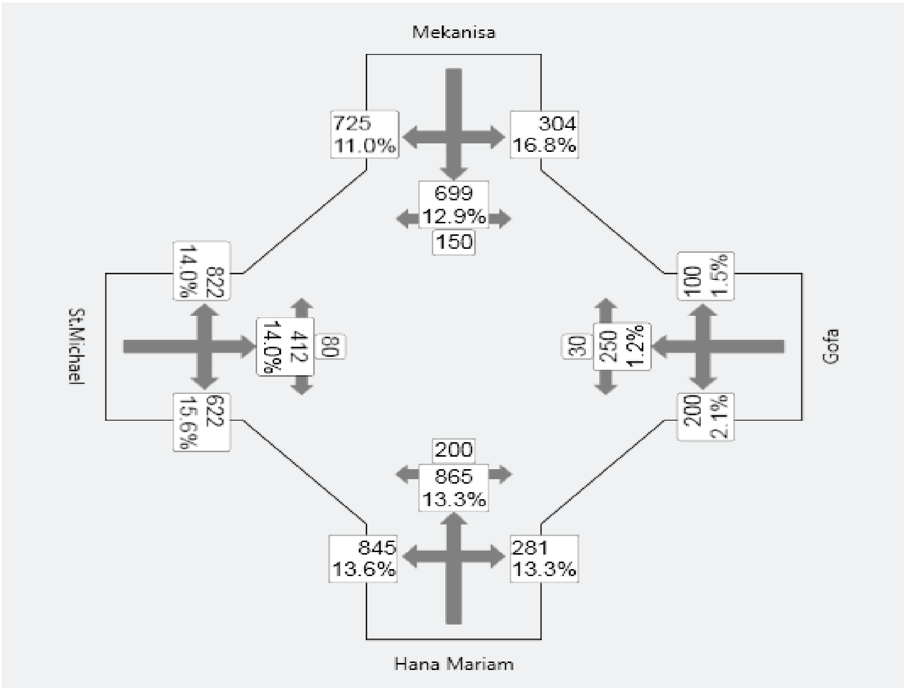

Figure: - 2 Traffic Volume Distribution and Truck Percentage on the German Intersection

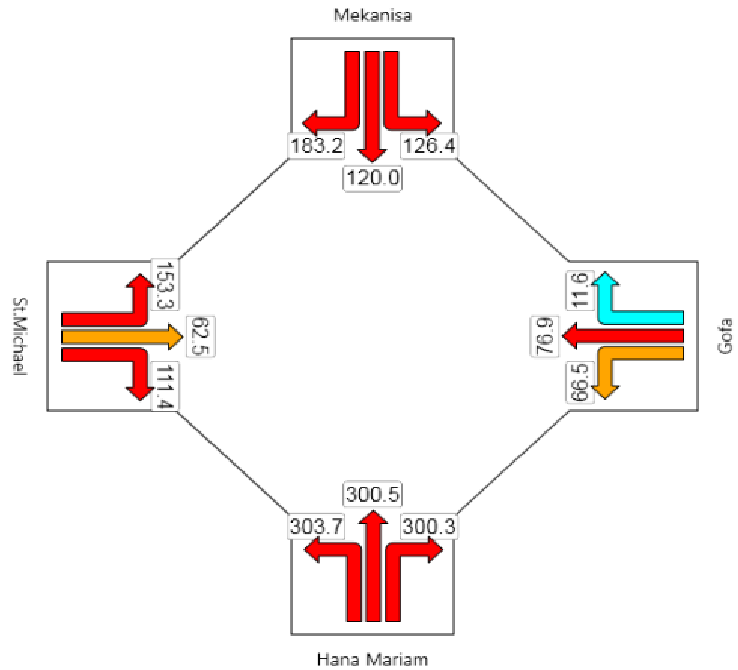

Figure: - 3 Delay in second for all movement ID

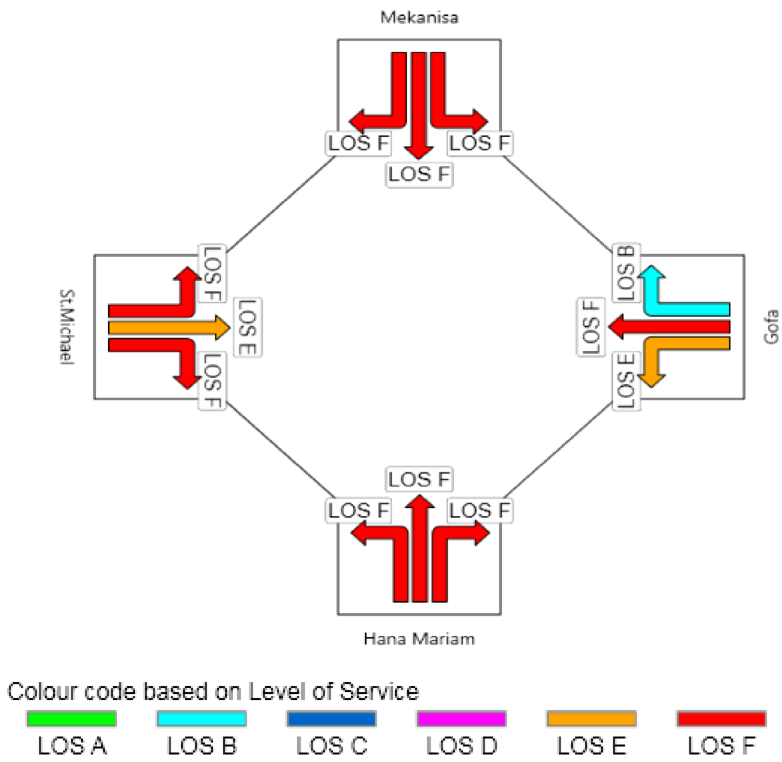

Figure: - 4 LOS values for German Intersection

Table: 7 in Put Data for LOS Analysis at Jemo Michael Intersection

Intersection Parameters	
Title	St.Michael Intersection
Intersection ID	St.Michael
Unit Time (for volumes)	60 minutes
Peak Flow Period (for performance)	15 minutes
Signal Analysis Method	Fixed Time

Geometry - Approach Data						
Location	Name	Type	No. of App. Lanes	No. of Exit Lanes	Median Width m	Extra Bunching %
South	Germen	Two-way	3	3	3.00	0.0
East	Lideta	Two-way	3	3	1.00	0.0
North	Ayer Tena	Two-way	3	3	3.00	0.0
West	Jemo	Two-way	3	2	14.00	0.0

Geometry - Approach Lane Data - Signalised

Lane Number	Lane Type	Lane Discip.	Basic Satn Flow tcu/h	Utilisation Ratio %	Saturation Speed km/h	Capacity Adjustment %	Buses Stopping veh/h	Parking Man. veh/h	SL Green Constraint	Free Queue L veh	Free Queue T veh	Free Queue R veh
South Germen												
App. Lane 1	Normal	LT	1900	-	-	0.0	-	-	No	0	0	0
App. Lane 2	Normal	T	1900	-	-	0.0	-	-	No	0	0	0
App. Lane 3	Normal	R	1900	-	-	0.0	-	-	No	0	0	0
East Lideta												
App. Lane 1	Normal	LT	1900	-	-	0.0	-	-	No	0	0	0
App. Lane 2	Normal	T	1900	-	-	0.0	-	-	No	0	0	0
App. Lane 3	Normal	R	1900	-	-	0.0	-	-	No	0	0	0
North Ayer Tena												
App. Lane 1	Normal	LT	1900	-	-	0.0	-	-	No	0	0	0
App. Lane 2	Normal	T	1900	-	-	0.0	-	-	No	0	0	0
App. Lane 3	Normal	R	1900	-	-	0.0	-	-	No	0	0	0
West Jemo												
App. Lane 1	Normal	LT	1900	-	-	0.0	-	-	No	0	0	0
App. Lane 2	Normal	T	1900	-	-	0.0	-	-	No	0	0	0
App. Lane 3	Normal	R	1900	-	-	0.0	-	-	No	0	0	0

Geometry - Approach & Exit Lane Data

Lane Number		Lane Width m	Lane Length m	Grade %	SL Type
South	Germen				
App. Lane 1		3.50	300.0	0.50	–
App. Lane 2		3.50	300.0	0.50	–
App. Lane 3		3.50	300.0	0.50	–
Exit Lane 1		3.50	300.0	0.50	–
Exit Lane 2		3.50	300.0	0.50	–
Exit Lane 3		3.50	300.0	0.50	–
East	Lideta				
App. Lane 1		3.00	300.0	0.50	–
App. Lane 2		3.00	300.0	0.50	–
App. Lane 3		3.00	300.0	0.50	–
Exit Lane 1		3.00	300.0	0.50	–
Exit Lane 2		3.00	300.0	0.50	–
Exit Lane 3		3.00	300.0	0.50	–
North	Ayer Tena				
App. Lane 1		3.50	300.0	0.50	–
App. Lane 2		3.50	300.0	0.50	–
App. Lane 3		3.50	300.0	0.50	–
Exit Lane 1		3.50	300.0	0.50	–
Exit Lane 2		3.50	300.0	0.50	–
Exit Lane 3		3.50	300.0	0.50	–
West	Jemo				
App. Lane 1		3.00	300.0	0.50	–
App. Lane 2		3.00	300.0	0.50	–
App. Lane 3		3.00	300.0	0.50	–
Exit Lane 1		3.00	300.0	0.50	–
Exit Lane 2		3.00	300.0	0.50	–

Lanes are numbered from left to right in the direction of travel.

Volumes

To Approach		Total veh	HV %	Peak Flow Factor %	Vehicle Occupancy pers/veh	Flow Scale %	Growth Rate %/year
From: South	Germen						
West		567.0	14.17	98.5	1.20	100.00	2.00
North		650.0	16.10	98.9	1.20	100.00	2.00
East		598.0	15.10	98.5	1.20	100.00	2.00
From: East	Lideta						
South		380.0	8.60	93.4	1.20	100.00	2.00
West		745.0	14.90	97.1	1.20	100.00	2.00
North		400.0	15.10	95.9	1.20	100.00	2.00
From: North	Ayer Tena						
East		315.0	3.10	83.8	1.20	100.00	2.00
South		765.0	16.98	98.9	1.20	100.00	2.00
West		411.0	16.00	97.9	1.20	100.00	2.00
From: West	Jemo						
North		204.0	5.85	87.6	1.20	100.00	2.00
East		918.0	5.29	97.0	1.20	100.00	2.00
South		499.0	15.10	93.0	1.20	100.00	2.00

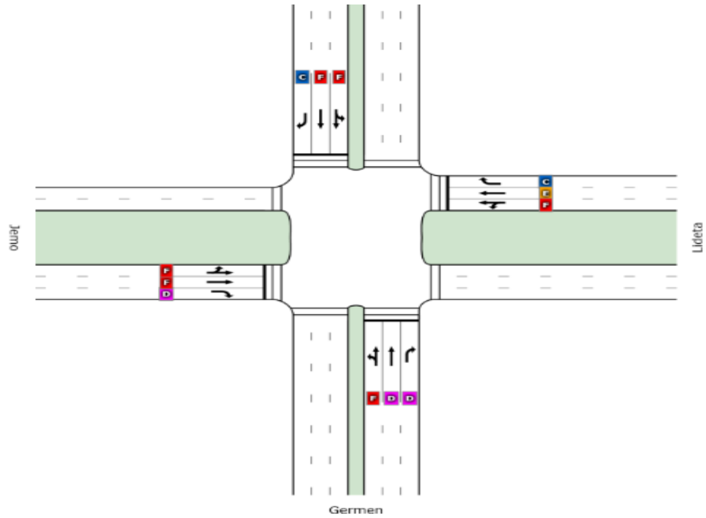

Figure: - 5 Lay out for Jemo Michael intersection

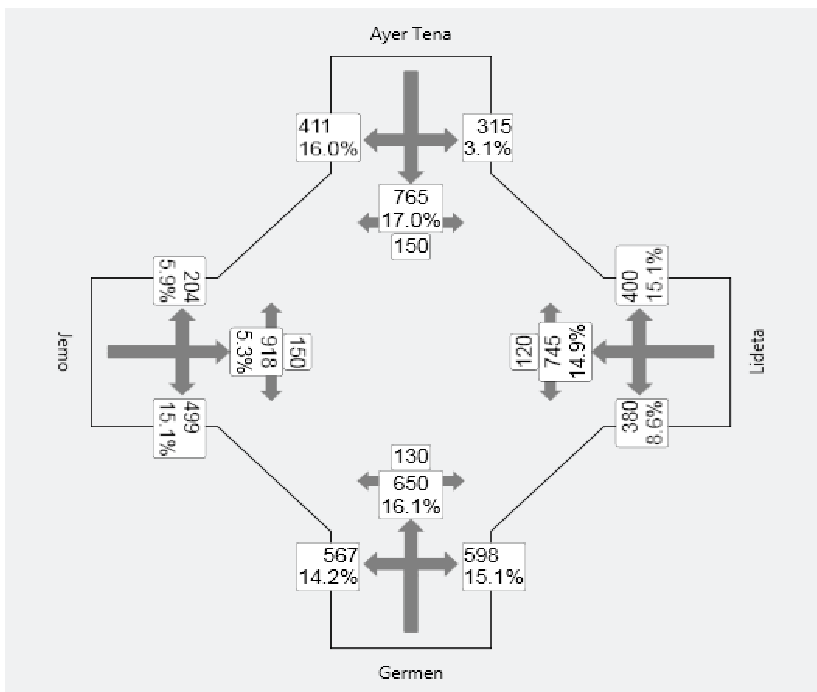

Figure: - 6 Traffic Volume Distribution and Truck Percentage on the Jemo Michael Intersection.

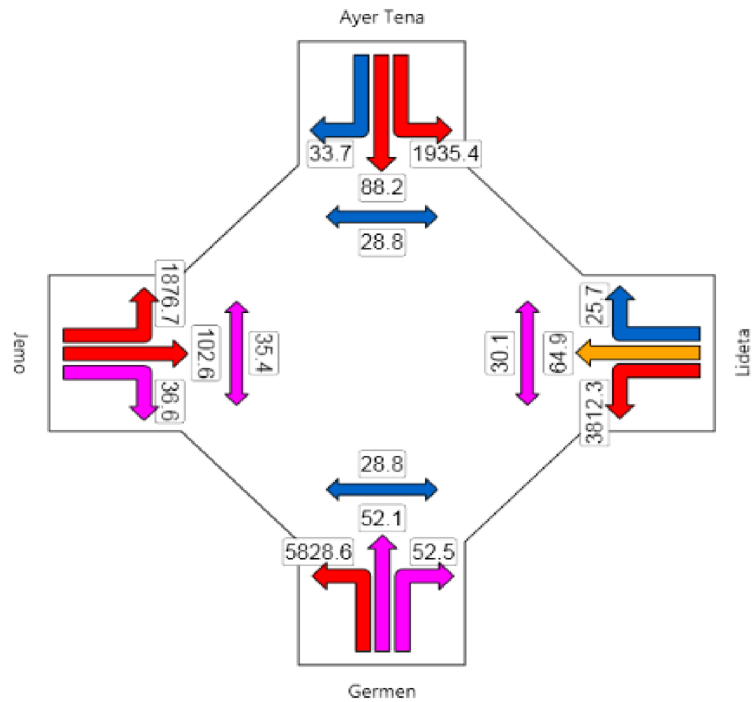

Figure: - 7 Delay in second for all movement ID

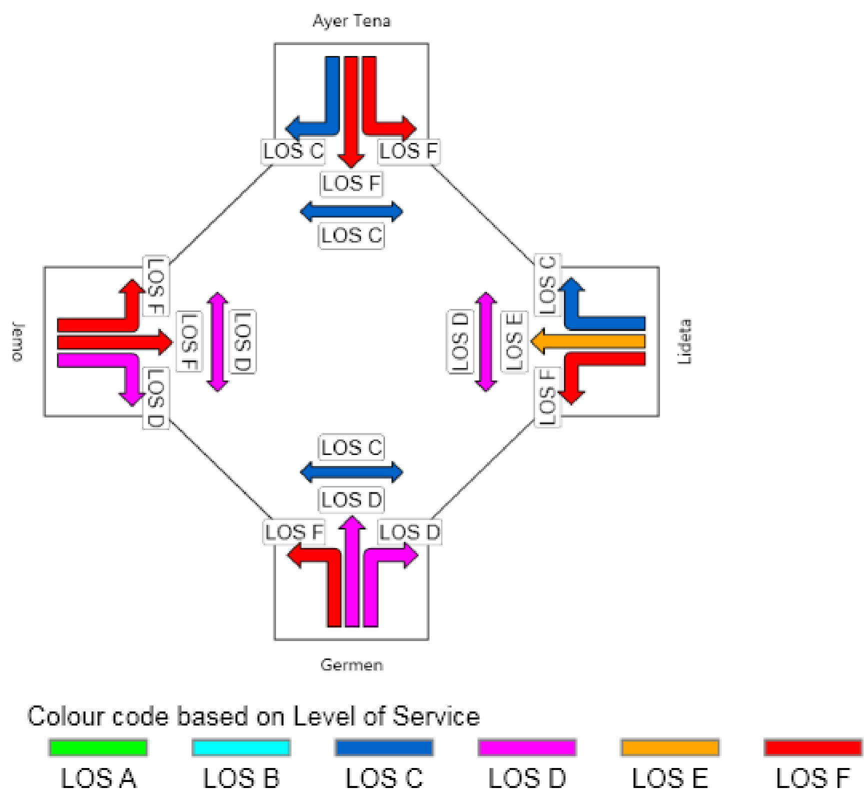

Figure: - 8 LOS values for Jemo Michael Intersection.

Appendix – D: Questionnaires

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Addis Ababa University

Addis Ababa Institute of Technology

School of Civil & Environmental Engineering

Dear Sir/Madam

I, the researcher, Is a student in Addis Ababa Institute of Technology, currently doing my M.Sc. in Civil Engineering under Road and Transport Engineering at Addis Ababa Institute of technology. I am doing my M.Sc. research/thesis entitled: **Estimating Total Traffic Congestion Costs for Selected Road of Addis Ababa city (A case study: Mekanisa - Jemo road)** with the aim of assessing the causes and impact of traffic congestion, quantify the performance and the level of service of the selected intersection, road segments and finally analyses the total traffic congestion cost of selected study area of Addis Ababa city.

Your best honest and good response to the questionnaire will have contribution to the success of the research. Your response will be kept as confidential data, Moreover, the information you provide will be used strictly for academic purpose. Filling the questionnaire will not take more than 10 minutes. I thank you in advance for the time you devote, effort you make, and consideration you give in filling this questionnaire.

If you have any question concerning the items of the questionnaire, please call on mobile: +2519 16071771, or e-mail admasu.netsanet1@gmail.com

With great respect.

Netsanet Admasu.

Questionnaire

Title of the Thesis: - Estimating Total Traffic Congestion cost for selected road of Addis Ababa city (A case study of Mekanisa to Jemo road)

Objective of the study.

- ✓ To assess the main cause of traffic congestion problem.
- ✓ To evaluate the performance and level of services of the intersections
- ✓ To estimate the total traffic congestion cost of the intersections.
- ✓ To suggest some possible and probable solution for those selected area.

Part I: General Information

1. Respondent's name (optional) :-____
2. Respondent's sex (mark √) Female____________ Male________
   Age group: 15-20________ 21-30_______ 31-40_______ 41-50_______ above 50

Part II: Respondent's perception towards traffic congestion in selected study area.

1. Do you think that there is a traffic congestion problem which is occurring at GERMAN Roundabout?
   Yes_______________ No_______________
2. If your answer for question number 1 is yes. What do you think that the level of traffic congestion?
   Very high____ High _____ Medium____ Low______ Very low________
3. What do you think the cause of traffic congestion at this selected intersection?
   Bottlenecks problem________ Driver's behavior____
   Reduction in road capacity___ Weather condition______
   Traffic incidents (crash)_____ Special events__________
   Others____
   ____
4. What do you suggest in order to minimize the occurrence of traffic congestion at this intersection?
   Improve the geometric design of the road and intersection________
   Improve the capacity of the road__________
   Adding the additional traffic lane to existing lanes________
   Constructing some street which connect to major road___________
   Others____
   ____

Questionnaire

Title of the Thesis: - Estimating Total Traffic Congestion cost for selected road of Addis Ababa city (A case study of Mekanisa to Jemo road)

Objective of the study.

- ✓ To assess the main cause of traffic congestion problem.
- ✓ To evaluate the performance and level of services of the intersections. To estimate the total traffic congestion cost of the intersections as well as the road segments.
- ✓ To suggest some possible and probable solution for those selected intersection area.

Part I: General Information

1. Respondent's name (optional) :-____
2. Respondent's sex (mark √) Female___________ Male________
   Age group: 15-20________ 21-30_______ 31-40_______ 41-50_______ above 50

Part II: Respondent's perception towards traffic congestion in selected study area.

1. Do you think that there is a traffic congestion problem which is occurring at JEMO MCHAEL SIGNAL intersection?
   Yes_______________ No_______________
2. If your answer for question number 1 is yes. What do you think that the level of traffic congestion?
   Very high____ High _____ Medium____ Low______ Very low________
3. What do you think the cause of traffic congestion at this selected intersection?
   Lower Performance of signal timing_ ______ Driver's behavior____
   Reduction in road capacity______ Weather condition____
   Traffic incidents (crash)___________ Special events________
   Pedestrian movements____________
   Others____
   ____
4. What do you suggest in order to minimize the occurrence of traffic congestion at this intersection?
   Improve the geometric design of the road and intersection________
   Improve the capacity of the road__________
   Improve the performance of signal timing_________
   Others____
   ____