MEKELLE UNIVERSITY, EIT-M SCHOOL OF CIVIL ENGINEERING MASTER OF SCIENCE IN ROAD AND TRANSPORT ENGINEERING

ESTIMATING TRAFFIC CONGESTION COSTS FOR SELECTED INTERSECTION OF MEKELLE CITY

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MEKELLE UNIVERSITY, EIT-M SCHOOL OF CIVIL ENGINEERING

MASTER OF SCIENCE IN ROAD AND TRANSPORT ENGINEERING

ESTIMATING TRAFFIC CONGESTION COSTS FOR SELECTED INTERSECTION OF MEKELLE CITY

The thesis is submitted to School of civil engineering of Mekelle University in partial fulfilment of the requirement for Masters of Science Degree in Civil Engineering (Road and Transport Engineering Stream)

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DECLARATION

I certify that this M.Sc. thesis study work titled Estimating Traffic Congestion Costs for selected Road of Mekelle City it is my own work. The work has not been presented somewhere else for assessment and award of any degree or diploma. Where material has been used from other sources it has been properly acknowledged and referred.

Wahd Solomun ……………………… ……………………….

Name Signature Date

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ABSTRACT

Traffic congestion is a problem which occurs on road network characterized by slower speed, longer trip time due to excessive vehicles from different direction. Traffic congestion have a negative impact on society such as late reach to work place by increasing travel time, on health by creating stress, mentality and physical discomfort, increasing fuel consumption and air pollution. Mekelle is one of the fastest growing city in Ethiopia. Accordingly, traffic congestion is growing extremely in the city and results time wastage on travel and other direct and indirect effects on the society. This study is concentrated on two selected intersection the first one is four leg signalized intersection which is found around commercial bank of Ethiopia, main branch and the second one is four leg intersection which is found around Relief Society of Tigray in this intersection traffic light is not functional for about two years but after data collection performed the traffic signal was maintained and the intersection become signalized. Then again traffic volume data was conducted at signalized case. The main objective of this study is to estimate traffic congestion costs for selected intersection of Mekelle city and to suggest the possible counter measure for the problem.

Primary and secondary data was collected to accomplish the study objectives. Primary data traffic volume, vehicle occupancy, signal timing, geometric data and daily labour cost was collected. The traffic volume count was made using video recording starting in the morning peak time 7:00AM-10:00AM, at noon time 11:00 AM-2:30 PM and the evening peak time 4:30 PM-7:30 PM at 15 minutes interval was done for both intersections. The vehicles were counted by type passenger car, bus and small and medium truck vehicles. The average vehicle occupancy was collected based on traffic engineering vehicle occupancy data collection manual. After the data was collected data analysis was made. Delay at the intersection was analysed using SYNCHRO software. Then using the collected data and delay annual peak hour cost of traffic congestion in both intersection was estimated. The cost of congestion consists travel time cost, fuel consumption cost and cost of co2 emission gas due to excess fuel usage. The result is found about (5,339,609.37ETB annual peak hour cost) at CBE four leg signalized intersection, (3,789,746.99ETB annual peak hour cost) at REST four leg unsignalized intersection, and (3,181,684.41ETB annual peak hour cost) at REST four leg signalized intersection. Annual peak hour travel time cost represents the opportunity costs of wasted time on congested intersection which shows the largest category at CBE intersection found about 4,311,552.5ETB nearly 81% of total cost of the intersection, at REST unsignalized is about 3,116,165ETB about 82% of cost of intersection and REST signalized have 2,618,690.9ETB about 82% of total intersection cost. Meanwhile annual peak hour cost of fuel is the second contributor to the overall cost of congestion with 1,009,870.3ETB at CBE, 661,988.9 ETB at REST unsignalized intersection and 552,987.4 ETB at REST signalized intersection which is about 18% of the total cost. On the other hand annual peak hour emissions costs is the least contributor to the overall cost of congestion and estimated about 18,186.57ETB at CBE intersection, about 11,611.09ETB at REST unsignalized intersection and 10,006.11 ETB at REST signalized intersection. The cost of congestion result shows the effect of congestion is highly concentrated on the travel time of public transport users' means 78% of the travel time cost is for the public transport users.

Key words: Traffic congestion, Delay, Level of service, Signalized Intersection, Congestion cost

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List of Acronyms

CBE- Commercial Bank of Ethiopia

CO2: - Carbon Dioxide

ETB- Ethiopian Birr

GHG- Greenhouse Gas

HCM- High way Capacity Manual

HPMS -Highway Performance Monitoring System

LOS- Level of Service

LT- Left Turn

NCHRP- National Cooperative Highway Research Program

PCU: - Passenger Car Unit

PHF: - Peak Hour Factor

PHV: - Peak Hour Volume

REST: - Relief Society of Tigray

RT: -Right Turn

TH: - Through movement

UMR: - Urban mobility report

USD: - United states dollar

VOT: - Value of Time

WHO: - World Health Organization

CHAPTER ONE

1. Introduction

Traffic congestion is a problem which occur due to imbalance of traffic demand and the road infrastructure capacity. As urbanization is increase due to a number of factors including increment of urban population, economic growth, opportunity of employment, number of people using car and number of vehicles but the existing transport infrastructure capacity is low, under investment in road infrastructure, shortage off-street parking, poor management and poor urban planning transport traffic congestion can occur (Institute of Transportation Engineers Publications, 1995).

Traffic congestion have a negative impact on society such as late reach to work place by increasing travel time, on health by creating stress, mentality and physical discomfort and increasing fuel consumption and air pollution. To evaluate the performance of the present road network quantifying and measuring the scope of traffic congestion is necessary (Pshtiwan & Somnath, 2013).

1.1 Background to the Study

Mekelle is one of the fastest growing city in Ethiopia. Accordingly traffic congestion is growing extremely in the city and results time wastage on travel and other direct and indirect effects on the society. The study area is situated in a selected area this area has a large number of movement of vehicles and peoples. According to the traffic police and road user's information in morning, noon and evening peak time there are huge traffic volume demand due to this reason the traffic demand and the road capacity for using these intersections are not balanced and then results to create traffic congestion.

Among different intersections in the city for this study the selected intersections are four leg signalized intersection around Commercial Bank of Ethiopia (CBE) main branch and four leg signalized intersection around Relief society of Tigray (REST). Because they are playing a great role for the occurrence of traffic congestion. The Main CBE intersection is signalized intersection that connects the south part to the Centre part of the city but the REST intersection signal was not functional for about two years but now a day the traffic light was installed.

Therefore, in order to develop policies to reduce traffic congestion, research has to be conducted. From which this thesis aims to assess the performance of major intersection and quantifies their level of traffic congestion in the city by relating with the negative effect on the society. The study result can be used to attain congestion mitigation measures.

1.2 Statement of Problem

Developing countries like Ethiopia, has gone through rapid road transport expansion which results from increment of economic activity and due to the consequence of income growth. From the Ethiopian city the urbanization expansion in Mekelle shows rapid growth and the transport in the city is depended on road transport.

In Mekelle city traffic congestion has negative effect on road user’s day to day activities. This negative effect in terms of cost has never been evaluated before. Now a days traffic congestion become threat in the city economy growth by limiting the mobility of the road uses and increase delay and fuel consumption. In order to reduce the congestion problem it is important measure the traffic congestion level and estimate the cost of congestion.

According to Mahmudah, et al., (2018) traffic congestion cost at signalized intersection in Yogyakarta city of Indonesia at peak hour is RP. 2830336 per hour. In Agartala city of five signalized intersection about 389.68 litres of diesel and 810.38 litres of petrol is wasted everyday due to idling of vehicles and the congestion cost of fuel is about Rs.61,072per day and Rs22,291,198.per annum (Dr.Manish & Dipankar, 2012).

In Mekelle city, longer queues, delays and congestions are becoming the major concerns to the road users and passengers approaching the intersections by increasing the travel time needed to traverse especially at peak hours (Mesele & Tsehaye, 2016).

According to the study result of Alemayehu Abadi (2017) the four leg signalized intersection around CBE main branch is congested with excessive delay and level of service F. This intersection connects the south part with the centre part of the city. It is busy with both motorized and non-motorized traffics throughout the day. There are too many vehicles come to use the intersection at the same time and during weekday morning, noon and afternoon periods.

Commercial Bank of Ethiopia-Axum Hotel is road which cross's the REST intersection. This road is one of the major road in the city and it is impounded by many colleges, banks, shops, business centres, restaurants and café, hotels, offices, health centre, other services (Telecommunication, Ethiopian airlines office) and there is partial on street parking on both side of the road on some sections of this route creates traffic congestions especially on peak hours of the day time. Thus, the main function of the road is to serve as traffic movement from these centres so the road receipts very high volume of pedestrians and motorized vehicles because of this the route creating traffic congestion (transportation plan and implementation study of Mekelle city, 2011).

1.3 Research Questions

The major research questions are listed below:

- Dose presence of traffic congestion at the selected intersection?
- What are the level of service for the selected intersection?
- Dose traffic congestion affect travel time, fuel consumption and emission gas?
- What are the costs of traffic congestion?
- What are the possible countermeasures?

1.4 Objective of the Study

1.4.1 General Objective

The main objective of this study is to estimate traffic congestion costs for selected roads of Mekelle city and to suggest the possible counter measure for the problem.

1.4.2 Specific Objectives

- ✓ To analysis the level of service for those selected intersections.
- ✓ To identify the extent to which traffic congestion adversely will affect.
- ✓ To estimate the traffic congestion cost for selected intersection
- ✓ To suggest possible counter measures for the problem

1.4 Significance of the Study

The society in Mekelle city is adversely affect by traffic congestion in their day to day activity. Therefore, it is important to measure the traffic congestion level and estimate the traffic congestion cost. This measure of congestion and cost estimation is important to the urban planners to update the existing road network and traffic management and to review urban development with respect to the future social and demographic change.

1.5 Scope of the Study

This research is concentrated on recurrent traffic congestion only which is observed in many time of the day at cross intersection excluding roundabout. There are many different variables in traffic congestion cost estimation but due to time and economic constraint the researcher limit to study only the three congestion costs at peak hour. The travel time income lost, excess fuel consumption cost and co_2 emission due to excess fuel consumption cost are the variables for this study.

CHAPTER TWO

2. Literature Review

2.1 Introduction

Transportation is the movement of peoples or things from one place to another place. The availability of transportation facilities can affect the growth and development of a region or nation. As population increase the need for traffic demand also increase. When demand of traffic at the same time period increase results traffic congestion (Garber & Hoel, 2009)

Cities in the world have varies transport challenges of those traffic congestion is the major challenge. It creates continuous increases in transport fare especially for low income groups, lack of smooth traffic flow, lack of infrastructures for non-motorized transport for walking and cycling, high rate of traffic accidents and increasing air and noise pollution (Peixoto Neto, et al., 2008).

2.2 Definition of Traffic Congestion

The definition of congestion is imprecise and it have multiple definitions since people have different views and expectations of how the method should execute based on whether they are in urban or rural areas, at peak and or off peak (Bertini, 2005).

Definition of traffic congestion is various because different researchers contribute their own perceptions. There is no constant definition of traffic congestion in terms of a particular or set of measures that reflects severity, duration and spatial extent (Popoola , et al., 2013).

Traffic congestion definition depends on the opinion of the road users. depend on this the definition of traffic congestion implies as congestion which is the travel time or delay in excess of that normally under free flow travel condition and the other one is insupportable congestion which is defined as travel time or delay in excess of an agreed upon norm (Tim Lomax et.al, 1997)**.**

Traffic congestion is a state of traffic delay (when the movement of traffic is reducing speed below reasonable speeds) because the number of vehicles trying to use the road goes above the traffic network capacity to handle them (Weisbrod G., et al., 2003)**.**

In the transportation, traffic congestion usually relates to high number of vehicles on the roadway segment at the same time resulting using low speeds that are slower-sometimes much slower-than the free flow speeds (Cambridge Systematics & , 2005).

2.3 Characteristics of Traffic Congestion

Traffic congestion may be defined as state of traffic flow on a transportation facility characterized by high densities and low speeds, relative to some chosen reference state (with low densities and high speeds) (Bovy & Salomon, 2002).

Traffic congestion is a condition formed on road networks characterized by traffic delay (when the flow of traffic is slowed below required speeds) because the number of vehicles trying to use the road exceeds the traffic network capacity to handle those (Weisbrod, et al., 2001).

In a study done by Mohan & Ramachandra, (2012) states that, the volume-capacity ratio on any given roadway were adopted to identify where congestion was occurring. To understand presence of congestion it is necessary to measure and discuss benefit of using travel time and delay.

Traffic congestion condition on road network occurs as a result of excessive use of road infrastructure beyond capacity, and it is characterized by slower speeds, longer trip hours and increased vehicular queuing. Congestion has become one of the most important aspects of modern life in big cities (Rodrigue, et al., 1997).

2.4 Types of Congestion

Types of traffic congestion are described as recurrent congestion, non-recurrent congestion and Pre-congestion state they are classified based on the frequency and predictability of the congestion factors which will impact on driver behaviour. The costs related with all type of congestion are possible to be different. It is difficult to quantify the non-recurrent traffic congestion because it needs a number of data with different characteristics adequately. Drivers have not expect in their journey because the occurrence of non- recurrent traffic congestion is suddenly happen at the way of their traveling time due to that cost could be greater. Non recurrent congestion occurs increasingly at some roots this makes opportunity to teach drivers to expect the cost in terms of likely delay and successful contingency routes. The Pre-congestion state will carry some costs similar to those of congestion, including loss of control over drivers' environment, deterioration in the environment and other impacts (Dr. Susan & Mr James, 2006)**.**

1. Recurrent congestion: - occurs when a lot of vehicles come to use the road at the same time. Recurrent congestion usually occurs during weekday morning and afternoon peak periods, when most people go to work and return home at a particular time. In large urban areas, the peak periods can range from 7:30 to 9:30 a.m. and from 4:30 to 7:00 p.m. In smaller urban areas, the peaks may have a shorter duration (one or two hours). Of notice 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).
2. Non-Recurrent congestion: - is the additional main source of traffic congestion. Non-recurrent congestion is associated with unsystematic 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 expect and address.
3. Pre-congestion (Borderline congestion):- Occurs where free-flow conditions collapse but full congestion has not yet occurred. This may occur either side of the time period when Congestion happens or upstream or downstream of congestion that is already happening.

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

2.5 Cause of Congestion

Traffic congestion causes by two broadly factors (a) micro-level factors for example, many people want to move at the same time, too many vehicles for limited road space. (b) macro-level factors that relate to overall demand for road use for example car ownership trends, land-use patterns and dynamics of the regional economic etc. (Mohan & Ramachandra , 2012).

Traffic congestion mostly happened when the road system is unable to accommodate traffic at adequate speed, there are conflicts among different types of vehicle, and traffic controls are improperly used (Lomax et al, 1997)**.**

Road congestion can occur due to the poorly and narrow constructed streets and roads that are useless in handling many vehicle types. This results in the incapacity to efficiently manage traffic, creating blockages that last for long periods (Jain, et al., 2012).

The uselessness of public transport to offer services efficiently gives rise to traffic congestion, which in turn has serious impacts on the socio-economic activities of a country (Harriet, et al., 2013).

According to Bashir & waziri (2008) the study of with in urban traffic in Lagos Nigeria have been found that due to traffic congestion about 57% of commuters and motorists use from 30 to 60 minutes on the road and the worst traffic congestion occurred on Monday. According to the Researcher, causes of traffic congestion in Lagos were described as; Presence of pot holes/bad road, trading activities, on- street parking, loading and discharging of passengers, unlawful bus stops, flooding/poor drainage, vehicle interruption, insufficient road sections, religious activities, great volume of traffic, and limitation of parking space and absence of traffic light at some road intersections.

There are different factors that cause traffic congestion. Among those many people and lots of freight moving at the same time is the first one secondly, the slow growth in supply and thirdly that causes many trips to be delayed by events that are irregular. However, frequent crashes, vehicle breakdowns, improperly timed traffic signals; special events and weather are factors that cause a variety of traffic congestion problems (Schrank, et al., 2013).

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, lack of parking space and lack of traffic light at some road intersections (Popoola , et al., 2013)**.**

2.6 Consequence of Congestion

Employees they live in urban area spent less travel time to reach on their work place is more productive than one where travel times are longer. Productivity means superior economic growth, and better job creation. Congestion cost estimates the costs of traffic congestion, principally the value of lost time as well as excess fuel costs, increased emissions of air pollutants, greater transport and other affected costs and varying investment decisions are more and more recognized and felt across the country (Bivina, et al., 2016).

Delay is the most direct consequence of road traffic congestion. However, increase in travel time is not the only cost. Congestion invites both tangible and intangible costs for individual road users as well as the society as a whole. For example, apart from time wasted when people are held in congestion, the low movement adversely affects the business sectors. When goods or services cannot be transported on time, the business sectors need to suffer extra inventory costs and logistics costs (Transport Advisory Committee, 2014)**.**

The valuation of time losses should be based on opportunity costs of foregone benefits. The contracted amount of work time does not change by the time loss in traffic congestion, but reduces the value of individual free time in general, is individually low and might be neglected in first instance. Only occasionally, e.g. at the start or end of holiday and vacation travel, its value would increase. In case the congestion time loss decreases the available work time and accordingly the production volume the time valuation related to the income level is a good indication (Ingo Hansen, 2001).

The social costs of congestion are the economic costs that congestion imposes on all drivers and on society as a whole. The social costs include the loss of productive time and increases in fuel consumption, vehicle operating and related costs, incident risk, air pollution and GHG emissions. As noted, this study is an attempt to assess the social cost of congestion (Transport Canada Environmental Affairs, 2006)**.**

2.7 Congestion Impact

Traffic congestion has negative impact on economy by higher prices for consumers to delay, on environment by increased fuel consumption and air pollution, on health by creating stress, mentality and physical discomfort (FU, 2006).

According to Mahmud, et al., (2012) the impacts of traffic congestion can be viewed in three ways: impact on health, impact on economy, and impact on environment. Traffic congestion has great economic impact due the society losing money in four ways loosing man-hours; extra transportation cost; extra fuel consumptions; vehicle operating cost; and various cost.

Congestion has 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 (Mahmud, et al., 2012)**.**

the most significant effect of traffic congestion on Lagos-Ibadan expressway include: Delay movement, stress, accident, inability to forecast travel of time, fuel consumption, query at work, pollution, night driving, road rage and spill over effect are among the major effects suggested from this study (Popoola , et al., 2013).

2.8 Congestion Measures

Capacity and delay at intersection are the key congestion measurement parameters at signalized and unsignalized intersections. The automobile level of service obtained maybe by delay measurement and examining volume to capacity ratio (Pande, et al., 2016).

According to HCM, density in terms of passenger cars per kilometre per lane, speed in terms of mean passenger car speed, and Volume to capacity ratio are indication of how well traffic flow is being accommodated by the highway. Travel time and speed are the common indicator of the happening of congestion that is when a given vehicle drives 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.

The study by Lomax et.al (1997) conclude that suggested measure related to travel time, delay and speed are more flexible and suitable for wide range of analysis and also it is simply understandable by the professionals and the public. And measure of congested roadway or system interacts with four main components. Those components are duration, extent, intensity and reliability. Among and within urban areas they vary for example– smaller urban areas have shorter durations of congestion than larger areas. Accordingly, The four components are defined as:-

1. Duration – this is defined as the amount of time congestion affects the travel system.
2. Extent – this is described by estimating the number of people or vehicles affected by congestion, and by the geographic distribution of congestion.
3. 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
4. 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.

Like speed, access, user costs, delay, reliability are some of the congestion measures. They use for study of different problem statements regarding congestion and will motivate sometimes fundamentally different strategy interventions (Euiropean of Ministers of Transport, 2007)**.**

Many of the measures are currently used by transportation agencies in evaluating system performance. The measures are grouped into five categories: Time-related measures, volume measures, congestion indices, delay measures, and LOS measures (Jia, et al., 2012).

According to Aftabuzzaman (2007) study measure of traffic congestion can be categorized into four broad groups: basic measures; ratio measures; level of service; and indices. Subsequent sections examine in detail each group of measures.

1. Basic measures: - Basic measures are related to delay estimation. Delay has been defined as the additional time accomplished by a road user in contrast to the free flow travel or the suitable travel time. For delay estimation, research has used different threshold values for the beginning of delay. Lindley (1987) used a threshold of congestion to begin at a volume to capacity (V/C) ratio 0f 0.77 (or the speed of 88 km/h corresponding to V/C of 0.77). Lomax et al., (1997) used certain specified values for different roadway categories based on consensus among technical and non-technical groups to determine acceptable travel time and threshold for the beginning of congestion.
2. Ratios: - Ratio measures of traffic congestion are usually developed by dividing one travel time or delay element by another. Several ratio measures (delay rate, relative delay rate and delay ratio) were developed by Lomax, et al., (1997) based on travel rate. Travel

rate (in minute per mile) was defined as rate at which a road segment is travelled. It is the reciprocal of speed multiplied by appropriate conversion factor. Acceptable travel rate was defined as the maximum rate of travel (or the lowest travel speed) at which a segment is traversed or trip is completed without experiencing an acceptable level of mobility.

3. Indices: - Some researchers have developed index measures of traffic congestion by including several congestion related elements in an equation to produce a single measure. A congestion index was developed by Taylor (1992) and D/Este et al. (1999) as a measure of congestion. This congestion index is the ratio of link delay (the difference between actual and acceptable travel time) to acceptable travel time. The recent report, the 2005 urban mobility report (Schark and Lomax, 2005), reported a travel rate index (IRI) of 85 urban areas. STPP (2001) developed a ‘congestion burden index’ to quantify congestion. The congestion burden index was calculated by multiplying the travel rate index for each metro area by the percentage of workforce driving to work. Roadway congestion index (RCI) was developed by Schrank et. al., (1990) and was refined by Schrank and Lomax (1997). This was weighted average of vehicle miles travelled and miles of freeway and principal arterial. The congestion severity index (CSI) was originally developed by Lindley (1987) to measure freeway congestion interims of total delay (vehicle-hour) per million vehicle miles travel (VMT).
4. Level of Service measures: - Traditionally, the use of level of service (LOS) has been one of the popular measures traffic congestion. The LOS concept as adopted in the 1994 and 2010 Highway capacity Manual represents a range of operating conditions. The LOS of a facility is determined by traffic flow characteristics such as vehicle density, volume-to-capacity ratio, average speed and intersection delay, depending on facility type. The scale of LOS measure has six discrete classes ranging from A to F. The main advantage of LOS measure is that it is comprehensible by most non-technical audience. However, it has weakens as stated by Byrne and Mulhall (1995), it only represents location-specific congestion phenomenon and does not reflect overall or regional congestion condition.

LOS A defines mainly free-flow operation. Vehicles are completely unrestricted in their capability to move within the traffic stream. Control delay at the boundary intersections is negligible. The travel speed exceeds 85% of the base free-flow speed.

LOS B defines reasonably unrestricted process. The facility to move within the traffic stream is only somewhat limited and control delay at the border intersections is not significant. The travel speed is between 67% and 85% of the base free-flow speed.

LOS C describes stable operation. The ability to manoeuvre and change lanes at mid segment locations may be more restricted than at LOS B. Longer queues at the boundary intersections may contribute to lower travel speeds. The travel speed is between 50% and 67% of the base free-flow speed.

LOS D indicates a less stable condition in which small increases inflow may cause substantial increases in delay and decreases in travel speed. This operation may be due to adverse signal progression, high volume, or inappropriate signal timing at the boundary intersections. The travel speed is between 40% and 50% of the base free-flow speed.

LOS E is characterized by unstable operation and significant delay. Such operations may be due to some combination of adverse progression, high volume, and inappropriate signal timing at the boundary intersections. The travel speed is between30% and 40% of the base free-flow speed.

LOS F is characterized by flow at extremely low speed. Congestion is likely occurring at the boundary intersections, as indicated by high delay and extensive queuing. The travel speed is 30% or less of the base free-flow speed. Also, LOS F is assigned to the subject direction of travel if the through movement at one or more boundary intersections has a volume-to-capacity ratio greater than 1.0.

Table 1 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 Levels of Service Criteria for Different Type of Intersections. (*HCM 2000)*

	Signalized Intersection	Un signalized 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 Intersection Traffic Congestion

Road intersections where traffic movements in different direction join play an important role in the road network. They are the greatest complex locations in a traffic system and they have a very significant effect on vehicle safety and movement's effectiveness. Urban road network holds many intersections. As a result, the traffic condition in urban areas is characterized by disturbances. Consequently, traffic delay is often a noticeable feature of urban road intersection. Traffic delay is the most prominent traffic congestion feature (a problem which has characterized almost all urban areas in the world, especially in the developing countries). Traffic delay can be defined as the time lost due to traffic friction and traffic devices (Adedimila, 1981), or more simply as unwanted journey time (Tillotson, 1981).

Considering the contribution of freight vehicles to traffic delays in Lagos, Ogunsanya noted that, 54.7% of the delays experienced in Lagos were at road intersections. Satisfactory time due to slow or unpredictable travel speeds. Additionally, on the study on the causes of delay in Ilorin, Ogunsanya found that, of the various types of delay, those that are caused by road intersections are the greatest accounting for 31.75% (Ogunsanya, 1983).

According to Isaac study Traffic delay at intersection in Nigeria attends each day. Intra-urban movements to work, markets, schools and shops recreational centres are becoming very difficult and are characterized by waste of time, delays, discomfort, energy and resources. The problem is more occurred at morning and evening peak periods. When vehicles stand still in long queues creates in stress and reduction in the productive hours of travellers (Isaac, 2013).

2.10 Definition of Traffic Congestion Cost

Traffic congestion cost can be defined as the external intrusion costs imposed by each road user on the other society, including travel delay, increased vehicle operating costs, pollution, and driver stress and etc. Congestion costs rise more than consistently, mainly when facilities are highly saturated (Zegras & Littman, 1997).

The study conducted by Australian Government, Department of Transport and Regional Service, estimated congestion cost for a year approximately USD 10 billion which comprises of operating cost, private time cost and business time cost for all Australian cities.

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 removal of congestion is possible, the cost of congestion measure has a real meaning and the cost can be avoided. It also can be acceptable on effectiveness grounds: it is comparing the cost of the current network with the cost if the network was operating at maximum productivity, i.e. with roads working at their extreme capacity. Congestion can be seen as the situation where there is so much traffic that the network cannot operate efficiently (Grimmond, 2017).

The study Koopmans & Kroes (2003) definition of traffic congestion identifies three different groups, the first one is the economists' definition of congestion is the presence of interactions between vehicles on the road. Secondly road users perceive roads to be congested when speeds fall below an acceptable level (which may differ by location and over time), which perceived congestion; and the third one is engineers definition which classify a road as congested when more vehicles are attempting to use the road than it has capacity to carry.

The study by HDR for the Office of Economic and Strategic Analysis, U.S. Department of Transportation (2009) result shows the overall cost of congestion in all urban areas is estimated at $85.4 billion, travel time represents the largest category at $60.6 billion, nearly 71 percent of total. Meanwhile vehicle operating costs are second contributor to the overall cost of congestion with $11.3 billion. Emissions costs on the other hand were the least contributor to the overall cost of congestion at an estimated at $330 million. At the same time, annual congestion costs were estimated at $763 per commuter, mainly due to a $541 in annual wasted travel time cost for each commuter.

2.11 Estimating Traffic Congestion Costs.

The INRIX speed data replicates the effects of both recurring (or usual) delay and occurrence 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 inference that zero congestion is a possible or desirable goal for policy (Mahmudah, et al., 2018).

Theory of Tzedakis (FU, 2006) highlighted the congestion cost resulted by slow traffic by time period (i.e. per hour) that can be estimated by considering the followings:

1. Slow vehicle (traffic) due to congestion will cause the delay of fast vehicle;
2. As a result the queuing time will be occurred on the road segment or intersection;
3. The expected value of the sum queuing time of fast vehicle impeded by the slow one is then estimated;
4. Based on the expected value of the sum queuing time, the expected value of delay costs and the change in vehicle operating costs are then quantified;
5. These costs per hour are then estimated by multiplying the costs per slow vehicle journey by the hourly number of slow vehicle journeys;
6. The formula to calculate the congestion cost is as written on equation below;

$C = N * [G A + (1 – A/B) V'] T$ ……………………………………………………Eq. 2.1

Where: C = Congestion Cost (Rupiah),

N = Vehicle Volume (Vehicle),

G = Vehicle Operating Cost (Rp/veh.km),

A = Existing Speed (km/hour or kph),

B = Ideal Speed (km/hour or kph)

V' = Vehicle Time Value (Rp/veh. Hour)

T = Delay Time (Hour).

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. A unit price value was determined for each of the three main components of congestion (Transport Canada, 2006).

According to the study of Falcocchio & Levinson, (2015) the various components of travel cost in congested traffic was calculated as:

TC = [(ATT)*(VTT)] + [AFC] + [CAC] + [CAAP]……………………………………Eq. 2.2

Where: TC= Travel Cost Per Vehicle in Congested Traffic

ATT= Additional Trip Time from Congestion, VTT= Value of Travel Time

AFC= Additional Fuel Cost From Congestion, CAC= Cost of Additional Crashes

CAAP= Cost of Additional Air Pollution to Human Health

2.11.1 Travel Time Cost

Travel time is one of the major categories of transport costs, and time savings are often the supreme predictable advantage of transport upgrading projects. Factors such as passenger comfort and the time to traverse the given distance reliability can be calculated 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). Depending on travel conditions, trip type and preferences of traveller the travel time unit costs vary. 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, 2013).

The most frequently occurred and also the most familiar factor of the traffic congestion cost is the travel time delay; commonly called travel time costs. It is the economic idea that the time consumed on travelling has an opportunity cost as it could be used for another activity which could produce some important usefulness. The greatest broadly used technique to estimate the related cost is to enforce the Value of Time (VOT) on the estimated delay due to the traffic congestion (Khan & Islam, 2013).

Khan & Islam (2013) Uses the model for computing TTC (for passenger travel) as follow, includes all the effects of various factors:

TTC = ijkm (t x TT x VOT) ijkm +TTV …………………………………………………Eq. 2.3

Where, TTC = Travel time cost per vehicle-person per day, t = % Trips

TT = Travel Time, i = vehicle type

j = trip purpose (i.e. work trip, W.T. or non-work trip, N.W.T)

k = Time factor (peak or off-peak hour)

m = allowance for short distance and/or less-time sensitive trips (L.T.S)

VOT = Value of Time (varying according to travel condition, travel time, mode choice, travel purpose etc.)

TTV = Travel Time Variability

According to Errampalli, et., (2015) the travel time cost for passenger vehicles is obtained by multiplying the travel time per km with the VOT of passengers and average occupancy of the vehicle. Mathematically it can be represented as;-

$PTTC_{ih} = T_{ih} * O_i * VOT_i$ ……………………………………………………………………Eq. 2.4

Where, PTTC = Passenger Travel Time Cost in Rs/Veh-km

T = Average Travel Time in min/km;

O= Occupancy

VOT= Value of Travel Time of the passengers in Rs/min

Subscripts ‘i’ and ‘h’ represents vehicle type and traffic flow respectively

According to Mitiku (2015), the cost of time lost due to vehicles delay at the road intersection could be calculated as:

$CT = LD * WD * ta * vp$…………………………………………………………….. Eq. 2.5

Where:

C_T= Cost of time lost per hour;

L_D =Difference in number of vehicles waiting in the system;

W_D = Difference in average waiting time per vehicles;

ta = Average value of time;

v_p = Vehicle occupancy;

2.11.2 Excess Fuel Consumptions Cost

Vehicles at the junction waits their turn to cross the intersection, the drivers normally keep the engines of their vehicle on as a result vehicle delay and fuel loss are increased particularly at the signalized intersection (Pal & Sarkar, 2012).

Traffic congestion leads to excess fuel usage due to two effects the first one time spent idling Ingrid lock, and the second one is the start-and-stop nature of travel in congested conditions, as travel at a steady speed uses fuel at a lower rate (Ingo Hansen, 2001).

Fuel consumption can be defined as 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 litres. The rate of the average fuel consumption at low speeds from 10 to 50 km/hr is greater than fuel consumption at speed 60 km/hr by 43.3 %. However, the fuel consumption rate of speeds from 80 to 120 km/hr is greater than fuel consumption rate of speed 60 km /hr by 21.6 % (Ibrahim, et al., 2001)..

Depending on the type of vehicle and type of fuel use fuel consumption rates is vary (i.e. Gasoline/diesel-powered automobile) and driving environment (i.e. urban versus freeway travel, un-congested versus congested travel) (Khan & Islam, 2013)

According to Tewelde (2016) study Fuel consumption of cars is depend on car model, type of engine, and vintage. The average fuel efficiency of the private automobiles in Mekelle city is 12.115km/litre.

According to the Road and transportation Bureau of Mekelle city information public minibus Taxi fuel efficiency of new vehicle is 8km/litre, for the old 5km/litre and all the minibus taxi that present in the city in giving service are old.

Excess fuel are consumed when drivers keep on engine of their vehicles when waiting for their turn to clear the intersection. Small amount of fuel wasted, aggregated over number of cycles per day, number of days per month and number of signalized intersections becomes a huge quantity of fuel is loss (Parida & Gangopadhyay, 2008).

According to Mitiku (2015), to calculate costs due to extra fuel wasted:

$ECEFC = Cu * Fc * Wd * Ld$……………………………………………………………….Eq. 2.6

Where:

ECEFC= Expected Cost of Extra Fuel Consumed per hour;

Cu =Unit cost of fuel (19 ETB);

FC=Extra fuel consumed by one vehicle per hour (1.263 litre per vehicle);

Wd =Difference in average waiting time at the road junction; and

Ld= the difference in number of vehicles waiting at the road junction

In order to calculate the amount of fuel lost by the idling of vehicles, it is required to first know the value of fuel consumption of various vehicles types considered. Table 3 below shows the fuel consumption values obtained from (Dr.Manish & Sarkar, 2012), (Parida & Gangopadhyay, 2008) (Ch.Ravi & Pranoy, 2013).

Table 3 idling fuel consumption mi/hr

No.	Vehicle type	Fuel consumption ml/hr	Fuel
1	Motor Cycle	197	gasoline
2	Three wheel (passenger)	376	gasoline
3	LCV	621	diesel
4	Car	649	diesel
5	Car	706	gasoline
6	Minibus taxi	649.2	diesel
7	Bus	930	diesel
8	Truck	1032	diesel

Source: idling fuel consumption test result (Parida & Gangopadhyay, 2008), (Dr.Manish & Sarkar, 2012) and (Ch.Ravi & Pranoy, 2013)

2.11.3 Greenhouse Gas Emission Cost

GHGs are produced from multiple sectors of the economy, including industrial sources, electric power plants, residences, and agriculture; as well as the different transportation modes. The relative effect of transportation emissions on the global climate can be approximated by their relative magnitude compared to all other global emissions. The primary GHGs produced by the transportation sector are carbon dioxide, methane, nitrous oxide, and hydro fluorocarbons (U.S. Department of Transportation Federal Transit Administration, 2010).

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).

When vehicles spend more time on road due to traffic congestion, crawling or idling, and undergoing many deceleration and acceleration events results increase of emissions (Barth & Boriboonsomsin, 2009). A number of studies presents, transportation is one of the source of air prolusion in developed and developing countries both from direct exhaust and indirect road dust. Increasing fuel consumption on the road gives increase of emissions the air quality will only get worse.

Transportation Research Board (2002) States those Vehicles are the dominant sources of many air pollutant emissions in urban areas than country area. Congestion has the potential to significantly worsen ambient air quality, particularly near major roadways.

vehicle emissions Impacts should have been strong attention, and recent epidemiological studies show raised up dangers of non- allergic breathing morbidity, cardiovascular morbidity, cancer, allergic illnesses, adverse pregnancy and birth outcomes, and diminished male fertility for drivers, commuters and individuals living near roadways (World health organization, 2005).

Federal transport authority (2012) 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 succeed.

McKinnon & Piecyk (2009) identified two basic approaches of measuring carbon dioxide emissions from road transport. These are:

1. Energy based approach: This approach is the simplest and accurate way of calculating CO2 emissions of motor vehicles. This is because; almost all motor vehicles are energy related. This approach is based on recorded energy use, and employs standard emission factors to convert energy values into CO2. The unit of energy for the measurement is litres of fuel. The main problem with this approach is lack of direct access to energy data.
2. Activity-based approach: This approach is used in the absence of energy data. It is possible to make a rough estimate of the carbon dioxide emissions of a transport operation by applying a simple formula shown below:

CO2 emissions = Tones transported x average distance travelled x CO2 Emissions factor per ton-km.

Diesel vehicles emit most of the harmful air pollutants, as much as 80-90% in some countries. Although the technology is improving, gasoline generates low harmful pollutants than diesel. In addition, the combustion of one litre of diesel causes more CO2 emissions than the combustion of one litre 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 (Tewelde, 2016)**.**

Vehicle's emission factor is computed based on the averaged details of number of vehicle, fuel specification, distance travelled per annum, whether condition, average speed of vehicles, and road distribution by type of road (Cambridge Systematics & , 2005).

The vehicle's emission factor for any diesel and gasoline car in Ethiopia is 2.67kg CO2/litre and 2.42kg CO2/litre respectively (Federal Democratic Republic of Ethiopia, 2011).

2.12 Summery of Literature Review

Traffic congestion can be perceived as unavoidable consequences of scarce transport facilities. Traffic congestion condition on road network occurs as a result of excessive use of road infrastructure beyond capacity, and it is characterized by slower speeds, longer trip hours and increased vehicular queuing.

The effects of traffic congestion are obvious, however the causes are complex. In general, factors causing congestion can be broadly classified into two categories: recurrent and noncurrent. Recurrent congestion refers to congestion that happens on regular (e.g., daily) basis. Causes of recurrent congestion include excess traffic, physical capacity limitation, and operation networks (e.g. Traffic signal control). Causes of noncurrent congestion include traffic incidents such as accidents, vehicle breakdown, police checks, and closures due to roadwork, special events such as sport games and strikes, and adverse weather.

Congestion involves slower speeds, queuing and increased trip times, which impose higher costs on the economy and also generate impacts on urban regions and their inhabitants. Congestion also has a range of indirect impacts including the marginal environmental and resource impacts of congestion, impacts on the quality of life, stress, and safety as well as impacts on non-vehicular road space user such as the users of sidewalk and road frontage properties.

Congestion means just waste of valuable time and health. The time wasted in congestion could effectively be used in doing some productive work. The sudden stop and go driving pattern in congestion leads to the more fuel consumption in the city and thereby increasing the pollution level in the city by emitting more carbon into the environment. The slow speed of vehicle in the traffic jams also leads to the emission of oxides of nitrogen and some hydrocarbons which is major culprit of a term known as photo chemical smog.

Traffic congestion measures can be categorized into four broad groups: basic measures; ratio measures; level of service; and indices. Traffic congestion cost consists cost of travel time delay, cost of excess fuel consumption due to delay and co2 emission cost.

Previous study failed consider in work evaluation of traffic management systems in Mekelle. This study will fills this gap with estimate problems of traffic congestion for the intersection users and society in terms of cost and come up with solving problem techniques.

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1 General

To accomplish thesis objectives data was gathered from different sources. This portion of study includes the methods of data collection and sources of data. Primary and secondary data was collected those data consists using observation survey, performing interviews with workers on different sectors, the manual traffic counts, Field measures.

To select the study road first the researcher performed interview with the traffic police those who works on different part of the city and transport bureau of Mekelle city; then they provide information about the total city road traffic flow condition. According to their information most of the Mekelle city intersection are impose to traffic congestion by different cases. Reviewing previous study works on city also performed in order to select the specific area of the study. The previous study result at CBE four leg signalized intersection presented in Mekelle University by Alemayehu Aadi in (2017) title of performance evaluation of signalized intersection shows the intersection is very congested with level of service F at all approach. Other study conducted by Hanna Seboka (2018) presents the traffic volume and delay at intersections CBE and is very high.

3.2 Sampling Technique

There are about thirteen major intersections in Mekelle city of those intersections five are roundabout but, this study is limited to concentrate at cross intersection only. Sampling technique is needed to select specific intersections in which detailed study will be conducted. The intersections should definitely be selected based on their traffic volume in order to conduct a problem solving research. Therefore, a purposive sampling technique is used in this research to purposefully solve congestion problems. Traffic volume count was conducted at seven intersections at peak hour period starting 7:00-9:00AM morning, 12:00-2:00pm noon and 5:00-7:00pm evening. Signalized intersection around CBE main branch and unsignalized intersection around REST was found with highest traffic volume then selected for the study.

3.3 Description of the Study Area

Mekelle is the capital city of Tigray National regional state and it is located around 780 km north of the Ethiopian capital city Addis Ababa with an elevation of 2254m above sea level. Mekelle has a population of about 383,000 making it the biggest city in Tigray. According to study of Mekelle City (transportation plan and implementation study of Mekelle city, 2011) Mekelle is divided into seven local administrations: Hawelti, Adi-Haki, Kedamay Weyane, Hadnet, Ayder, Semien and Quiha. Within each local administration there are kebeles or ketenas. The sub cities have a unique administrative relationship with the regional government.

3.3.1 Description of Selected Study Area

The selected study area for estimation of traffic congestion cost are intersection at CBE Mekelle main branch and REST intersection. CBE intersection is located at 13º29'22.68"N 39º28'9.77"E, in Kedamay weyane sub city. The kedamay weyane Sub city is called to be the central zone of the city with high traffic attraction from other zones of the city stated in the origin destination matrix study of Mekelle City (transportation plan and implementation study of Mekelle city, 2011). It is four-legged fixed timing signal controlled intersection with two number of lanes from each approach roads. The average width of lanes is about 3.5 m and the two opposite approaches Romanat and Abrha Castl have median sized about 1.0 m but the rest two opposite approaches have no median. The surface of the three approach roads are made of asphalt but the fourth approach Enda Michael approach is made of cobble stone.

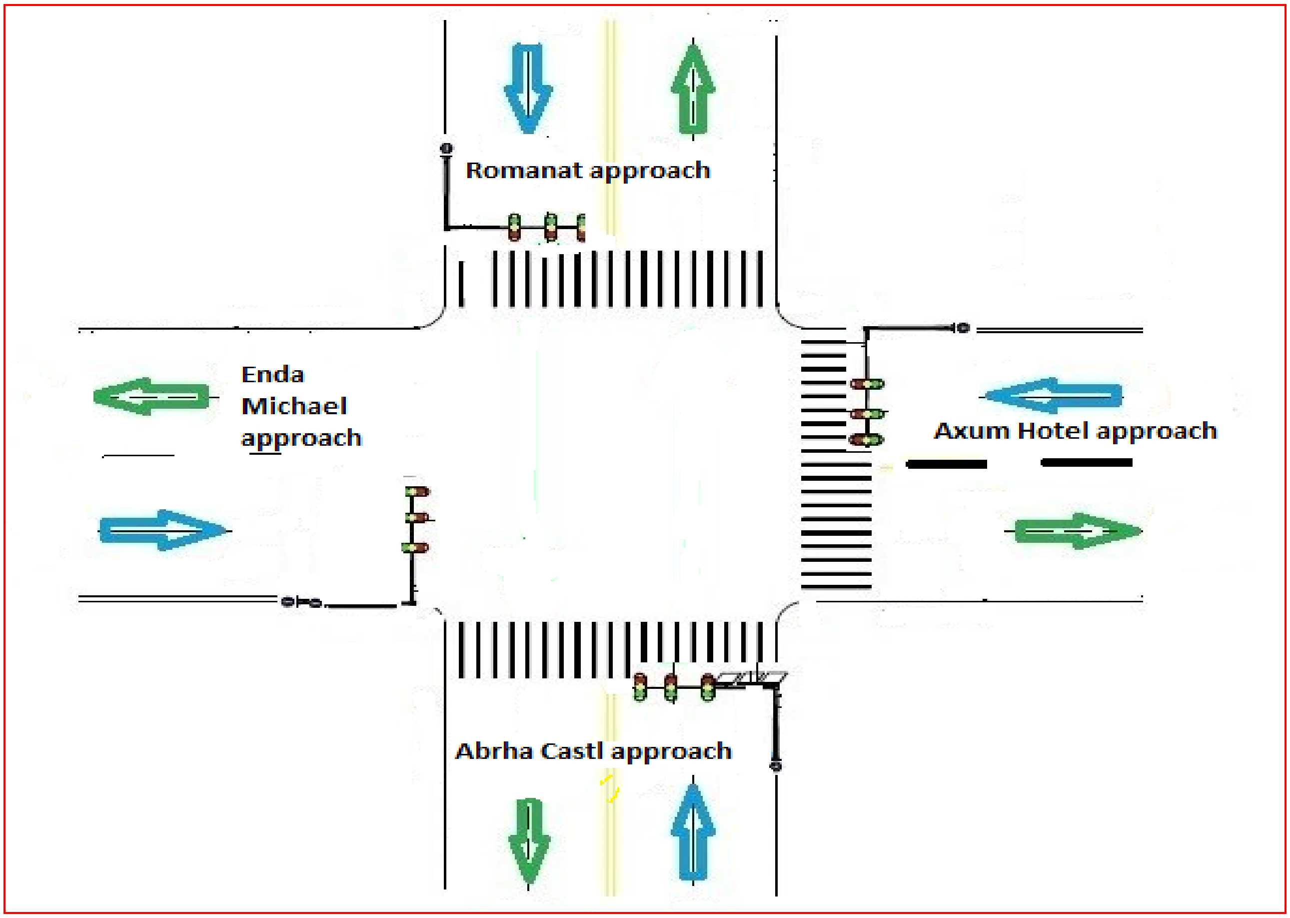

Figure 1 Main CBE intersection

The second intersection is along the REST organization located at 13º29'14.75"N 39º28’17.75’’E in Hadnet sub city with four approach legs. These are along Axum hotel approach along CBE main branch approach, approach along Grand Awash and approach along Atse Yohannes primary school. It is impounded by many colleges, banks, shops, business centres, restaurants and café, hotels, offices and other services (Tele, Ethiopian airlines office). This intersection traffic light was not functional for about two years but now a day the signal was maintained and giving service.

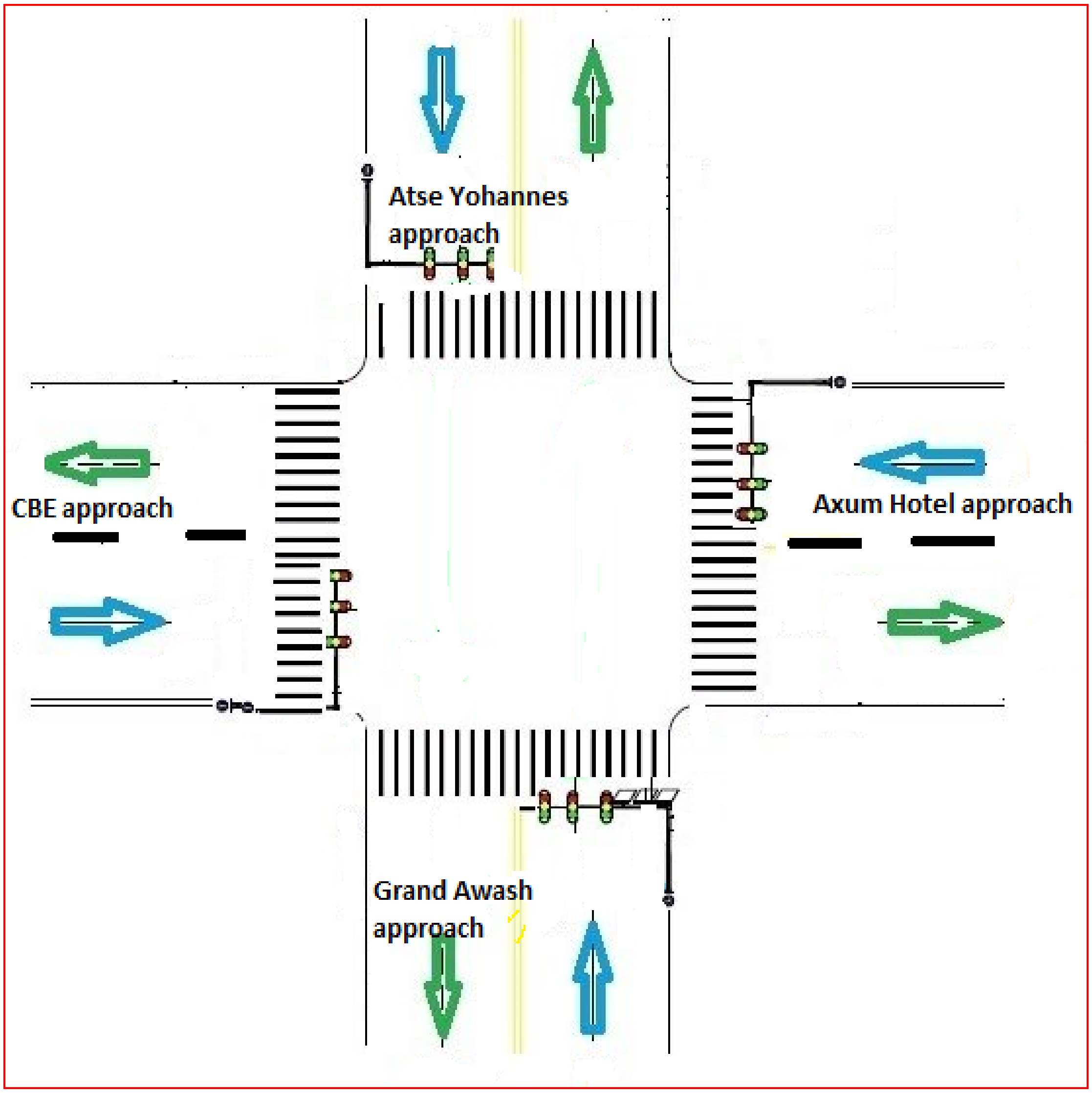

Figure 2 REST Intersection

3.4 Research Procedures

The methodology flow chart, which consists of the detail works and procedures of the study is shown below.

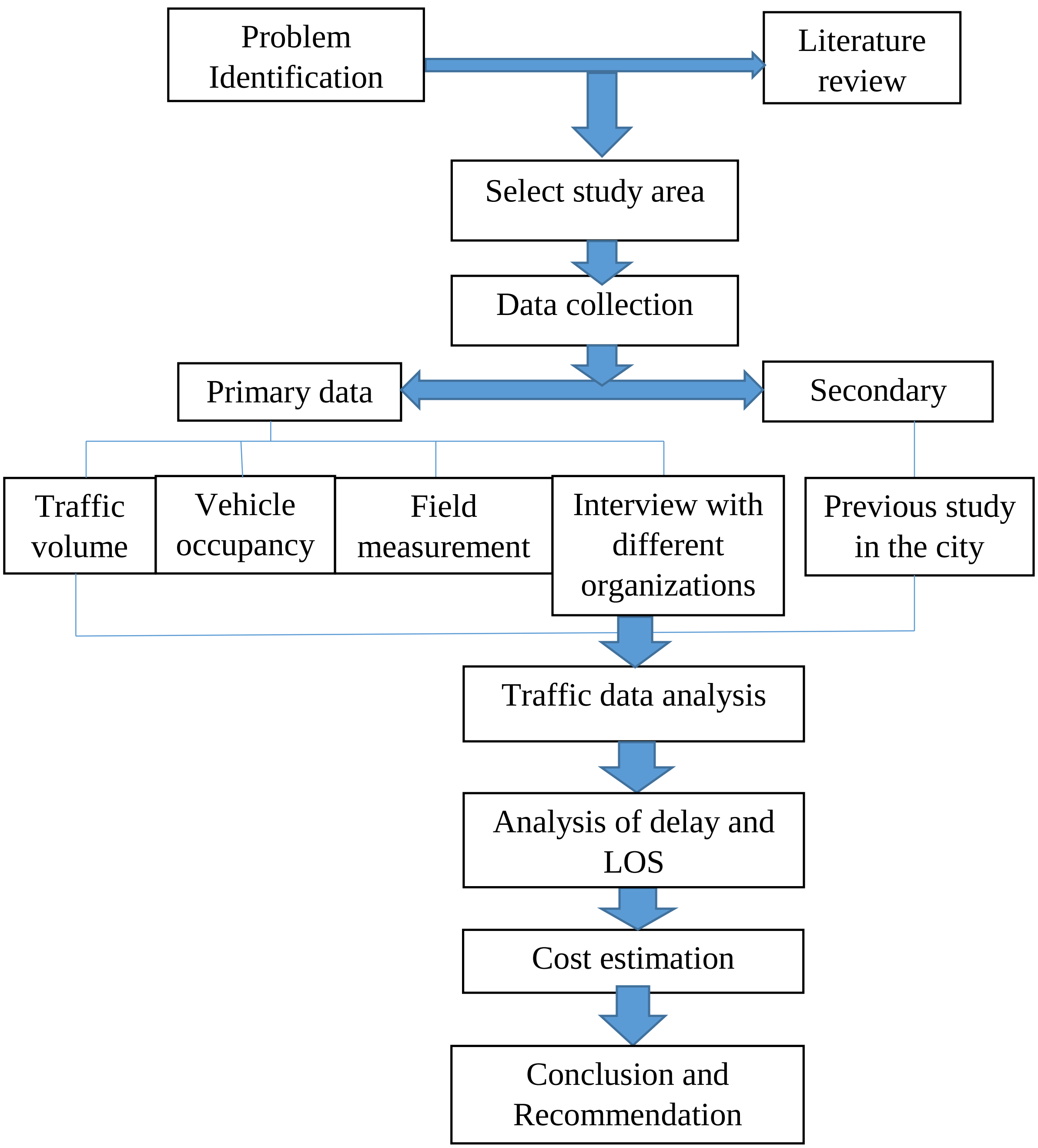

Figure 3 flow chart of the research process

3.5 Research Methods

In this study like other research works, firstly reviewing literatures and describing the study area was made in order to fill the previous works gap and to set the boundaries or scope of the study. Next the data collection process was performed. In this stage all the necessary data for the analysis of delay and level of service like traffic volume, filed measurement related with cross sectional elements of the roadway was collected. In addition, vehicle occupancy and daily labour cost data was collected to estimate the traffic congestion cost. Then data analysis was made to get the result and based on the finding the possible recommendation was put.

3.6 Data collection

3.6.1 Traffic Volume Data

For the analysis of level of service to determine the peak period and peak flow rates, determine and identify the flow form in the facility, to assess the correlation between traffic volume and the congestion condition, traffic volume count data are very important. And traffic volume count data also required for analysing the level of service of a facility and quantifying the congestion intensity. Traffic count during Monday morning and Friday afternoon shows extremely high volumes and are not suggested normally to use for the analysis, therefore, counts are usually conducted on Tuesday, Wednesday and Thursday (Smith, 2002).

According to transportation plan and implementation study of Mekelle city (2011), the survey Conducted in the city, 59.6% of the trips are for going to or from work, 9.7%, for shopping, 11.7% visiting relatives and friends, 5.4% recreation and 13.7% for others and follow-up of different cases. Since, the highest share is made by working trips, the traffic volume count was done on the weekday. According to the traffic police information, with in the week almost all the day presence congestion, but the traffic volume on Monday is very congested than the other days then based on the traffic volume count guide and traffic police who works on the intersection information the data collection was done by using video camera on Tuesday, Wednesday and Thursday at signalized CBE intersection and at REST intersection.

During the peak hour (morning, noon and evening) traffic congestion becoming daily and it is commonly present of long line to find transport service (Mesele & Tsehaye, 2016). The traffic volume count was made using video recording starting in the morning peak time 7:00AM-10:00AM, noon 11:00 AM-2:30 PM and the evening peak time 4:30 PM-7:30 PM at 15 minutes interval. The vehicles were counted by type; passenger's car and truck. The passenger's cars category includes vehicle types namely; Motorcycle, Bajaj, cars and taxis, pickup & 4WD, minibus taxi, mid-bus and standard bus, whereas the truck category include vehicle types of light commercial vehicle and truck. After collecting the data traffic volume count has been made then the peak hour volume by vehicle type shown below:-

Table 4 Peak Hour Volume by Vehicle Type at CBE Signalized Intersection Vehicle per hour

Approaches	Bajaj	Car& Taxi	Pickup & 4WD	Mini Bus Taxi	Medium Bus	Bus	Motor Cycle	Small Truck	Medium Truck
Romanat	195	195	219	213	3	9	49	5	11
Enda Michael	107	81	83	40	2	2	21	3	8
Axum Hotel	151	130	143	49	1	8	31	4	7
Abrha castl	198	194	217	221	1	4	32	6	9

Table 5 Peak Hour Volume by Vehicle Type at REST Unsignalized Intersection Vehicle per hour

Approach	Bajaj	Car& Taxi	Pickup & 4WD	Mini Bus Taxi	Medium Bus	Bus	Motor Cycle	LCV	Medium Truck
CBE	75	72	94	92	2	3	30	18	5
Atse Yohannes	226	185	241	278	5	7	28	34	11
Axum Hotel	193	173	162	166	4	5	29	23	9
Grand Awash	157	158	194	114	10	6	26	31	8

Table 6 Peak Hour Volume by Vehicle Type at REST Signalized Intersection Vehicle per hour

Approach	Bajaj	Car& Taxi	Pickup & 4WD	Mini Bus Taxi	Medium Bus	Bus	Motor Cycle	LCV	Medium Truck
CBE	56	61	82	97	2	2	28	25	9
Atse Yohannes	187	190	206	278	3	7	32	37	10
Axum Hotel	180	182	155	176	4	8	24	34	8
Grand Awash	86	163	181	114	6	6	28	38	9

3.7 Vehicle Occupancy Data

Vehicle occupancy is the number of person per each vehicle data which uses for the estimation of travel time cost. The vehicle occupancy was collected manually using paper and pencil. Data recorders were stand along the roadside of the entry to the intersection and observed the passing vehicle type and recorded the number of occupants with in the vehicle (Heidtman, et al., 1997). For the Medium bus and standard bus the sample size was used only the average of peak hour volume vehicle occupancy. Based on traffic engineering vehicle occupancy data collection manual (2007), vehicle occupancy data was collect by recording each person in each vehicle including driver during peak hour and the sample size should be as follow:-

Table 7 Minimum Sample Size to collect Vehicle Occupancy

Confidence level	99%	98%	97%	96%	95%	94%	93%	92%	91%	90%
Sample Size	19,208	4,802	2,134	1,201	768	534	392	300	237	192

Source; Traffic Engineering Manual (2007)

In this study the minimum sample size 192 at confidence level of 90% was used for the vehicle occupancy data collection of car & taxi, pickup & 4WD, minibus taxi and Bajaj but for bus it is difficult to count standing along the roadside due to this reason simply used average vehicle occupancy by making interview with the drivers of bus.

3.8 Field Measurements

For all traffic engineering studies time is a principal parameter, for the quality of collected data selection of a particular time interval has a significant role. But there is no difference in the measured or collected data of field measures because the geometric characteristics of the road is a permanent feature of the road, which is observed throughout the design period of the roadway. Therefore, field data's can be collected at any month of a year, any weeks of a month, any days of a week and any hours of a day without any interval or duration.

For the analysis of delay and level of service using SYNCHRO Software as input geometric data including area type, Number of lanes (N), average lane width (W), Median width and Grade (G) was collected. The width of traffic lane and median measurement were done manually using tape meter.

Table 8 Geometric Data for CBE intersection

Approach	Number of lane	Lane width (m)	Median width (m)	Grade (%)	Cross walk
Romanat	2	3.5	1	2	Yes
Enda Michael	2	3.5	0	1	NO
Axum Hotel	2	3.5	0	-2	Yes
Abrha Castl	2	3.5	1	-3	Yes

Table 9 Geometric Data for REST intersection

Approach	Number of lane	Lane width (m)	Median width (m)	Grade (%)	Cross walk
Main CBE	2	3.5	0	2	Yes
Atse Yohannes	2	3.5	1	1	Yes
Axum Hotel	2	3.5	0	-2	Yes
Grand Awash	2	3.5	1	-3	Yes

3.9 Other Data Related to Traffic Congestion Cost

For the analysis of traffic congestion cost the data like daily labour value (birr/day), fuel value (birr/litre) and CO_2 pricing (US$/ton) also collected by different methods. The daily labour cost varies from season to season, year to year and place to place due to this reason there is no fixed value. Therefore for this study data of daily labour was collected by making interview with different construction area like seasonal workers consist of digging, carrying to and from the work site, load and unload of truck, hotels and restaurants which consists porter, waiter, garages and transportation facilities consist of taxi conductors and from other daily workers like garden workers, cleaning workers and guard. The average value (birr/day) was used for the analysis. Fuel value (birr/litre) also gate from the fuel station. And the co2 credit was used from literatures of carbon pricing.

3.10 Data Analysis

In this section the procedures and methods used to analyze the data collected in the field like traffic volume, vehicle occupancy and field measurement are discussed. Also based on the collected data how to analyze the traffic congestion measurements such as delay, level of service and cost estimation are included.

3.10.1 Traffic Volume Study

In this study the main objective of analysing the traffic volume count is to get the Peak hour volume, which is needed to determine the peak hour factor, level of service, delay and to estimate cost of congestion. The traffic volume count is done for three days at each intersection in order to get the maximum hourly volume of vehicles. Based on the count, the PHV was found at 12:00AM-1:00pm at CBE four leg signalized intersection, at 6:15PM-7:15PM for REST four leg signalized intersection and 6:00PM-7:00PM for REST four leg unsignalized intersection.

In relation to the PHV, another parameter used in the analysis of traffic volume is PHF. It is done based on the result of PHV that is, after selecting an hour with maximum number of vehicles; the 15-minute volume split is prepared for this analysis. Then by using the following HCM equation, it can be computed to know the distribution of vehicles at those separate 15-minutes.

$$PHF= \frac{PHV}{4*Vpeak\ 15-min} \quad \ldots\ldots\ldots\ldots \quad \text{Eq.3.1}$$

The value of PHF indicates the distribution of volume of vehicles within the hour which means if the value of PHF approaches to one it describes that the hourly volume is evenly distributed to the 15-minutes volume or the flow rate is more or less the same as the hourly volume. But if the result of PHF is far from one that means the PHV is largely dominated by one specific 15-minute interval volume. Another parameter determined from traffic volume study is vehicle classification and turning movement. In this study the data analysis was conducted by directional movement with respect to the vehicle class as shown below.

Table 10 Peak hour turning movement volume (Veh/hr) for CBE intersection

	Total traffic volume		
Approach	LT	TH	RT
Romanat	137	708	80
Enda Michael	161	118	128
Axum Hotel	158	53	279
Abrha Castl	62	647	131

Table 11 Peak hour turning movement volume (Veh/hr) for REST Unsignalized intersection

Total traffic volume			
Approach	LT	TH	RT
Main CBE	263	357	179
Atse Yohannes	385	130	93
Axum Hotel	358	279	646
Grand Awash	139	280	245

Table 12 Peak hour turning movement volume (Veh/hr) for REST signalized intersection

	Total traffic volume		
Approach	LT	TH	RT
Main CBE	212	280	207
Atse Yohannes	407	328	152
Axum Hotel	392	361	350
Grand Awash	99	286	189

To assess the congestion severity and level of service using the SYNCHRO software the existing cycle time of the signal uses as input data. Therefore, the cycle time of the signal of each intersection shown on table below are used for the analysis.

Table 13 Cycle time of CBE signalized intersection

	Cycle time (second)		
Approach	Green	Yellow	Red
Romanat	18	5	83
Enda Michael	14	5	87
Axum Hotel	15	5	86
Abrha Castl	18	5	83

Table 14 Cycle time of REST signalized intersection

	Cycle time (Second)		
Approach	Green	Yellow	Red
Main CBE	15	5	92
Atse Yohannes	25	5	82
Axum Hotel	22	5	85
Grand Awash	22	5	85

3.11 Passenger Car Unit

Different types of vehicles in a traffic stream have variations in characteristics like width, length and height and sometimes they produce inconvenience for other vehicles, so for expressing highway capacity a unit is used called passenger car unit. A passenger car unit is essentially the impact that a mode of transport has on traffic variables (such as headway, speed, density) compared to a single car. PCU refers to the relative value of different categories of vehicles with respect to a passenger car. Accordingly, to convert vehicles to a single unit the software uses 2 for the heavy vehicles and 1 for the other type of vehicle.

3.12 Ideal Flow Rate and Saturation Flow Rate

The saturation flow rate is the flow in vehicles per hour. The saturated flow rates are the actual maximum flow rate for this lane group after adjusting for all of the interference factors. The saturated flow rates represent the number of lanes multiplied by the ideal saturated flow rate and interference factors due to heavy vehicles, buses, parking manoeuvres, lane widths, area type, grade, and turning movements. The saturated flow rates are used in capacity and delay calculations, and for optimization calculations. The saturated flow rates are calculated based on the following;

$S = S_o * N * Fw * Fn * Fhv * Fg * Fp * Fbb * Fa * Flu * Flt * Frt * FLpb * FRpb$ …… Eq. 3.2

Where

S= saturation flow rate for subject lane group, expressed as a total for all lanes in lane group (Veh/hr);

S_o= base saturation flow rate per lane (pc/h/ln);

N= number of lanes in lane group;

f_w= adjustment factor for lane width;

f_{hv}= adjustment factor for Heavy vehicle in traffic stream

f_g= adjustment factor for approach grade;

f_p= adjustment factor for existence of a parking lane and parking activity adjacent to lane group;

f_{bb}= adjustment factor for blocking effect of local buses that stop with in intersection area

f_a= adjustment factor for area type;

f_{Lu}= adjustment factor for lane utilization;

f_{Lt}= adjustment factor for left turns in lane group;

f_{RT}= adjustment factor for right turns in lane group;

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

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

Highway Capacity Manual (HCM, 2010) describes that, Ideal flow rate or base saturation flow rate is usually taken 1900 vphpl. The software also uses 1900vphpl.

3.13 Cost Estimation

The cost of traffic congestion in this study focused on three components those are 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.

In this research after analysis the traffic congestion in order to estimate the traffic congestion cost delay was used from the output of software. The estimated traffic congestion cost consists of the travel time cost (passenger income lost due to extra travel time delay), fuel consumption cost (excess fuel consumption due to delay) and associated CO_2 emission cost due to excess fuel consumption.

3.13.1 Travel Time Cost

After estimating the travel time delay the passenger income lost can be calculate using the base income of daily labour. Income lost can get total intersection delay per peak hour multiplied by labour cost (birr/hour) multiplied by average vehicle occupancy multiplied by number of vehicle at peak hour by vehicle mode. The peak hour delay was used from the software output of delay and level of service analysis. The average vehicle occupancy was collected based on traffic engineering vehicle occupancy data collection manual. Based on traffic engineering manual (2007) minimum sample size for 90% confidence level is 192 vehicles. And the following formula used for the computation of travel time cost (passenger income lost due to extra travel time).

TTC= TSD x NV x AVO x LC ……………………………………………………….Eq. 3.3

Where; TTC = Travel time cost (birr) = passenger income lost (birr)

TSD =Total delay at peak hour (Vehicle-Hr)

NV= Number of vehicle

AVO = Average vehicle occupancy (person/veh)

LC = labour cost (birr/day)

3.13.2 Total Fuel Consumption Cost

The total fuel consumption cost was calculated from idling fuel consumption (Lit/hr) of different mode of vehicle multiplied by total intersection delay per hour (Vehicle-Hr) multiplied by fuel cost (birr/litre) multiplied by total number of vehicle at peak hour respecting with their mode. The idling fuel consumption was used from different literatures.

3.13.3 CO_2 Emission Cost due Excess Fuel Consumptions.

Traffic congestion creates excess fuel use due to this reason the extra fuel consumption causes to increase co_2 emission. Because increase fuel consumption on the road means emission increase (Shoaeb, et al., 2016).

To estimate co_2 emission cost it is necessary to know amount of co_2 per litre for diesel as well as gasoline. For this study, the vehicle emission factor for any diesel use vehicle is used 2.67 kgco_2/litre and for gasoline use vehicles is 2.42kg co_2/litre (Federal Democratic Republic of Ethiopia, 2011).

According to the World Bank's state and trends of carbon pricing the carbon tax rate is US$5/t$CO_2$e (Telaye, et al., 2019). Based on this for the estimation of co_2 gas emission cost $ 5 USD was used.

CHAPTER FOUR

4. ANALYSIS, RESULT AND DISCUSSION

The analysis was done by using the collected data as input for the selected intersections. The analysis was done also by using the world acceptable manuals like HCM and other related manuals and a SYNCHRO studio which is worldwide acceptable and one of the leading traffic analysis application. Following the analysis the outcomes and results are presented and the full discussion and explanation is presented briefly in this chapter and the detail results are presented in detail in the following sections.

4.1 Traffic Volume Analysis

From the video captured data traffic volume count by the different type of vehicle was done. The traffic count was conducted for three hours of each peak time and off-peak period of time of the day for all approaches of the two intersections. Directional traffic volume count also conducted at 15 minute interval.

4.1.1 Traffic Volume at CBE Intersection

This intersection is located at the centre of the city. The traffic count was done starting from 7:00AM-10:00AM morning, 11:00AM-2:30PM noon and 4:30PM-7:30PM evening on each approach's. Accordingly Abrha Castl and Romanat approach have high number of traffic volume at the morning, noon of the day and evening period but the morning and evening period volume is relatively less than the noon period. And Axum Hotel approach shows relatively lower volume than Abrha Castl and Romanat approach. Enda Michael approach have the lowest traffic volume throughout the day. The traffic count data shows the traffic volume at CBE intersection on Tuesday was the highest peak hour volume then used for the analysis.

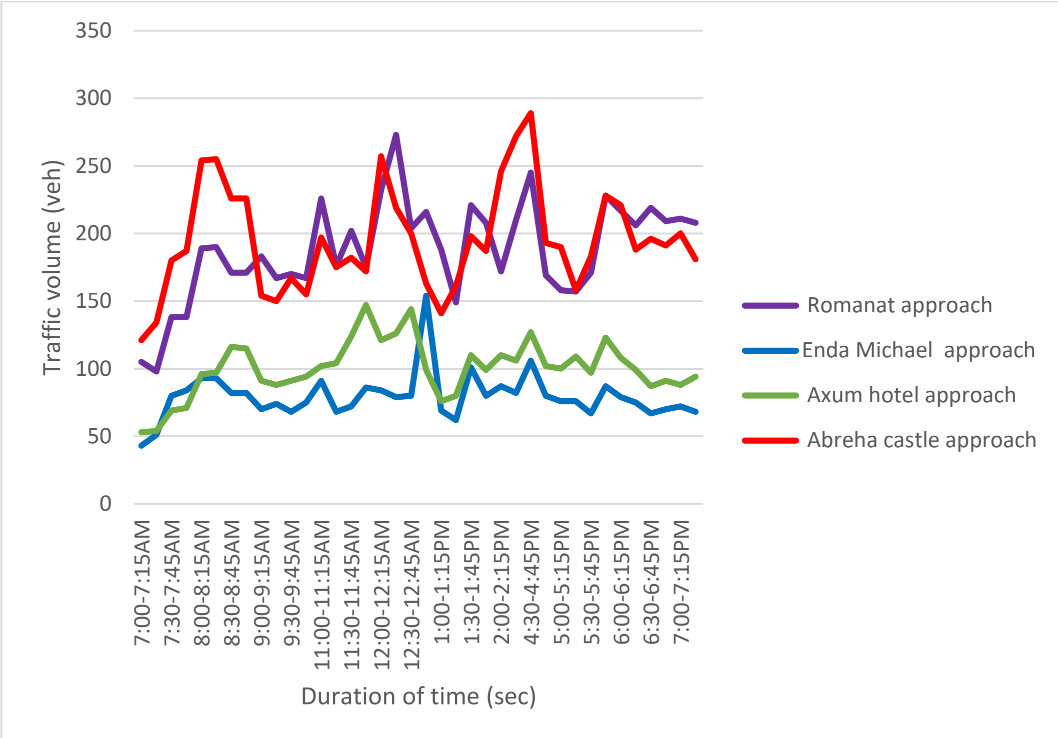

Figure 4 Total traffic volume count data at CBE intersection

Table 15 Traffic volume by vehicle class at CBE signalized intersection

	Abrha Castle approach	Romanat approach	Enda Michael approach	Axum Hotel approach
Bajaj	1092	1416	910	981
Car& Taxi	1283	1493	816	1042
Pickup & 4WD	1463	1721	738	1092
Mini Bus Taxi	2072	1789	555	619
Medium bus	9	9	11	12
Standard BUS	37	48	31	33
LCV	161	197	119	123
Medium Truck	34	41	48	39
Motor cycle	216	251	72	123

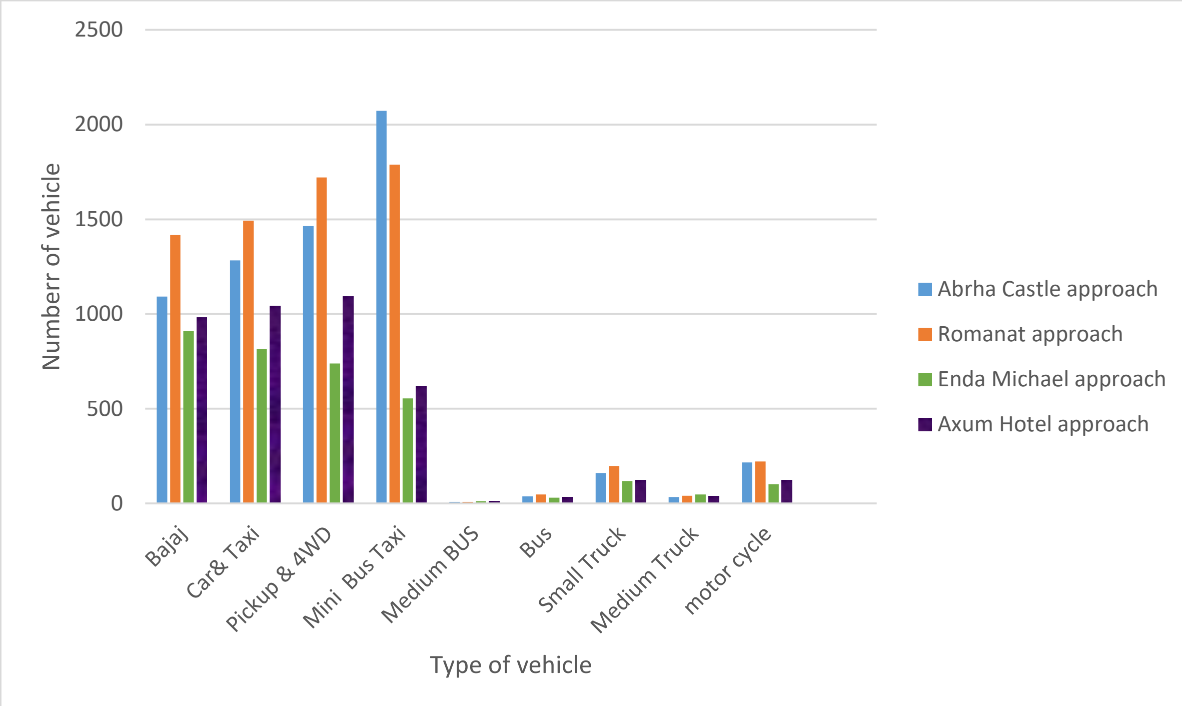

Figure 5 Traffic volume by vehicle type at CBE intersection

Traffic composition by vehicle class of each approach of Main CBE intersection figure 5 shows mini bus taxi, pickup & 4WD, car & taxi and Bajaj have high volume but medium Bus, standard Bus, small truck medium truck, large truck and motor cycle shows low volume. Among the four approaches, the Abrha Castl approach have high volume of mini bus taxi composition and Romanat approach is next to Abrha castl approach by minibus taxi volume. Axum Hotel approach have the highest volume of pick up & 4WD of the four approach but Enda Michael approach have the highest volume of Bajaj of the four approaches.

4.1.2 Traffic Volume at REST Intersection

This intersection connects the Atse Yohannes elementary school - Abrha castl road with the major road of Commercial Bank of Ethiopia-Axum Hotel. This intersection was previously unsignalized intersection but on the month of June the traffic light was installed, consequently due to this reason traffic volume data was collected in both at the absence of traffic light and after traffic signal installed then the analysis also done for both cases.

4.1.2.1 Traffic Volume at REST Unsignalized Intersection

Traffic count was done for three days starting from 7:00AM-10:00AM morning, 11:00AM-2:30PM noon, and 4:30PM-7:30PM evening on each approach. From the collected traffic volume data the highest peak hour volume was found on Tuesday then used for the analysis.

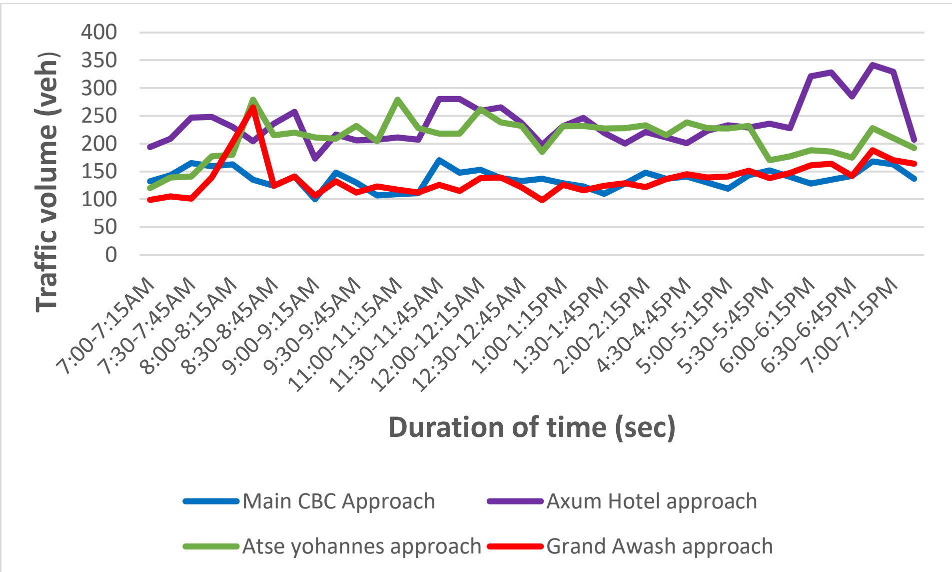

Figure 6 Total traffic volume count data at REST unsignalized intersection

Figure 6 shows traffic volume of CBE and Axum Hotel approach have the highest volume at the evening. But the traffic volume of Atse Yohannes have the highest volume on midday on the other hand Grand Awash approach have the highest traffic volume on morning period of the day.

Table 16 Traffic volume by vehicle class at REST Unsignalized intersection

	Main CBE approach	Atse Yohannes approach	Axum Hotel approach	Grand Awash approach
Motor cycle	173	267	281	181
Bajaj	1055	1532	2105	825
Car& Taxi	1175	1572	1951	1012
Pickup & 4WD	1185	1942	2637	1248
Mini Bus Taxi	1015	2076	2208	782
Medium BUS	11	12	10	9
Bus	48	53	58	56
LCV	161	191	179	165
Medium Truck	25	39	71	43

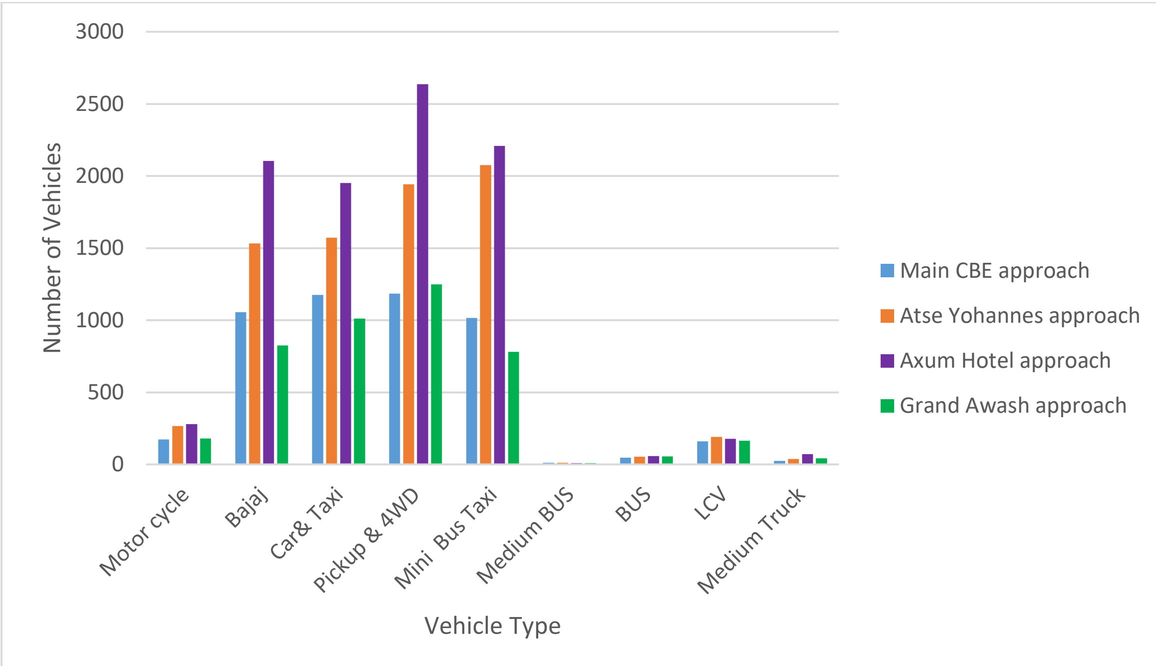

Figure 7 Traffic volume by vehicle type at REST unsignalized intersection

Like Main CBE Intersection REST intersection also have different types of vehicle composition. As we have seen from the above figure 7 pickup & 4WD have the highest vehicle composition in all four approaches. Mini bus taxi have the highest volume composition of vehicles at Axum Hotel approach and Atse Yohannes approach. When we see the volume of Bajaj the highest volume have Axum hotel approach but, Grand Awash approach have the lowest volume. The composition of Medium Bus in all approach shows the lowest volume.

4.1.2.2 Traffic Volume at REST Signalized Intersection

For the signalized intersection traffic count was performed starting from 7:00AM-10:00AM morning, 11:00AM-2:30PM noon and 4:30PM-7:30PM evening on each approach. From the collected traffic volume data the highest volume of vehicle was found on Wednesday then uses for the analysis.

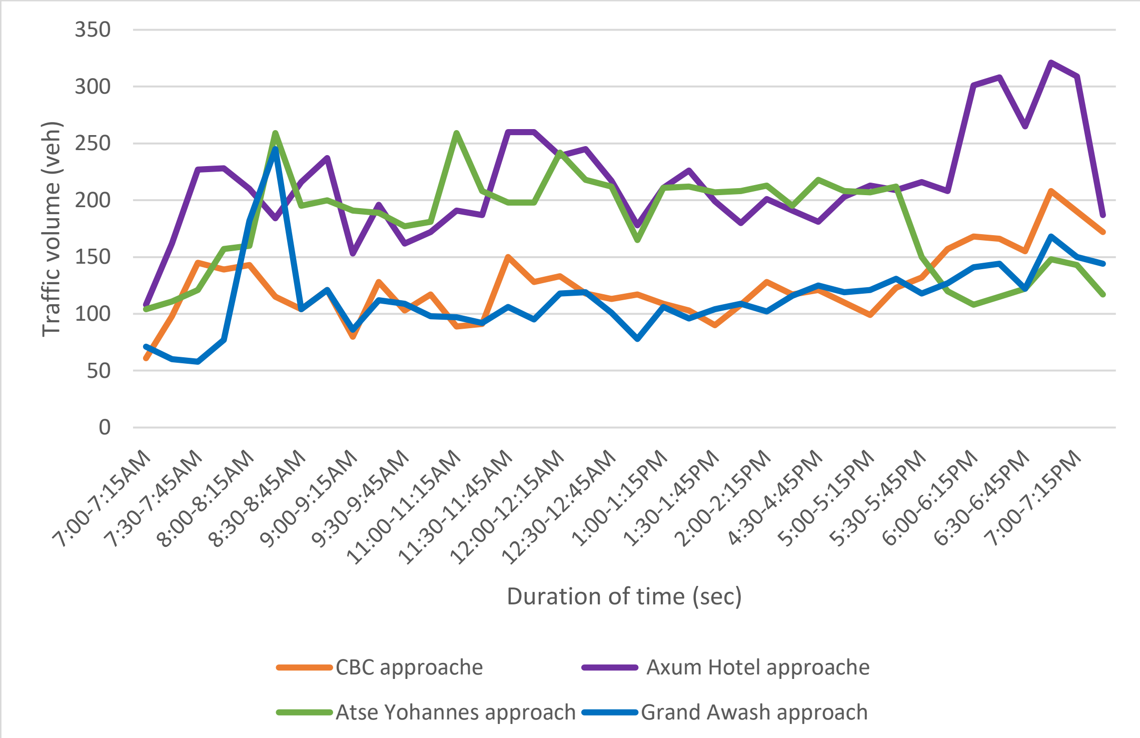

Figure 8 Total traffic volume count data at REST signalized intersection

The above figure indicates that the number of vehicles at Main CBE and Axum Hotel approach have the highest volume at the evening period. But Atse Yohannes and Grand Awash approach shows the highest volume at the morning period.

Table 17 Traffic volume by vehicle class at REST signalized intersection

vehicle type	Main CBE approach	Atse Yohannes approach	Axum Hotel approach	Grand Awash approach
Motor cycle	141	225	239	149
Bajaj	899	1388	1963	949
Car& Taxi	1009	1308	1689	1096
Pickup & 4WD	1099	1778	2338	1220
Mini Bus Taxi	749	2312	1925	606
Medium BUS	9	11	12	8
Bus	45	54	49	47
LCV	149	179	167	153
Medium Truck	33	47	79	51

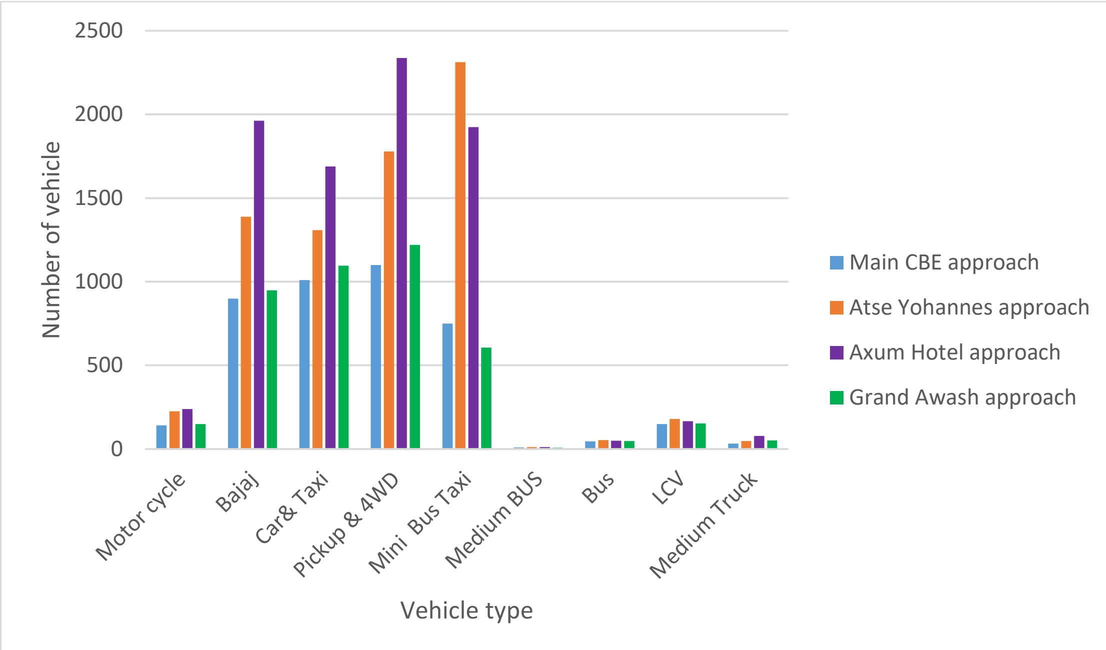

Figure 9 Traffic volume by vehicle type at REST signalized intersection

The traffic volume by vehicle class figure 9 shows Axum Hotel approach have the highest volume by pick up & 4WD but by Mini bus taxi Atse Yohannes approach have the highest volume. Main CBE approach shows the lowest volume with all vehicle class when we compare to the other approach of the intersection. The traffic composition of medium bus shows lowest volume at all approach.

4.2 Intersection Level of Service Analysis

It is necessary to check whether the intersections are congested or not, in this study analysis was done using SYNCHRO software. It is roughly equivalent to the HCM 2000. Due to the availability of traffic flow data the level of service (LOS) was done for the two intersections.

For the analysis purpose of intersection level of service the existing operational geometric feature of the intersection, the directional hourly volume data, the peak hour factor and the proportions of heavy vehicles were used as an input data for the SYNCHRO software.

Table 18 Input data for level of service analysis of CBE signalized intersection

Approach	number of lane	Lane width (m)	Grade (%)	Cross walk width	Median width (m)	Peak hour volume			Peak hour factor (%)			Heavy Vehicle factor (%)		
						LT	TH	RT	LT	TH	RT	LT	TH	RT
Romanat	2	3.5	2	1.5	1	137	708	80	55.2	78.7	80	4.4	0.85	8.75
Enda Michael	2	3.5	1	1.5	0	161	118	128	65.9	67	65.3	2.5	2.5	2.3
Axum Hotel	2	3.5	-2	1.5	0	158	53	279	80.6	69.7	90.5	3.1	7.5	2.1
Abrha castl	2	3.5	-3	1.5	1	62	647	131	57.4	78.9	65.5	3.2	1.2	5.3

Table 19 Input data for level of service analysis of REST unsignalized intersection

Approach	number of lane	Lane width (m)	Grade (%)	Cross walk width	Median width (m)	Peak hour volume			Peak hour factor (%)			Heavy Vehicle factor (%)		
						LT	TH	RT	LT	TH	RT	LT	TH	RT
Main CBE	2	3.5	2	1.5	0	160	174	154	83	82	82	7.6	5	9.5
Atse Yohannes	2	3.5	1	1.5	1	521	438	204	96	92	85	1.8	4.6	9.6
Axum Hotel	2	3.5	-2	1.5	0	198	146	200	84	87	86	3.3	4.6	2.5
Grand Awash	2	3.5	-3	1.5	1	139	317	223	59	89	84	7.2	2.1	4.1

Table 20 Input data for level of service analysis of REST signalized intersection

Approach	number of lane	Lane width (m)	Grade (%)	Cross walk width	Median width (m)	Peak hour volume			Peak hour factor (%)			Heavy Vehicle factor (%)		
						LT	TH	RT	LT	TH	RT	LT	TH	RT
Main CBE	2	3.5	2	1.5	0	150	188	130	91	85	83	8	7.1	7.2
Atse Yohannes	2	3.5	1	1.5	1	512	341	205	93	96	87	4.7	6.4	5.2
Axum Hotel	2	3.5	-2	1.5	0	99	261	164	71	92	77	3	3.9	5.4
Grand Awash	2	3.5	-3	1.5	1	179	278	207	91	83	91	14	8.7	5.8

Table 21 LOS Output for CBE Signalized intersection

Signalized Main CBE intersection			
Intersection	Approach	Delay (sec)	LOS
Main CBE	Romanat	490.3	F
	Enda Michael	200.1	F
	Axum Hotel	171.3	F
	Abrha castl	655.8	F

For Main CBE signalized intersection level of service analysis was done using input data from Table 18 and the output result was presented on Table 21. From the result all approaches of the intersection have very high delay with level of service F. But when we compare the approach delay with in the intersection the Abrha Castl approach have exceptional delay and the Romanat approach have very high delay next to Abrha Castl approach. The Enda Michael approach and Axum hotel approach have lower delay than Romanat and Abrha castl approach.

Table 22 LOS Output for REST Unsignalized intersection

Unsignalized REST intersection							
Unsignalized Intersection	Approach	Delay (sec)			LOS		
		LT	TH	RT	LT	TH	RT
REST	Main CBE	80.6	70.8	60.9	F	F	F
	Atse Yohannes	695.3	465.6	235.9	F	F	F
	Axum Hotel	94.4	81.6	68.9	F	F	F
	Grand Awash	189.5	189.4	189.3	F	F	F

Based on the data shown on Table 19 analysis was done and the output result is presented on Table 22 accordingly, Atse Yohannes approach have level of service F for both turning and through movement with very high delay but the left and through movement of Atse Yohannes approach have high delay than right turn movement. When we see the Grand Awash approaches it have level of service F with similar delay in both turning and through movement. But Main CBE and Axum Hotel approach have level of service F with lower delay compare with the other approach in both turning and through movement. Generally, the REST Unsignalized intersection have level of service F with very high delay.

Table 23 LOS Output for REST Signalized intersection

Signalized REST intersection			
Intersection	Approach	Delay (sec)	LOS
REST	Main CBE	230.8	F
	Atse Yohannes	358.9	F
	Axum Hotel	97.8	F
	Grand Awash	194.5	F

Using the input data from Table 20 level of service analysis was performed at REST signalized intersection and the output result is presented on Table 23 level of service analysis result shows all approaches have very high delay and level of service F. But when we compare each approaches with in the intersection Atse Yohannes approach shows very high delay and Main CBE approach also have very high delay next to Atse Yohannes approach. Of those approaches Axum Hotel approach have lower delay.

Generally, the level of service analysis result for Main CBE signalized intersection, REST signalized intersection and REST Unsignalyzed intersection shows very high delay with level of service F.

4.3 Cost of Traffic Congestion

To estimate cost of traffic congestion a number of parameters to be used in the analysis. But it was difficult to obtain all the parameters to determine the cost of traffic congestion at the intersections. Travel time cost, fuel consumption cost and associated CO2 emission cost due excess fuel consumptions are the three main costs of traffic congestion.

4.3.1 Travel Time Delay Cost

Travel time delay costs is represented by the opportunity costs of wasted time on congested roads, is the major donor to the overall cost of congestion. To estimate cost of passenger wasted time it is necessary to know total delay per day (Vehicle-Hr), number of vehicle, average vehicle occupancy (person/veh) which means average number of peoples who can be seen in different modes of transportation, Labour Cost (birr/Day). Therefore, for this study the following data was used for cost estimation.

Table 24 Average vehicle occupancy of different vehicle mode

Vehicle type	Bajaj	Mini Bus taxi	Medium Bus	Bus	Car& taxi	Pickup& 4WD	Motor Cycle
Average Vehicle occupancy	2	11	20	50	2	2	1

To estimate the passenger income lost due to traffic congestion daily labour income 100birr/day was used as a base for the analysis. And the working hour of a day are 8 hr/day. The total delay per hour was used from the software output. The number of vehicle by vehicle type are shown on Table 25, Table 26, and Table 27 below.

Table 25 Peak hour volume by vehicle class at CBE signalized intersection

Approach	Bajaj	Car& Taxi	Pickup & 4WD	Mini Bus Taxi	Medium Bus	Bus	Motor cycle	LCV	Medium Truck
Romanat	195	195	219	213	3	9	49	5	11
Enda Michael	107	81	83	40	2	3	21	3	8
Axum Hotel	151	130	143	49	3	9	31	4	7
Abrha castl	198	194	217	221	1	5	32	6	9

The above table 25 indicates pickup & 4WD at peak hour have the highest value and the volume of Bajaj was the follower value. Car & Taxi have a volume next to the volume of Bajaj but the volume of Mini Bus taxi was next to the volume of car & taxi. And Medium Bus volume shows the lowest value.

Table 26 Peak hour volume by vehicle class at REST unsignalized intersection

Approach	Bajaj	Car& Taxi	Pickup & 4WD	Mini Bus Taxi	Medium Bus	Standard Bus	Motor Cycle	LCV	Medium Truck
Main CBE	75	72	94	92	2	3	30	18	5
Aste Yohannes	226	185	241	278	5	7	28	34	11
Axum Hotel	193	173	162	166	4	5	29	23	9
Grand Awash	157	158	194	114	10	6	26	31	8

From the peak hour traffic volume composition data of REST unsignalized intersection Table 26 the volume of pickup & 4WD, bajaj and minibus taxi shows the highest volume in successive order. The volume of car & taxi have next to volume of minibus taxi but the volume of medium bus shows the lowest value.

Table 27 Peak hour volume by vehicle class at REST signalized intersection

Approach	Bajaj	Car& Taxi	Pickup & 4WD	Mini Bus Taxi	Medium Bus	Standard Bus	Motor Cycle	LCV	Medium Truck
Main CBE	56	61	82	97	2	2	28	25	9
Aste Yohannes	187	190	206	278	3	7	32	37	10
Axum Hotel	180	182	155	176	4	8	24	34	8
Grand Awash	86	163	181	114	6	6	28	38	9

Table 27 shows the intersection peak hour volume of different vehicle by mode. The volume of Mini bus taxi have the highest and the volume of pickup &4WD was the secondary. The volume of Bajaj was next to the volume of car & taxi but Medium bus shows the lower volume at the intersection.

Table 28 Total travel time cost at CBE intersection

Approach		Bajaj	Car& Taxi	Pickup & 4WD	Mini Bus Taxi	Medium Bus	Bus	Motor Cycle
Romanat	Annual income lost (birr)	153739.7	157294.4	167069.7	957984.9	17773.4	199950.5	21772.4
Enda Michael	Annual income lost (birr)	38806.9	29377.2	30102.5	79789.9	7253.6	27201.1	3808.2
Axum Hotel	Annual income lost (birr)	37568.2	40362.6	41294.0	83674.7	3104.8	69858.3	4812.5
Abrha castl	Annual income lost (birr)	210388.8	213954.8	234161.6	1300963.7	11886.4	148579.7	19018.2
Total annual peak hour income lost at the intersection (birr)					4311552.5 ETB			

The result shows the annual peak hour travel income lost at the main CBE intersection presents about 4311552.5 ETB. Of this birr about 49.6 % of the cost lost at Abrha castl approach, about 38.9 % cost lost at Romanat approach, about 6.5% cost lost at Axum Hotel approach and 5% cost lost at Enda Michael approach.

Table 29 Total travel time cost at REST unsignalized intersection

Approach		Bajaj	Car& Taxi	Pickup & 4WD	Mini Bus Taxi	Medium Bus	Bus	Motor Cycle
Main CBE	Annual income lost (birr)	9638.0	9252.5	12079.6	65024.2	2570.1	9638.0	1927.6
Atse Yohannes	Annual income lost (birr)	213332.7	174630.8	227492.0	1443299.6	47197.5	165191.3	13215.3
Axum Hotel	Annual income lost (birr)	28579.7	25618.1	23989.2	135198.2	5923.3	18510.2	2147.2
Grand Awash	Annual income lost (birr)	55347.4	54239.4	66597.8	215241.3	34328.8	51493.1	4462.738
Total annual peak hour income lost at the intersection (birr)					3116165 ETB			

The result of annual peak hour income lost at REST unsignalized intersection shows about 3116165 ETB. From this 71.7% of the cost lost at Atse Yohannes approach, 16.6% of the total cost lost at Grand Awash approach, 7.6 % of the cost lost at Axum Hotel approach and about 4% of intersection cost is lost at main CBE approach.

Table 30 Total travel time cost at REST signalized intersection

Approach		Bajaj	Car& Taxi	Pickup & 4WD	Minibus Taxi	Medium Bus	Bus	Motor Cycle
Main CBE	Annual income lost (birr)	23426.2	25517.8	34302.7	223176.4	8366.5	20916.3	5856.6
Atse Yohannes	Annual income lost (birr)	121644.7	123596.2	134004.3	994624.1	19515.2	113838.6	10408.1
Axum Hotel	Annual income lost (birr)	31907.3	32261.8	27475.7	171590.1	7090.5	35452.5	2127.2
Grand Awash	Annual income lost (birr)	30317.7	57462.6	63808.2	221037.1	21151.9	52879.7	4935.44
Total income lost at the intersection (birr)					2618690.9 ETB			

The annual peak hour travel time cost at REST signalized intersection result shows about 2618690.9 ETB. From this the highest income lost about 56.5% was found at Atse Yohannes approach, about 17.8 % of total cost was at Grand Awash approach, 15% of intersection travel time cost was at main CBE approach and about 10.5 % of intersection travel time income lost was found at Axum Hotel.

4.3.2 Fuel Consumption Cost

When vehicle are waiting for the green time to cross the intersection at signalized intersection the driver keep on their vehicle`s engine then this results extra fuel consumption. Even this fuel consumption is small this small amount of fuel wasted aggregated over a number of cycle per year and a number of intersection results vast quantity of fuel (Pal & Sarkar, 2012).

To estimate the excess fuel consumption cost due to stoppage of vehicles during the red phases of the signal control by multiplying fuel consumption rate of each vehicle mode at idling with number of idling vehicles multiplying with idling time multiplying with fuel price (birr/ litre). Based on this the result showed as follow:-

Table 31 Fuel consumption cost at main CBE intersection

Approach Annual fuel cost (birr)				
	Romanat	Enda Michael	Axum Hotel	Abrha castl
Bajaj (gasoline)	48557.1	12256.8	10492.7	66449.2
Car & pickup (gasoline)	182874.6	33553.2	46032.0	252357.6
Car & pickup (diesel)	7736.2	1403.2	1952.1	10922.5
Minibus taxi(diesel)	84239.1	7016.2	7357.8	114398.4
Bus (diesel)	7390.6	1256.8	2582.1	4942.6
Motor cycle (gasoline)	6035.3	1055.6	1334.0	5271.8
LCV (diesel)	23441.2	9231.1	6609.3	42905.1
Truck (diesel)	3417.1	836.8	477.5	5484.7
Total intersection Annual peak hour fuel cost (birr)				1009870.3

The result of CBE signalized intersection fuel consumption cost estimation shows the fuel consumption cost of Abrha Castl approach have the highest value and the Romanat approach shows next to Abrha Castl. The car & pickup they use gasoline have the highest percentage of fuel consumption cost in all approaches. The cost of Enda Michael approach have the lowest value at the intersection.

Table 32 Fuel consumption cost at REST unsignalized intersection

	Approach Annual fuel cost (birr)			
	Main CBE	Atse Yohannes	Axum Hotel	Grand Awash
Bajaj (gasoline)	3044.05605	67379	9026.607	17022.5561
Car (gasoline)	12041.0767	226719.04	27926.16	67996.7951
Car (diesel)	497.200756	9587.0685	1217.493	2988.46407
Minibus taxi(diesel)	5717.8087	126914.53	11888.46	18926.9391
Bus (diesel)	445.297287	7850.296	923.6307	3806.56953
Motor cycle (gasoline)	534.3289 87	3663.2812	595.1978	1237.07084
LCV (diesel)	1070.43722	14852.254	1576.131	4924.74933
Truck (diesel)	494.136345	7985.3548	1024.932	2112.03213
Total intersection Annual fuel cost (birr)				661988.9

The fuel cost of REST unsignalized intersection presents Atse Yohannes approach have the highest value with all vehicle mode and the Grand Awash approach have the highest value next to Atse Yohannes. The result shows fuel cost of car & pickup they use gasoline have the highest percentage of the other mode and fuel cost of minibus taxi have next to car & pickup. But the main CBE approach have the lowest fuel cost of all approaches.

Table 33 Fuel consumption cost at REST signalized intersection

Approach Annual fuel cost (birr)				
	Main CBE	Atse Yohannes	Axum Hotel	Grand Awash
Bajaj (gasoline)	7398.931	38420.25	10077.59	9575.53842
Car (gasoline)	33739.35	145437.6	33639.6	68573.3635
Car (diesel)	1416.216	5977.542	1457.415	2727.94209
Minibus taxi(diesel)	19624.7	87460.87	15088.54	19436.5874
Bus (diesel)	1159.657	4508.242	1474.192	2931.80217
Motor cycle (gasoline)	1623.436	2885.125	589.646	1368.10328
LCV (diesel)	4839.698	11138.27	2789.075	6199.34297
Truck (diesel)	2895.402	5002.695	1090.585	2440.016
Total intersection Annual fuel cost (birr)				552987.4

The above table presents the fuel consumption cost of REST signalized intersection. Of this result the Atse Yohannes approach have the highest value and the Grand Awash approach is the next one. Axum Hotel approach have the lower percentage of the total fuel cost. The car & pickup mode of transport they use gasoline type of fuel have the highest percentage of fuel consumption cost value of all mode of transport.

4.3.3 CO_2 Emission due to Excess Fuel Cost

Traffic congestion creates excess fuel use due to this reason the extra fuel consumption causes to increase co_2 emission. Because increase fuel consumption on the road means emission increase (Shoaeb, et al., 2016).

To estimate co_2 emission cost it is necessary to know amount of co_2 per litre for diesel as well as gasoline. Therefore, for this study the vehicle emission factor for any diesel use vehicle is 2.67 kg co_2/ litre and for gasoline use vehicles is 2.42kg co_2/ litre was used (Federal Democratic Republic of Ethiopia, 2011).

According to the World Bank's State and Trends of Carbon Pricing 2018, carbon tax rate is US$5/t$CO_2$e then for the analysis of emission cost in this study was used. The co_2 emission cost was calculated and shown in table below for each intersection.

Table 34 CO_2 Emission cost due to excess fuel consumptions at CBE intersection

Approach		Romanat	Enda Michael	Axum Hotel	Abrha castl
Gasoline	cost of co_2	3943.33	778.24	960.79	5381.59
Diesel	cost of co_2	2616.55	409.28	393.42	3703.37
Total Annual peak hour co_2 emission cost at CBE intersection					18186.57 ETB

The CO_2 emission cost estimation at Main CBE intersection result shows the cost for Abrha castl approach is the highest for both the gasoline and diesel fuel type but the Enda Michael approach shows the lowest value.

Table 35 CO_2 emission cost due to excess fuel consumptions at REST unsignalized intersection

Approach		Main CBE	Atse Yohannes	Axum Hotel	Grand Awash
Gasoline	cost of co_2	259.38	4944.57	623.51	1432.36
Diesel	cost of co_2	170.5	3465.73	35.98	679.07
Total Annual peak hour co_2 emission cost at REST unsignalized intersection			11611.09 ETB		

When we see the co_2 emission cost estimation result of REST unsignalized intersection the cost of Atse Yohannes approach shows the highest value of all approach for both gasoline as well as diesel fuel type.

Table 36 CO_2 Emission cost due to excess fuel consumptions at REST signalized intersection

Approach		Main CBE	Atse Yohannes	Axum Hotel	Grand Awash
Gasoline	cost of co_2	710.09	3101.02	735.75	1320.44
Diesel	cost of co_2	620.55	2364.96	453.97	699.32
Total Annual peak hour co_2 emission cost at REST signalized intersection			10006.11 ETB		

The result of co_2 cost estimation at REST signalized intersection presents the cost of Atse Yohannes is the highest value of all approach at the intersection for both gasoline and diesel fuel type.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5. 1 Conclusion

From the study result, the finding shows the traffic volume distribution of CBE intersection have noon peak period with very high congested nature for all approaches at the intersection. The traffic volume distribution for REST intersection in both signalized and unsignalized condition shows the Grand Awash and Atse Yohannes approach shows highly traffic volume at morning peak period, but Axum Hotel approach have highest volume at the evening peak period. The main CBE approach shows almost the same throughout the day.

The level of service result for main CBE intersection shows, all approaches have traffic demand above their capacity, gives LOS F with maximum delay 655.8 second at Abrha castl approach and minimum delay 171.3 second at Axum Hotel approach. The REST intersection for both signalized and unsignalized condition are performing above their capacity with LOS F. when we compare the two conditions the signalized condition have excessive delay than un signalized condition although the volume of unsignalized condition is highest.

The total annual peak hour cost at CBE intersection was found about 5,339,609.58 ETB. Of this cost the travel time cost represents the largest category with highest percent of total cost and the CO_2 emission cost contributes the lower percent. For the main CBE intersection by assuming travel time cost, excess fuel consumption cost and CO_2 emission cost the maximum cost is about 2,650,770.04 ETB at Abrha castl approach. The total annual peak hour cost at REST unsignalized intersection by assuming Travel time cost, excess fuel consumption cost and CO_2 emission cost was found about 3,180,079.91 ETB. From the total intersection cost the travel time cost contributes the highest percent. For signalized intersection of REST intersection total annual peak hour traffic congestion cost estimation result shows about 3,181,684.87 ETB is loss of this the maximum percent covers by travel time cost and with the Atse Yohannes approach.

Travel time represents the opportunity costs of wasted time on congested intersection is the largest category at CBE intersection found about 4,311,552.5ETB nearly 81% of total cost of the intersection, at REST unsignalized intersection was found 3,116,165ETB about 82% of the cost of intersection and at REST signalized intersection 2,618,690.9ETB was found which is about

82% of total intersection cost. Meanwhile fuel costs are second contributor to the overall cost of congestion with (1,009,870.3ETB annual peak hour cost) at CBE, (661,988.9 ETB annual peak hour) at REST unsignalized intersection and (552,987.4 ETB annual peak hour cost) at REST signalized intersection which is about 18% of the total cost. Emissions costs on the other hand were the least contributor to the overall cost of congestion and estimated about (18,186.57ETB annual peak hour cost) at CBE intersection, about (11,611.09ETB annual peak hour cost) at REST unsignalized intersection and (10,006.11 ETB annual peak hour cost) at REST signalized intersection. The cost of congestion result shows the effect of congestion is highly concentrated on the travel time of public transport users' means 78% of the travel time cost is for the public transport users.

Generally, the finding of the study result shows the aggregated of peak hour lost cost over a year have very high amount of ETB lost due to the traffic congestion. Of the total cost the 78% is due to travel time delay for public transport vehicles users.

5.2 Recommendation

Based on the study conducted, the following recommendations were recommended.

- The intersections served, for all mode of transport during whole day. There was no restriction for any mode transport. It is common to see Heavy vehicle including truck to drive on main roads of city. Since, heavy truck has slow speed, large dimension it has adverse impact on quality of service. Hence, to have healthy and efficient driveway restriction of heavy vehicle during rush hour morning, noon and evening was proposed as mitigation for congestion.
- Mass movement or public transport such as city bus service is vital element of transport system of urban areas. However, public bus transport is nil or negligible in Mekelle, there are only two or three city bus which are restricted in specific line. These limited city buses have also poor performance and are largely inaccessible to many in habitants. Therefore the city administration should improve the performance of public transport Introduce a subsidized mass transportation (city buses).
- Shifting of private vehicle (Car, pickup and 4WD) to uncongested to minor routes outside the system outside the intersection. Those private and semiprivate vehicles allowed them out from main road intersection to minor roads joint at the peak hour period small vehicle must be allowed to move on those roads.
- Those private and semiprivate vehicles cause extra congestion and blocking problem, however their occupancy is very low. Then, private vehicle must be constrained to encourage public transportation. In order to attract more people to use the bus is necessary to introduce certain bus priority strategies.

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Appendix -A: Traffic Volume Data

Table 37 Traffic volume data at CBE Intersection

	Romanat			Enda Michael			Axum Hotel			Abrha Castl		
Time	Tuesday	Wednesday	Thursday	Tuesday	Wednesd	Thursday	Tuesday	Wednesd	Thursday	Tuesday	Wednesd	Thursday
7:00-7:15AM	103	105	102	44	43	45	52	53	51	119	121	118
7:15-7:30AM	96	98	95	52	51	53	53	54	52	132	134	131
7:30-7:45AM	136	138	135	81	80	82	68	69	67	178	180	177
7:46-8:00AM	136	138	135	85	84	86	70	71	69	185	187	184
8:00-8:15AM	187	189	186	94	93	95	95	96	94	252	254	251
8:15-8:30AM	188	190	187	94	93	95	96	97	95	253	255	252
8:30-8:45AM	169	171	168	83	82	84	115	116	114	224	226	223
8:45-9:00AM	169	171	168	83	82	84	114	115	113	224	226	223
9:00-9:15AM	181	183	180	71	70	72	90	91	89	152	154	151
9:15-9:30AM	165	167	164	75	74	76	87	88	86	148	150	147
9:30-9:45AM	168	170	167	69	68	70	90	91	89	165	167	164
9:45-10:00AM	165	167	164	76	75	77	93	94	92	153	155	152
11:00-11:15AM	224	226	223	92	91	93	101	102	100	195	197	194
11:15-11:30AM	174	176	173	69	68	70	103	104	102	173	175	172
11:30-11:45AM	200	202	199	73	72	74	123	124	122	180	182	179
11:45-12:00AM	173	175	172	87	86	88	146	147	145	170	172	169
12:00-12:15AM	230	232	229	85	84	86	120	121	119	255	257	254
12:15-12:30AM	271	273	270	80	79	81	125	126	124	217	219	216
12:30-12:45AM	202	204	201	81	80	82	143	144	142	198	200	197
12:45-1:00AM	214	216	213	155	154	156	98	99	97	161	163	160
1:00-1:15PM	186	188	185	70	69	71	75	76	74	139	141	138
1:15-1:30PM	147	149	146	63	62	64	79	80	78	159	161	158
1:30-1:45PM	219	221	218	102	101	103	109	110	108	196	198	195
1:45-2:00PM	206	208	205	81	80	82	98	99	97	185	187	184
2:00-2:15PM	170	172	169	88	87	89	109	110	108	244	246	243
2:15-2:30PM	208	210	207	83	82	84	105	106	104	270	272	269
4:30-4:45PM	243	245	242	107	106	108	126	127	125	287	289	286
4:45-5:00PM	167	169	166	81	80	82	101	102	100	191	193	190
5:00-5:15PM	156	158	155	77	76	78	99	100	98	188	190	187
5:15-5:30PM	155	157	154	77	76	78	108	109	107	156	158	155
5:30-5:45PM	169	171	168	68	67	69	96	97	95	181	183	180
5:45-6:00PM	226	228	225	88	87	89	122	123	121	226	228	225
6:00-6:15PM	215	217	214	80	79	81	107	108	106	219	221	218
6:15-6:30PM	204	206	203	76	75	77	98	99	97	186	188	185
6:30-6:45PM	217	219	216	68	67	69	86	87	85	194	196	193
6:45-7:00PM	207	209	206	71	70	72	90	91	89	189	191	188
7:00-7:15PM	209	211	208	73	72	74	87	88	86	198	200	197
7:15-7:30PM	206	208	205	69	68	70	93	94	92	179	181	178

Table 38 Traffic volume data at REST unsignalized Intersection

	CBE			Atse Yohanns			Axum Hotel			Grand Awash		
Time	Tuesday	Wednesda	Thursday	Tuesday	Wednesda	Thursday	Tuesday	Wednesda	Thursday	Tuesday	Wednesda	Thursday
7:00-7:15AM	67	44	78	86	66	69	24	88	99	92	100	106
7:15-7:30AM	55	75	70	90	97	84	43	111	117	164	114	128
7:30-7:45AM	125	124	126	99	97	98	148	146	145	204	205	203
7:46-8:00AM	119	118	120	135	133	134	211	209	208	205	206	204
8:00-8:15AM	123	122	124	138	136	137	70	68	67	187	188	186
8:15-8:30AM	95	94	96	237	235	236	87	85	84	161	162	160
8:30-8:45AM	84	83	85	173	171	172	52	50	49	193	194	192
8:45-9:00AM	101	100	102	178	176	177	78	76	75	214	215	213
9:00-9:15AM	60	59	61	169	167	168	63	61	60	130	131	129
9:15-9:30AM	108	107	109	167	165	166	172	170	169	173	174	172
9:30-9:45AM	91	90	92	95	93	94	89	87	86	86	87	85
9:45-10:00AM	78	77	79	67	65	66	63	61	60	57	58	56
11:00-11:15AM	69	68	70	237	235	236	167	165	164	168	169	167
11:15-11:30AM	71	70	72	186	184	185	163	161	160	69	70	68
11:30-11:45AM	130	129	131	176	174	175	236	234	233	83	84	82
11:45-12:00AM	108	107	109	176	174	175	236	234	233	72	73	71
12:00-12:15AM	113	112	114	220	218	219	215	213	212	95	96	94
12:15-12:30AM	98	97	99	196	194	195	221	219	218	96	97	95
12:30-12:45AM	93	92	94	190	188	189	193	191	190	78	79	77
12:45-1:00AM	97	96	98	143	141	142	154	152	151	55	56	54
1:00-1:15PM	89	88	90	189	187	188	187	185	184	83	84	82
1:15-1:30PM	83	82	84	190	188	189	202	200	199	73	74	72
1:30-1:45PM	70	69	71	185	183	184	175	173	172	81	82	80
1:45-2:00PM	88	87	89	186	184	185	156	154	153	86	87	85
2:00-2:15PM	108	107	109	191	189	190	177	175	174	79	80	78
2:15-2:30PM	97	96	98	173	171	172	167	165	164	93	94	92
4:30-4:45PM	101	100	102	196	194	195	157	155	154	102	103	101
4:45-5:00PM	90	89	91	186	184	185	179	177	176	96	97	95
5:00-5:15PM	79	78	80	185	183	184	189	187	186	98	99	97
5:15-5:30PM	103	102	104	190	188	189	185	183	182	108	109	107
5:30-5:45PM	112	111	113	128	126	127	192	190	189	95	96	94
5:45-6:00PM	137	136	138	98	96	97	184	182	181	104	105	103
6:00-6:15PM	148	147	149	86	84	85	277	275	274	118	119	117
6:15-6:30PM	118	117	119	189	187	188	254	252	251	181	182	180
6:30-6:45PM	104	103	105	171	169	170	241	239	238	174	175	173
6:45-7:00PM	111	110	112	172	170	171	267	265	264	167	168	166
7:00-7:15PM	120	119	121	169	167	168	255	253	252	181	182	180
7:15-7:30PM	132	131	133	95	93	94	163	161	160	121	122	120

Table 39 Traffic volume data at REST signalized Intersection

	CBE			Atse Yohanns			Axum Hotel			Grand Awash		
Time	Tuesday	Wednesda	Thursday	Tuesday	Wednesda	Thursday	Tuesday	Wednesda	Thursday	Tuesday	Wednesda	Thursday
7:00-7:15AM	78	66	44	69	85	66	99	23	88	106	91	100
7:15-7:30AM	70	54	75	84	89	97	117	42	111	128	163	114
7:30-7:45AM	125	124	123	97	98	96	144	147	145	198	203	194
7:46-8:00AM	119	118	117	133	134	132	207	210	208	190	204	201
8:00-8:15AM	123	122	121	136	137	135	66	69	67	185	186	187
8:15-8:30AM	95	94	93	235	236	234	83	86	84	159	160	161
8:30-8:45AM	84	83	82	171	172	170	48	51	49	191	192	197
8:45-9:00AM	101	100	99	176	177	175	74	77	75	212	210	214
9:00-9:15AM	60	59	58	167	168	166	59	62	60	128	131	130
9:15-9:30AM	108	107	106	165	166	164	168	171	169	171	175	173
9:30-9:45AM	91	90	89	93	94	92	85	88	86	88	87	96
9:45-10:00AM	78	77	76	65	66	64	59	62	60	57	56	57
11:00-11:15AM	69	68	67	235	236	234	163	166	164	166	167	168
11:15-11:30AM	71	70	69	184	185	183	159	162	160	78	69	69
11:30-11:45AM	130	129	128	174	175	173	232	235	233	81	80	83
11:45-12:00AM	108	107	106	174	175	173	232	235	233	70	73	72
12:00-12:15AM	113	112	111	218	219	217	211	214	212	93	96	95
12:15-12:30AM	98	97	96	194	195	193	217	220	218	94	93	96
12:30-12:45AM	93	92	91	188	189	187	189	192	190	76	80	78
12:45-1:00AM	97	96	95	141	142	140	150	153	151	53	51	55
1:00-1:15PM	89	88	87	187	188	186	183	186	184	81	86	83
1:15-1:30PM	83	82	81	188	189	187	198	201	199	71	68	73
1:30-1:45PM	70	69	68	183	184	182	171	174	172	79	80	81
1:45-2:00PM	88	87	86	184	185	183	152	155	153	84	85	86
2:00-2:15PM	108	107	106	189	190	188	173	176	174	77	78	79
2:15-2:30PM	97	96	95	171	172	170	163	166	164	91	92	93
4:30-4:45PM	101	100	99	194	195	193	153	156	154	100	101	102
4:45-5:00PM	90	89	88	184	185	183	175	178	176	94	95	96
5:00-5:15PM	79	78	77	183	184	182	185	188	186	96	97	98
5:15-5:30PM	103	102	101	188	189	187	181	184	182	106	107	108
5:30-5:45PM	112	111	110	126	127	125	188	191	189	93	94	95
5:45-6:00PM	137	136	135	96	97	95	180	183	181	102	103	104
6:00-6:15PM	148	150	146	102	107	101	273	270	274	136	140	138
6:15-6:30PM	118	114	116	187	184	186	240	249	241	175	173	177
6:30-6:45PM	104	106	102	169	173	168	207	216	208	180	176	182
6:45-7:00PM	111	107	109	170	178	169	213	210	214	165	161	167
7:00-7:15PM	110	109	108	147	148	146	201	204	202	169	173	171
7:15-7:30PM	102	101	100	93	94	92	149	152	150	119	117	121

Appendix –B: Travel Time Cost

Table 40 Travel Time Cost at CBE

		Travel Time Cost at CBE Signalized Intersection						
		Vehicle Type						
Approach		Bajaj	Car& Taxi	Pickup & 4WD	Mini Bus Taxi	Medium Bus	Bus	Motor cycle
Romanat	Total Traffic (veh-hr)	173	177	188	196	2	9	49
	Delay in hour	0.14	0.14	0.14	0.14	0.14	0.14	0.14
	Labor cost (birr/hour)	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	Average occupancy	2	2	2	11	20	50	1
	Annual working day	261	261	261	261	261	261	261
	Annual income lost (birr)	153739.7	157294.4	167069.7	957984.9	17773.4	199950.5	21772.4
	Total income lost at the approach (birr)				1675584.9			
Enda Michael	Total Traffic (veh-hr)	107	81	83	40	2	3	21
	Delay in hour	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	Labor cost (birr/hour)	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	Average occupancy	2	2	2	11	20	50	1
	Annual working day	261	261	261	261	261	261	261
	Annual income lost (birr)	38806.9	29377.2	30102.5	79789.9	7253.6	27201.1	3808.2
	total income lost at the approach (birr)				216339.4			
Axum Hotel	Total Traffic (veh-hr)	121	130	133	49	1	9	31
	Delay in hour	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Labor cost (birr/hour)	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	Average occupancy	2	2	2	11	20	50	1
	Annual working day	261	261	261	261	261	261	261
	Annual income lost (birr)	37568.2	40362.6	41294.0	83674.7	3104.8	69858.3	4812.5
	total income lost at the approach (birr)				280675.1			
Abrha castl	Total Traffic (veh-hr)	177	180	197	199	1	5	32
	Delay in hour	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	Labor cost (birr/hour)	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	Average occupancy	2	2	2	11	20	50	1
	Annual working day	261	261	261	261	261	261	261
	Annual income lost (birr)	210388.8	213954.8	234161.6	1300963.7	11886.4	148579.7	19018.2
	Total income lost at the approach (birr)				2138953.2			
	Total income lost at CBE signalized intersection (birr)						4311552.5	

Table 41 Travel Time Cost at REST Unsignalized Intersection

	Travel Time Cost at REST Unsignalized Intersection							
				Vehicle type				
Approach		Bajaj	Car& Taxi	Pickup & 4WD	Mini Bus Taxi	Medium Bus	Standard bus	motor cycle
Main CBE	Total Traffic (veh-hr)	75	72	94	92	2	3	30
	Delay in hour	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	Labor cost (birr/hour)	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	Average occupancy	2	2	2	11	20	50	1
	Annual working day	261	261	261	261	261	261	261
	Annual income lost (birr)	9638.0	9252.5	12079.6	65024.2	2570.1	9638.0	1927.6
	Total income lost at the approach (birr)				110129.9			
Atse Yohannes	Total Traffic (veh-hr)	226	185	241	278	5	7	28
	Delay in hour	0.14	0.14	0.14	0.14	0.14	0.14	0.14
	Labor cost (birr/hour)	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	Average occupancy	2	2	2	11	20	50	1
	Annual working day	261	261	261	261	261	261	261
	Annual income lost (birr)	213332.7	174630.8	227492.0	1443299.6	47197.5	165191.3	13215.3
	total income lost at the approach (birr)				2284359.0			
Axum Hotel	Total Traffic (veh-hr)	193	173	162	166	4	5	29
	Delay in hour	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	Labor cost (birr/hour)	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	Average occupancy	2	2	2	11	20	50	1
	Annual working day	261	261	261	261	261	261	261
	Annual income lost (birr)	28579.7	25618.1	23989.2	135198.2	5923.3	18510.2	2147.2
	total income lost at the approach (birr)				239965.7			
Grand Awash	Total Traffic (veh-hr)	157	158	194	114	10	6	26
	Delay in hour	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Labor cost (birr/hour)	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	Average occupancy	2	2	2	11	20	50	1
	Annual working day	261	261	261	261	261	261	261
	Annual income lost (birr)	55347.4	54239.4	66597.8	215241.3	34328.8	51493.1	4462.7375
	Total income lost at the approach (birr)				481710.5			
	Total income lost at REST Unsignalized intersection (birr)						3116165.0	

Table 42 Travel Time cost at REST signalized Intersection

		Travel Time Cost at REST Signalized Intersection						
				Vehicle type				
Approache		Bajaj	Car& Taxi	Pickup & 4WD	Mini Bus Taxi	Medium Bus	Standard bus	motor cycle
Main CBE	Total Traffic (veh-hr)	56	61	82	97	2	2	28
	Delay in hour	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	Labor cost (birr/hour)	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	Average occupancy	2	2	2	11	20	50	1
	Annual working day	261	261	261	261	261	261	261
	Annual income lost (birr)	23426.2	25517.8	34302.7	223176.4	8366.5	20916.3	5856.6
	Total income lost at the approach (birr)				341562.4			
Atse Yohannes	Total Traffic (veh-hr)	187	190	206	278	3	7	32
	Delay in hour	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	Labor cost (birr/hour)	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	Average occupancy	2	2	2	11	20	50	1
	Annual working day	261	261	261	261	261	261	261
	Annual income lost (birr)	121644.7	123596.2	134004.3	994624.1	19515.2	113838.6	10408.1
	total income lost at the approach (birr)				1517631.1			
Axum Hotel	Total Traffic (veh-hr)	180	182	155	176	4	8	24
	Delay in hour	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Labor cost (birr/hour)	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	Average occupancy	2	2	2	11	20	50	1
	Annual working day	261	261	261	261	261	261	261
	Annual income lost (birr)	31907.3	32261.8	27475.7	171590.1	7090.5	35452.5	2127.2
	total income lost at the approach (birr)				307905.0			
Grand Awash	Total Traffic (veh-hr)	86	163	181	114	6	6	28
	Delay in hour	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Labor cost (birr/hour)	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	Average occupancy	2	2	2	11	20	50	1
	Annual working day	261	261	261	261	261	261	261
	Annual income lost (birr)	30317.7	57462.6	63808.2	221037.1	21151.9	52879.7	4935.4375
	Total income lost at the approach (birr)				451592.5			
	Total Income Lost at REST Signalized intersection (birr)						2618690.9	

Appendix –C: Fuel Consumption Cost

Table 42 fuel consumption cost at CBE Intersection

	Fuel Consumption Cost at CBE Signalized Intersection								
Approache		Bajaj (gasoline)	Car (gasoline)	Car (diesel)	Minibus taxi(diesel)	Bus (diesel)	Motor cycle (gasoline)	LCV (diesel)	Truck (diesel)
Romanat	Total Traffic (veh-hr)	173	347	18	196	12	49	57	5
	Delay in hour	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
	Fuel consumption (l/hr)	0.38	0.71	0.65	0.65	0.93	0.17	0.62	1.03
	Annual working day	261	261	261	261	261	261	261	261
	annual fuel consumption(litr)	2312.24	8708.314	415.257	4521.6888	396.702	287.39547	1258.2	183.421
	Fuel cost (birr/l)	21	21	18.63	18.63	18.63	21	18.63	18.63
	Annual income lost (birr)	48557.1	182874.6	7736.24	84239.062	7390.55	6035.3049	23441	3417.14
	Total income lost at the approach (birr)				363691.2				
Enda Michael	Total Traffic (veh-hr)	107	156	8	40	5	21	55	3
	Delay in hour	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	Fuel consumption (l/hr)	0.376	0.706	0.649	0.649	0.93	0.165	0.621	1.032
	Annual working day	261	261	261	261	261	261	261	261
	annual fuel consumption(litr)	583.656	1597.77	75.3216	376.60821	67.4587	50.267621	495.5	44.9144
	Fuel cost (birr/l)	21	21	18.63	18.63	18.63	21	18.63	18.63
	Annual income lost (birr)	12256.8	33553.18	1403.24	7016.211	1256.76	1055.62	9231.1	836.756
	Total income lost at the approach (birr)				66609.609				
Axum Hotel	Total Traffic (veh-hr)	121	250	13	49	12	31	46	2
	Delay in hour	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Fuel consumption (l/hr)	0.376	0.706	0.649	0.649	0.93	0.165	0.621	1.032
	Annual working day	261	261	261	261	261	261	261	261
	annual fuel consumption(litr)	565.026	2191.998	104.781	394.94457	138.599	63.524464	354.77	25.6333
	Fuel cost (birr/l)	21	21	18.63	18.63	18.63	21	18.63	18.63
	Annual income lost (birr)	11865.6	46031.95	1952.07	7357.8173	2582.1	1334.0137	6609.3	477.549
	Total income lost at the approach (birr)				78210.384				
Abrha Castl	Total Traffic (veh-hr)	177	358	19	199	6	32	78	6
	Delay in hour	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	Fuel consumption (l/hr)	0.376	0.706	0.649	0.649	0.93	0.165	0.621	1.032
	Annual working day	261	261	261	261	261	261	261	261
	annual fuel consumption(litr)	3164.25	12017.03	586.284	6140.5489	265.304	251.04024	2303	294.402
	Fuel cost (birr/l)	21	21	18.63	18.63	18.63	21	18.63	18.63
	Annual income lost (birr)	66449.2	252357.6	10922.5	114398.43	4942.61	5271.845	42905	5484.7
	Total income lost at the approach (birr)				502731.95				
	Total Intersection Fuel Cost						1011243.1		

Table 42 Fuel Consumption Cost at REST unsignalized Intersection

	Fuel Consumption Cost at REST Unsignalized Intersection								
Approach		Bajaj (gasoline)	Car (gasoline)	Car (diesel)	Minibus taxi(diesel)	Bus (diesel)	Motor cycle (gasoline)	LCV (diesel)	Truck (diesel)
Main CBE	Total Traffic (veh-hr)	75	158	8	92	5	30	18	5
	Delay in hour	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	Fuel consumption (l/hr)	0.38	0.71	0.65	0.65	0.93	0.17	0.62	1.03
	Annual working day	261	261	261	261	261	261	261	261
	annual fuel consumption(litr)	144.95505	573.38461	26.688178	306.91405	23.902163	25.444237	57.457714	26.52369
	Fuel cost (birr/l)	21	21	18.63	18.63	18.63	21	18.63	18.63
	Annual income lost (birr)	3044.05605	12041.077	497.20076	5717.8087	445.29729	534.32899	1070.4372	494.13634
	Total income lost at the approach (birr)				23844.342				
Atse Yohannes	Total Traffic (veh-hr)	226	405	21	278	12	28	34	11
	Delay in hour	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
	Fuel consumption (l/hr)	0.376	0.706	0.649	0.649	0.93	0.165	0.621	1.032
	Annual working day	261	261	261	261	261	261	261	261
	annual fuel consumption(litr)	3208.52381	10796.145	514.60378	6812.3739	421.37928	174.44196	797.22241	428.62882
	Fuel cost (birr/l)	21	21	18.63	18.63	18.63	21	18.63	18.63
	Annual income lost (birr)	67379	226719.04	9587.0685	126914.53	7850.296	3663.2812	14852.254	7985.3548
	Total income lost at the approach (birr)				464950.82				
Axum Hotel	Total Traffic (veh-hr)	193	318	17	166	9	29	23	9
	Delay in hour	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	Fuel consumption (l/hr)	0.376	0.706	0.649	0.649	0.93	0.165	0.621	1.032
	Annual working day	261	261	261	261	261	261	261	261
	annual fuel consumption(litr)	429.838406	1329.817	65.351217	638.13542	49.577603	28.342751	84.60178	55.015146
	Fuel cost (birr/l)	21	21	18.63	18.63	18.63	21	18.63	18.63
	Annual income lost (birr)	9026.60653	27926.157	1217.4932	11888.463	923.63073	595.19778	1576.1312	1024.9322
	Total income lost at the approach (birr)				54178.612				
Grand Awash	Total Traffic (veh-hr)	157	334	18	114	16	26	31	8
	Delay in hour	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Fuel consumption (l/hr)	0.376	0.706	0.649	0.649	0.93	0.165	0.621	1.032
	Annual working day	261	261	261	261	261	261	261	261
	annual fuel consumption(litr)	810.597908	3237.9426	160.41138	1015.9388	204.32472	58.908135	264.34511	113.36726
	Fuel cost (birr/l)	21	21	18.63	18.63	18.63	21	18.63	18.63
	Annual income lost (birr)	17022.5561	67996.795	2988.4641	18926.939	3806.5695	1237.0708	4924.7493	2112.0321
	Total income lost at the approach (birr)				119015.18				
	Total Intersection Fuel Cost						661988.95		

Table 42 fuel consumption cost at REST Signalized Intersection

	Fuel Consumption Cost at REST Signalized Intersection								
Approach		Bajaj (gasoline)	Car (gasoline)	Car (diesel)	Minibus taxi(diesel)	Bus (diesel)	Motor cycle (gasoline)	LCV (diesel)	Truck (diesel)
Main CBE	Total Traffic (veh-hr)	56	136	7	97	4	28	25	9
	Delay in hour	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	Fuel consumption (l/hr)	0.376	0.706	0.649	0.649	0.93	0.165	0.621	1.032
	Annual working day	261	261	261	261	261	261	261	261
	annual fuel consumption(litr)	352.33	1606.64	76.02	1053.39	62.25	77.31	259.78	155.42
	Fuel cost (birr/litr)	21	21	18.63	18.63	18.63	21	18.63	18.63
	Annual income lost (birr)	7398.93101	33739.35	1416.216	19624.703	1159.657	1623.4357	4839.698	2895.402
	Total income lost at the approach (birr)				72697.393				
Atse Yohannes	Total Traffic (veh-hr)	187	377	19	278	10	32	37	10
	Delay in hour	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	Fuel consumption (l/hr)	0.376	0.706	0.649	0.649	0.93	0.165	0.621	1.032
	Annual working day	261	261	261	261	261	261	261	261
	annual fuel consumption(litr)	1829.53582	6925.602	320.8557	4694.6255	241.9883	137.38692	597.8673	268.529
	Fuel cost (birr/l)	21	21	18.63	18.63	18.63	21	18.63	18.63
	Annual income lost (birr)	38420.2522	145437.6	5977.542	87460.874	4508.242	2885.1253	11138.27	5002.695
	Total income lost at the approach (birr)				300830.64				
Axum Hotel	Total Traffic (veh-hr)	180	320	17	176	12	24	34	8
	Delay in hour	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Fuel consumption (l/hr)	0.376	0.706	0.649	0.649	0.93	0.165	0.621	1.032
	Annual working day	261	261	261	261	261	261	261	261
	annual fuel consumption(litr)	479.88504	1601.886	78.22949	809.90527	79.12998	28.07838	149.7088	58.53917
	Fuel cost (birr/l)	21	21	18.63	18.63	18.63	21	18.63	18.63
	Annual income lost (birr)	10077.5858	33639.6	1457.415	15088.535	1474.192	589.64598	2789.075	1090.585
	Total income lost at the approach (birr)				66206.635				
Grand Awash	Total Traffic (veh-hr)	86	328	16	114	12	28	38	9
	Delay in hour	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Fuel consumption (l/hr)	0.376	0.706	0.649	0.649	0.93	0.165	0.621	1.032
	Annual working day	261	261	261	261	261	261	261	261
	annual fuel consumption(litr)	455.97802	3265.398	146.4274	1043.2951	157.37	65.147775	332.7613	130.9724
	Fuel cost (birr/l)	21	21	18.63	18.63	18.63	21	18.63	18.63
	Annual income lost (birr)	9575.53842	68573.36	2727.942	19436.587	2931.802	1368.1033	6199.343	2440.016
	Total income lost at the approach (birr)				113252.7				
	Total Intersection Fuel Cost						552987.36		

Appendix –D: CO_2 Emission Cost

Table 42 CO_2 Emission Cost at CBE Signalized Intersection

		CBE Signalized Intersection			
	Aproach	Romanat	Enda Michae	Axum Hotel	Abrha castl
Gasoline	fuel (liter)	11307.95	2231.69	2755.17	15432.32
	co2 kg/lit	2.42	2.42	2.42	2.42
	Total co2(kg)	27365.25	5400.70	6667.52	37346.21
	Total co2 (ton)	27.37	5.40	6.67	37.35
	Average CO2 carbon credit per ton USD	5	5	5	5
	1 USD to ETB	28.82	28.82	28.82	28.82
	Exchange rate (1USD$to Birr)	144.1	144.1	144.1	144.1
	cost of co2	3943.33	778.24	960.79	5381.59
Diesel	fuel (liter)	6775.32	1059.80	1018.73	9589.55
	co2 kg/lit	2.68	2.68	2.68	2.68
	Total co2(kg)	18157.85	2840.26	2730.19	25699.99
	Total co2 (ton)	18.16	2.84	2.73	25.70
	Average CO2 carbon credit per ton USD	5	5	5	5
	1 USD to ETB	28.82	28.82	28.82	28.82
	Exchange rate (1USD$to Birr)	144.1	144.1	144.1	144.1
	cost of co2	2616.55	409.28	393.42	3703.37
Total Annual Peack Hour Emission Cost at Main CBE Intersection				18186.57	

Table 42 CO2 Emission Cost at REST Unsignalized Intersection

	REST Unsignalized Intersection				
	Aproach	Main CBE	Atse Yohannes	Axum Hotel	Grand Awash
Gasoline	fuel (liter)	743.78	14179.11	1788.00	4107.45
	co2 kg/lit	2.42	2.42	2.42	2.42
	Total co2(kg)	1799.96	34313.45	4326.96	9940.03
	Total co2 (ton)	1.80	34.31	4.33	9.94
	Average CO2 carbon credit per ton USD	5	5	5	5
	1 USD to ETB	28.82	28.82	28.82	28.82
	Exchange rate (1USD$to Birr)	144.1	144.1	144.1	144.1
	cost of co2	259.37	4944.57	623.51	1432.36
Diesel	fuel (liter)	441.49	8974.21	93.15	1758.39
	co2 kg/lit	2.68	2.68	2.68	2.68
	Total co2(kg)	1183.18	24050.88	249.64	4712.48
	Total co2 (ton)	1.18	24.05	0.25	4.71
	Average CO2 carbon credit per ton USD	5	5	5	5
	1 USD to ETB	28.82	28.82	28.82	28.82
	Exchange rate (1USD$to Birr)	144.1	144.1	144.1	144.1
	cost of co2	170.50	3465.73	35.97	679.07
Total Annual peak hour Emission Cost at REST Unsignalized Intersection					11611.08

Table 42 CO2 Emission Cost at REST Signalized Intersection

	REST Signalized Intersection				
	Aproach	Main CBE	Atse Yohannes	Axum Hotel	Grand Awash
Gasoline	fuel (liter)	2036.27	8892.52	2109.85	3786.52
	co2 kg/lit	2.42	2.42	2.42	2.42
	Total co2(kg)	4927.78	21519.91	5105.84	9163.39
	Total co2 (ton)	4.93	21.52	5.11	9.16
	Average CO2 carbon credit per ton USD	5	5	5	5
	1 USD to ETB	28.82	28.82	28.82	28.82
	Exchange rate (1USD$to Birr)	144.1	144.1	144.1	144.1
	cost of co2	710.09	3101.02	735.75	1320.44
Diesel	fuel (liter)	1606.85	6123.87	1175.51	1810.83
	co2 kg/lit	2.68	2.68	2.68	2.68
	Total co2(kg)	4306.37	16411.96	3150.37	4853.01
	Total co2 (ton)	4.31	16.41	3.15	4.85
	Average CO2 carbon credit per ton USD	5	5	5	5
	1 USD to ETB	28.82	28.82	28.82	28.82
	Exchange rate (1USD$to Birr)	144.1	144.1	144.1	144.1
	cost of co2	620.55	2364.96	453.97	699.32
Total Annual peak hour Emission Cost at REST Signalized Intersection					10006.11

Appendix –E: Level of Service Analysis Input and Output of SYNCHRO software

Table 43 Level of Service Analysis Input and Output for CBE intersection

LANE SETTINGS	SEL	SET	SER	NWL	NWT	NWR	NEL	NET	NER	SWL	SWT	SWR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	161	118	128	158	53	279	62	647	131	137	708	80
Street Name												
Link Distance (m)	—	26.2	—	—	127.2	—	—	104.4	—	—	180.0	—
Links Speed (km/h)	—	35	—	—	35	—	—	35	—	—	35	—
Set Arterial Name and Speed	—	SE	—	—	NW	—	—	NE	—	—	SW	—
Travel Time (s)	—	2.7	—	—	13.1	—	—	10.7	—	—	18.5	—
Ideal Satd. Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (m)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Grade (%)	—	1	—	—	-2	—	—	-3	—	—	2	—
Area Type CBD	—	☑	—	—	☑	—	—	☑	—	—	☑	—
Storage Length (m)	0.0	—	0.0	0.0	—	0.0	0.0	—	0.0	0.0	—	0.0
Storage Lanes (#)	—	—	—	—	—	—	—	—	—	—	—	—
Right Turn Channelized	—	—	None	—	—	None	—	—	None	—	—	None
Curb Radius (m)	—	—	—	—	—	—	—	—	—	—	—	—
Add Lanes (#)	—	—	—	—	—	—	—	—	—	—	—	—
Lane Utilization Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Right Turn Factor	—	0.952	—	—	0.920	—	—	0.946	—	—	0.988	—
Left Turn Factor (prot)	—	0.981	—	—	0.983	—	—	0.996	—	—	0.990	—
Saturated Flow Rate (prot)	—	2927	—	—	2703	—	—	2995	—	—	3043	—
Left Turn Factor (perm)	—	0.981	—	—	0.983	—	—	0.996	—	—	0.990	—

VOLUME SETTINGS	SEL	SET	SER	NWL	NWT	NWR	NEL	NET	NER	SWL	SWT	SWR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	161	118	128	158	53	279	62	647	131	137	708	80
Conflicting Peds. (#/hr)	0	—	0	0	—	0	0	—	0	0	—	0
Conflicting Bicycles (#/hr)	—	—	0	—	—	0	—	—	0	—	—	0
Peak Hour Factor	0.66	0.67	0.65	0.81	0.70	0.91	0.57	0.79	0.25	0.55	0.79	0.80
Growth Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Heavy Vehicles (%)	2	2	2	3	8	2	3	1	5	4	1	9
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Adj. Parking Lane?	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐
Parking Maneuvers (#/hr)	—	—	—	—	0	—	—	—	—	—	—	—
Traffic from mid-block (%)	—	0	—	—	0	—	—	0	—	—	0	—
Link OD Volumes	—	—	—	—	—	—	—	—	—	—	—	—
Adjusted Flow (vph)	244	176	197	195	76	307	109	819	524	249	896	100
Traffic in shared lane (%)	—	—	—	—	—	—	—	—	—	—	—	—
Lane Group Flow (vph)	0	617	0	0	578	0	0	1452	0	0	1245	0

TIMING SETTINGS	SEL	SET	SER	NWL	NWT	NWR	NEL	NET	NER	SWL	SWT	SWR	PED	HOLD
Lost Time Adjust (s)	—	0.0	—	—	0.0	—	—	0.0	—	—	0.0	—	—	—
Lagging Phase?	☐	☐	—	☑	☑	—	☐	☐	—	☑	☑	—	—	—
Allow Lead/Lag Optimize?	☐	☐	—	☐	☐	—	☐	☐	—	☐	☐	—	—	—
Recall Mode	Max	Max	—	Max	Max	—	Max	Max	—	Max	Max	—	—	—
Speed limit (km/h)	—	35	—	—	35	—	—	35	—	—	35	—	—	—
Actuated Effct. Green (s)	—	14.0	—	—	15.0	—	—	18.0	—	—	18.0	—	—	—
Actuated g/C Ratio	—	0.16	—	—	0.17	—	—	0.20	—	—	0.20	—	—	—
Volume to Capacity Ratio	—	1.34	—	—	1.40dr	—	—	2.40	—	—	2.02	—	—	—
Control Delay (s)	—	200.1	—	—	171.3	—	—	655.8	—	—	490.3	—	—	—
Queue Delay (s)	—	0.0	—	—	0.0	—	—	0.0	—	—	0.0	—	—	—
Total Delay (s)	—	200.1	—	—	171.3	—	—	655.8	—	—	490.3	—	—	—
Level of Service	—	F	—	—	F	—	—	F	—	—	F	—	—	—
Approach Delay (s)	—	200.1	—	—	171.3	—	—	655.8	—	—	490.3	—	—	—
Approach LOS	—	F	—	—	F	—	—	F	—	—	F	—	—	—
Queue Length 50th (m)	—	~73.1	—	—	~66.2	—	—	~217.2	—	—	~177.1	—	—	—
Queue Length 95th (m)	—	#67.6	—	—	#66.7	—	—	#219.1	—	—	#182.8	—	—	—
Stops (vph)	—	321	—	—	392	—	—	611	—	—	662	—	—	—
Fuel Used (l/hr)	—	73	—	—	76	—	—	440	—	—	375	—	—	—
Dilemma Vehicles (#/hr)	—	0	—	—	0	—	—	0	—	—	0	—	—	—

Table 44 Level of Service Analysis Output for REST Unsignalized Intersection

LANE SETTINGS	SEL	SET	SER	NWL	NWT	NWR	NEL	NET	NER	SWL	SWT	SWR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	160	174	154	198	146	200	139	317	223	521	438	204
Street Name												
Link Distance (m)	—	108.0	—	—	96.2	—	—	113.3	—	—	146.9	—
Links Speed (km/h)	—	35	—	—	35	—	—	35	—	—	35	—
Set Arterial Name and Speed	—	SE	—	—	NW	—	—	NE	—	—	SW	—
Travel Time (s)	—	11.1	—	—	9.9	—	—	11.7	—	—	15.1	—
Ideal Satd. Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (m)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Grade (%)	—	2	—	—	-2	—	—	-3	—	—	1	—
Area Type CBD	—	☑	—	—	☑	—	—	☑	—	—	☑	—
Storage Length (m)	0.0	—	0.0	0.0	—	0.0	0.0	—	0.0	0.0	—	0.0
Storage Lanes (#)	—	—	—	—	—	—	—	—	—	—	—	—
Right Turn Channelized	—	—	None	—	—	None	—	—	None	—	—	None
Curb Radius (m)	—	—	—	—	—	—	—	—	—	—	—	—
Add Lanes (#)	—	—	—	—	—	—	—	—	—	—	—	—
Lane Utilization Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Right Turn Factor	—	0.952	—	—	0.945	—	—	0.954	—	—	0.971	—
Left Turn Factor (prot)	—	0.984	—	—	0.982	—	—	0.986	—	—	0.979	—
Saturated Flow Rate (prot)	—	2770	—	—	2916	—	—	2950	—	—	2934	—
Left Turn Factor (perm)	—	0.984	—	—	0.982	—	—	0.986	—	—	0.979	—

VOLUME SETTINGS	SEL	SET	SER	NWL	NWT	NWR	NEL	NET	NER	SWL	SWT	SWR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	160	174	154	198	146	200	139	317	223	521	438	204
Conflicting Peds. (#/hr)	0	—	0	0	—	0	0	—	0	0	—	0
Conflicting Bicycles (#/hr)	—	—	0	—	—	0	—	—	0	—	—	0
Peak Hour Factor	0.83	0.82	0.82	0.84	0.87	0.86	0.59	0.89	0.84	0.96	0.92	0.85
Growth Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Heavy Vehicles (%)	8	5	10	3	4	3	7	2	4	3	3	6
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Adj. Parking Lane?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Parking Maneuvers (#/hr)	—	—	—	—	—	—	—	—	—	—	—	—
Traffic from mid-block (%)	—	0	—	—	0	—	—	0	—	—	0	—
Link OD Volumes	—	—	—	—	—	—	—	—	—	—	—	—
Adjusted Flow (vph)	193	212	188	236	168	233	236	356	265	543	476	240
Traffic in shared lane (%)	—	—	—	—	—	—	—	—	—	—	—	—
Lane Group Flow (vph)	0	593	0	0	637	0	0	857	0	0	1259	0

HCM 2000 SIGNING SETTINGS	SEL	SET	SER	NWL	NWT	NWR	NEL	NET	NER	SWL	SWT	SWR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	160	174	154	198	146	200	139	317	223	521	438	204
Sign Control	—	Yield	—	—	Yield	—	—	Stop	—	—	Stop	—
Median Width (m)	—	0.0	—	—	0.0	—	—	1.0	—	—	1.0	—
TWLTL Median	—	☐	—	—	☐	—	—	☑	—	—	☑	—
Right Turn Channelized	—	—	None	—	—	None	—	—	None	—	—	None
Critical Gap, tC (s)	—	—	—	—	—	—	—	—	—	—	—	—
Follow Up Time, tF (s)	—	—	—	—	—	—	—	—	—	—	—	—
Volume to Capacity Ratio	0.98	0.98	0.90	1.03	1.03	0.94	1.31	1.31	1.31	2.47	2.47	1.43
Control Delay (s)	80.6	70.8	60.9	94.4	81.6	68.9	189.5	189.4	189.3	695.3	465.6	235.9
Level of Service	F	F	F	F	F	F	F	F	F	F	F	F
Queue Length 95th (m)	—	—	—	—	—	—	—	—	—	—	—	—
Approach Delay (s)	—	70.9	—	—	81.7	—	—	189.4	—	—	520.8	—
Approach LOS	—	F	—	—	F	—	—	F	—	—	F	—

Table 45 Level of Service Analysis Output for REST signalized Intersection

LANE SETTINGS	SEL	SET	SER	NWL	NWT	NWR	NEL	NET	NER	SWL	SWT	SWR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	150	188	130	99	261	164	179	278	207	512	341	205
Street Name												
Link Distance (m)	—	108.0	—	—	96.2	—	—	113.3	—	—	146.9	—
Links Speed (km/h)	—	35	—	—	35	—	—	35	—	—	35	—
Set Arterial Name and Speed	—	SE	—	—	NW	—	—	NE	—	—	SW	—
Travel Time (s)	—	11.1	—	—	9.9	—	—	11.7	—	—	15.1	—
Ideal Satd. Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (m)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Grade (%)	—	2	—	—	-2	—	—	-3	—	—	1	—
Area Type CBD	—	☑	—	—	☑	—	—	☑	—	—	☑	—
Storage Length (m)	0.0	—	0.0	0.0	—	0.0	0.0	—	0.0	0.0	—	0.0
Storage Lanes (#)	—	—	—	—	—	—	—	—	—	—	—	—
Right Turn Channelized	—	—	None	—	—	None	—	—	None	—	—	None
Curb Radius (m)	—	—	—	—	—	—	—	—	—	—	—	—
Add Lanes (#)	—	—	—	—	—	—	—	—	—	—	—	—
Lane Utilization Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Right Turn Factor	—	0.957	—	—	0.950	—	—	0.955	—	—	0.969	—
Left Turn Factor (prot)	—	0.985	—	—	0.989	—	—	0.987	—	—	0.976	—
Saturated Flow Rate (prot)	—	2794	—	—	2928	—	—	2810	—	—	2871	—
Left Turn Factor (perm)	—	0.985	—	—	0.989	—	—	0.987	—	—	0.976	—

VOLUME SETTINGS	SEL	SET	SER	NWL	NWT	NWR	NEL	NET	NER	SWL	SWT	SWR
Lanes and Sharing (#RL)												
Traffic Volume (vph)	150	188	130	99	261	164	179	278	207	512	341	205
Conflicting Peds. (#/hr)	0	—	0	0	—	0	0	—	0	0	—	0
Conflicting Bicycles (#/hr)	—	—	0	—	—	0	—	—	0	—	—	0
Peak Hour Factor	0.91	0.85	0.83	0.71	0.92	0.77	0.91	0.83	0.91	0.93	0.96	0.87
Growth Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Heavy Vehicles (%)	8	7	7	3	4	5	14	9	6	5	6	5
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Adj. Parking Lane?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Parking Maneuvers (#/hr)	—	—	—	—	—	—	—	—	—	—	—	—
Traffic from mid-block (%)	—	0	—	—	0	—	—	0	—	—	0	—
Link OD Volumes	—	—	—	—	—	—	—	—	—	—	—	—
Adjusted Flow (vph)	165	221	157	139	284	213	197	335	227	551	355	236
Traffic in shared lane (%)	—	—	—	—	—	—	—	—	—	—	—	—
Lane Group Flow (vph)	0	543	0	0	636	0	0	759	0	0	1142	0

TIMING SETTINGS	SEL	SET	SER	NWL	NWT	NWR	NEL	NET	NER	SWL	SWT	SWR	PED	HOLD
All-Red Time (s)	1.0	1.0	—	1.0	1.0	—	1.0	1.0	—	1.0	1.0	—	—	—
Lost Time Adjust (s)	—	0.0	—	—	0.0	—	—	0.0	—	—	0.0	—	—	—
Lagging Phase?	☑	☑	—	☐	☐	—	☑	☑	—	☐	☐	—	—	—
Allow Lead/Lag Optimize?	☐	☐	—	☐	☐	—	☐	☐	—	☐	☐	—	—	—
Recall Mode	Max	Max	—	Max	Max	—	Max	Max	—	Max	Max	—	—	—
Speed limit (km/h)	—	35	—	—	35	—	—	35	—	—	35	—	—	—
Actuated Effct. Green (s)	—	15.0	—	—	22.0	—	—	22.0	—	—	25.0	—	—	—
Actuated g/C Ratio	—	0.14	—	—	0.20	—	—	0.20	—	—	0.23	—	—	—
Volume to Capacity Ratio	—	1.40	—	—	1.07	—	—	1.33	—	—	1.72	—	—	—
Control Delay (s)	—	230.8	—	—	97.8	—	—	194.5	—	—	358.9	—	—	—
Queue Delay (s)	—	0.0	—	—	0.0	—	—	0.0	—	—	0.0	—	—	—
Total Delay (s)	—	230.8	—	—	97.8	—	—	194.5	—	—	358.9	—	—	—
Level of Service	—	F	—	—	F	—	—	F	—	—	F	—	—	—
Approach Delay (s)	—	230.8	—	—	97.8	—	—	194.5	—	—	358.9	—	—	—
Approach LOS	—	F	—	—	F	—	—	F	—	—	F	—	—	—
Queue Length 50th (m)	—	~80.6	—	—	~78.1	—	—	~109.3	—	—	~187.2	—	—	—
Queue Length 95th (m)	—	#105.2	—	—	#113.2	—	—	#129.6	—	—	#227.6	—	—	—
Stops (vph)	—	359	—	—	453	—	—	525	—	—	743	—	—	—
Fuel Used (l/hr)	—	93	—	—	50	—	—	114	—	—	318	—	—	—