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ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

SOCIO-ECONOMIC IMPACT OF TRAFFIC CONGESTION IN ADDIS ABABA:

(CASE STUDY: WELETE TO TOTAL)

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MSc. Thesis on

Assessing the Socio-Economic Impact of traffic congestion in Addis Ababa

(Case Study: welete to Total)

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Declaration

I certify that this research work titled "Optimal Traffic Signal Timing Allocation for Urban Congested Roundabouts" is my own work. The work has not been presented elsewhere for assessment and award of any degree or diploma. Where material has been used from other sources it has been properly acknowledged/ referred.

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ABSTRACT

Addis Ababa is the cities which is undergoing in a fast urbanization and facing traffic congestion in significant manner. It has both social and economical implication on the peoples of the country. The socio-economic impact of traffic congestion comes in many forms, such as increase stress and fatigue, constraint social relation, increase accident and incident, increase transport cost, difficulty to estimate travel time, missing appointment and late delivery, block for emergency vehicles, diversion to the local road, and health problem.

This study assesses the socio-economic impact of road traffic congestion in Addis Ababa city in case of Welete-Total road segment. Primary data collected using questionnaires and filed visit. The data collect from questionnaires analyze using Statistical Package for Social Sciences (SPSS) software to assess the cause, impact and solution of traffic congestion at study area. And the data collected from field visit of the three major intersections at the road segment was used for Traffic volume and Spot Speed analysis using Excel spread sheet.

And performance Analysis of the intersections was done by considering delay, queue and LOS using VISSIM 9 software. The level of service result of Ayertena signalized intersection, Zenebework Roundabout and Total Turbo Roundabout is LOS-F, LOS-B and LOS-D respectively. The estimated Total congestion cost of the all three intersections based on delay cost and change in vehicle operating cost at morning peak hour is **879,968.45 ETB.**

To enhance performance of Total 3kutr mazoriya Turbo Roundabout, this study proposed engineering solutions is signalizing the roundabout by maintaining its current geometry as it is. Signal timing design and approaching saturation flow rate were computed by using HCM 2010 and coded in vissim software to do performance analysis. The result showed significant reduction of delay from 72.59 seconds to 17.84 seconds and increase Level of service of the roundabout from LOS-D to LOS-B.

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ACRONYM

ERA	Ethiopian Road Authority
HCM	Highway Capacity Manual
LOS	Level of Service
VISSIM	Traffic Stimulation Software
CBD	Central Business District
CPI	Consumer Price Index
PHF	Peak Hour Factor
PCU	Passenger Car Unit

CHAPTER ONE: INTRODUCTION

1.1. Background

Traffic congestion is defined as a condition of traffic delay because the number of vehicles trying to use the road exceeds the traffic network capacity to handle them. Traffic congestion is widely viewed as a growing problem in many urban areas across world, because the volume of vehicular traffic in many areas continues to grow faster than the overall capacity of the transportation system. The resulting traffic slowdowns can have a wide range of negative effects on people and on the business economy, including impacts on air quality ,quality of life (due to personal time delays), and business activity (due to the additional costs and reduced service areas for workforce, supplier, and customer markets) (National Cooperative Highway Research (2001).

Daily time spent traveling in the city has increased and the cities are facing high levels of road traffic accidents, frequent congestion, and high levels of air pollution. These challenges are manifest even though motorization in Addis is quite low by world standards; investments in expansion of the road network has not been accompanied by improvements in traffic management or the development of public transport services (‘Ethiopia: Transport Systems Improvement Project’, 2016).

A region’s economy does better when people spend more time working and doing things they find valuable and less time traveling to do them. Whereas traffic congestion disrupts business activities and reduces productivity level, some researches has shown that it may also be a symbol of growth in an economy. Weisbrod, G. (2003)

Addis Ababa is a capital city and one of the largest cities in Ethiopia which faces significantly a transport congestion problem. The city is the principal commercial center of Ethiopia and is experiencing rapid urban growth. The population of 3,384,569 according to the 2015 year population census with annual growth rate of 3.8%. And this population more than doubled every decade since the 1980s. Even though Addis Ababa currently manifests low motorization rates by global standards (130 vehicles per 1,000 people, with a total registered vehicle fleet of about 426,500 in 2015), the rapid economic growth in recent years is expected to lead to a strong increase in vehicle ownership(‘Ethiopia: Transport Systems Improvement Project, 2016).

Addis Ababa experiences significant traffic congestion due to several reasons such as shortage of mass transport, poor traffic management, imbalance of vehicle volume and road capacity, especially at intersections, parking of passenger cars for loading and unloading of passengers near intersection entry and exit, on street parking on walkways and road ways which forces passengers to use roadways and conflict with vehicles, inflexible work zone and to some extent, traffic accidents.

This has an implication of, delays which is time during their day to activities, air pollution, noise pollution, excess fuel consumption of vehicles, excess vehicle operating costs like additional costs for spare parts, excess fuel, for those business men, it creates additional costs since supply may not be available at time, extra inventory cost to minimize congestion effects on their business, losing their workers time, their workers may not perform to their capacities because of being tired, stressed and bored as a result of congestion.

In order to mitigate the Impact of traffic congestion, measures mainly such as Improve LRT (Light rail transit), use mass transport, improve geometric design of roads, increase road capacity, improve traffic management strategies, improve parking management and parking capacity increasing especially off road- way parking facilities, mitigate illegal on street trade, flexible work schedule and introducing bus rapid transit were considered in Addis Ababa. Kefyalew, T (2017).

This study assesses the socio-economical impact of traffic congestion in Addis Ababa. It focuses on the transportation system in Addis Ababa city in case of Welete-Total road segment. And provide insights to the Government and policy-makers on the ways in which they can mitigate traffic congestion, manage traffic more effectively, adopt appropriate policies, and invest in infrastructural projects. The peoples of the study area and other commuters benefit from this study, as recommends the means of relieving the traffic congestion problem.

1.2. Statement of the problem

Traffic congestion becomes a threat for the country's economy growth. It limits road user mobility and decrease working time. Addis Ababa face traffic congestion problem significantly its leads people to wait longer time at bus and taxi station, delay to work places and school, delay or miss meetings due to longer transient time, spending more time to accomplish tasks, more energy consumption, air and noise pollution, delay in delivering time-sensitive logistics.

Each and every person living and working in Addis Ababa, as well as passersby, have had the misfortune of experiencing congestion and its effects. The government has been done many attempts to minimize traffic congestion problems in Addis Ababa by identifying the causes, consequences, and even suggesting solutions to these problems from time to time. However, these efforts have not been well compensated due to the continuous presence of road traffic congestion in the city. Thus, it has become compulsory to seek more information about traffic congestion situations in Addis Ababa especially in welete- total road.

Unlike the previous studies on traffic congestion which have always concentrated on the economic effects of traffic congestion, this study assesses both the economic and social effects. Based on the findings, the study proposes measures that can be put in place to alleviate the socio-economic effects of traffic congestion.

1.3. Objective

1.3.1. General objective

To assess socio-economic impact of traffic congestion in Addis Ababa city case of Welete-Total road segment.

1.3.2. Specific objective

- To assess the social impact of traffic congestion on the community
- To analyze the performance of the selected intersections
- To estimate traffic congestion cost based on intersection delay and vehicle operating cost.
- To propose measures that can be reduce the socio-economic effects of traffic congestion.

1.4. Research question

- Is congestion has impact on the society?
- How the intersections perform?
- How much will be the economical loss due to congestion?
- What measures can be put in place to alleviate road traffic congestion?

1.5. Significance of the study

Road traffic Congestion continues to remain a major problem in Addis Ababa, especially at morning and evening peak periods in massive delays, increased fuel wastage and monetary losses. In Addis Ababa, Welete-total road segment is the main gates in the south part of Ethiopia and have substantial daily traffic congestion. Investigated the cause and impact and estimate economical loss due to traffic congestion at study area and finally put some recommendation it will be used for policy makers and government bodies to know detail about this matter and also to review urban development and transport policies.

1.6. Scope of the study

The study only examine the cause, socio-economic effect of traffic congestion from the south entrance of Addis Ababa in Welete-Total road segment although it have several other effects and consequences.

1.7. Organization of the thesis

The thesis consisted five chapters. Chapter one deals with the background of the study, the statement of the problem, the study objectives, research questions, the significance, and the scope of the study. Chapter two presents the related literature reviewed in this study. Chapter three deals with an explanation of the sampling area, research approach, data collection, data analysis for the research under study. Chapter four describes the result and discussion of the analysis. And the final chapter deals with the conclusion and recommendation.

CHAPTER TWO: LITERATURE REVIEW

2.1. Definition of Traffic Congestion

A review of literature has revealed a persistent view that there is no single definition of congestion, although the concept is commonly understood and the term is used widely by academics, policy makers.

Congestion occurs when the road capacity does not meet traffic demand at an adequate speed, traffic controls are improperly used, or there is an incident on the road such as an accident or disabled vehicle.

Congestion can take various forms, such as recurring or nonrecurring, and can be located across a network or at isolated points. Recurring congestion exists when the traffic volume on roadway exceeds its capacity at a particular location during a predictable and repeated time of day. Nonrecurring congestion is caused by random or unpredictable events that temporarily increase, demand, or reduces capacity on a roadway. Such events include accidents, disabled vehicles, road construction, and inclement weather. Grant-M, SM and Lird, JJ (2007)

2.2 Cause of traffic congestion

Traffic congestion is a multi-dimensional problem and the increase in traffic congestion is essentially a function of demand for road use increasing at a faster rate than the capacity, combined with ineffective traffic management. So, this mismatching are caused by various factors depending on the features of the road geometry, character of traffic flow, behavior of road users and those external factors.

Multiple factors cause traffic congestion. Some of them are too many cars for the roadway due to inadequate mass transit options or other reasons; obstacles in the road causing a blockage and merger such as double parking, road work, lane closure due to utility work, road narrowing down, and an accident; Traffic signals out of sync many times on purpose or occasionally when the computers are malfunctioning; Inadequate green time; Too many pedestrians crossing not permitting cars to turn; Too many trucks on the road due to inadequate rail freight opportunities; Overdevelopment in areas where the mass transit system is already overcrowded and the road system is inadequate. Allan, N (2013).

Specific to Addis Ababa, Admassu, N (2017) reported that the cause of traffic congestion is due to higher number of road users during the morning and evening peak hours and the existence of large trucks signal timing, absence of posted seconds count down and driver's aggressive behavior.

Also, Solomon (2015) found limited road capacity, road side parking, un-integrated urban planning, and lack of mass transit, accident, poor vehicle condition, and road side illegal trade as a major cause of traffic congestion in Addis Ababa city. He also indicated that the root causes for traffic congestion in developing countries emanate from improper planning and misuse of limited road network.

While the commonest causes of traffic congestion are shortage of mass transport, poor traffic management, imbalance of vehicle volume and road capacity, especially at intersections, parking of passenger cars for loading and unloading of passengers near intersection entry and exit, on street parking on walkways and road ways which forces passengers to use roadways and conflict with vehicles, inflexible work zone and to some extent, traffic accidents. Kefyalew, T (2017).

2.3 Impacts of Traffic Congestion

2.3.1 Social impact of traffic congestion

Traffic congestion had a negative social effect. One is a health challenge. Road traffic congestion results serious health effect particularly public transport buses and rails remained source of communicable disease such as tuberculosis. Traffic congestion increases vehicle emissions of Carbon Dioxide (CO2), Carbon mono oxide (CO), and Nitrogen Dioxide (NO2) due to reduced vehicles travel speeds. The accumulation of these pollutants risk peoples to asthma, heart disease, cancer and other traits. Elisonguo, AD (2013) revealed that parents spend a lot more time on the roads than at home with their children due to road congestion. This led children to accidents in Dar Es Salaam.

The second traffic congestion social effect could be long commuting time contribute to increased stress levels and aggressive motorists' behavior. The third effect could be an effect of severance implying roadways separate communities and constrain societal relations. A lengthy travel time

impacts family life and is a renowned factor of work-family conflicts since it decreases the time available for parents to spend with their families. Fourth, traffic congestion interferes with an emergency service. The flow of emergency vehicles such as ambulances, alarm responses, fire fighters and police vehicles slow down hence leading to more deaths and damage of properties. Lastly, Congested main road has a spill-over effect to minor roads and side streets as motorists attempt substitute routes to evade congestion. (Mercyleen N., 2018).

2.3.2 Economic impact of traffic congestion

Economies of many cities or countries are affected by traffic congestion. The negative effects covered the business economy including impacts on air quality, quality of life due to personal time delays, and business activity due to the additional costs. Traffic congestion led society loses resources and impact the economy by loosing man-hours, extra transportation cost, extra fuel consumptions vehicle operating cost and miscellaneous cost.

Congestion mainly impacted society increasing loss of productivity and made them spent more time traveling to work rather than working; delaying (or missing) meetings; foregoing interactions among individuals or personal activities due to long travel time; and spending more time to accomplish tasks than would otherwise be necessary if we could reliably plan for accomplishing the same things at free-flow speeds. (Somuyiwa, 2015)

Weisbrod et al. (2003) stated that increased traffic congestion imposes cost upon commuters and affects business operations. They further affirm that businesses that have high needs for incoming deliveries are mostly affected by traffic congestion and thus reduce productivity. Thus traffic congestion increases the cost of businesses operations. For instance delay in delivering time-sensitive logistics can impose additional inventory and logistics cost.

Congestion affects speed and smooth traffic flow. This affects a wide range of activities, services, goods, markets opportunities in the cities which can best be delivered through transport mobility. Congestion also reduces productivity through increased inventory holding by manufacturers and retailers as a result of unreliable travel conditions within cities. Business activities depend on timely delivery of logistics. However, freight movement in cities is impaired by traffic congestion, thus making productivity suffer.

Alaa,G (2018) estimated about 184.5million Egyptian Pounds (EGP) traffic congestion related costs annually in Mansoura city of Egypt. The study informed that the problem greatly influence the daily life of the people and considerably affects the economy of the country.

The research work by Somuyiwa, (2015) in Nigeria show average distance, time and cost were found to be significantly related to traffic congestion. As per the result an average distance of about 5-10km is significantly related to workers' productivity at 5% level. Lateness of 30 minutes to work due to congestion is found to be positive and significantly related to workers' productivity. Further, lateness in the time bracket of 90 minutes is highly significant and negatively related to productivity. Result further shows that commuting cost has a significant and negative effect on productivity of workers by taking significant amount of cost from their salary so impacting on their effort rate. Time loss due to congestion is also found to significantly reduce the effectiveness of workers at a magnitude of 1.60 in general and younger workers experienced reduced level of effectiveness at a magnitude of 1.98.

The other research in Ghana, Kumasi Metropolis shows that more than 78% of the mini-bus drivers face an average income loss of 21.9% and more than 88% of the taxi drivers also face an average income loss of 14.3% to due to the traffic congestion. In the formal sectors, the average mandated number of hours of about 9 hours a day was reduced by 0.88 of an hour (52.8 minutes) a day, which represents an average of 9% loss of productive hours a day and loss of over two working days in a month which has implications on the economy. This has obvious implications on the economy. (Harriet and Emmanuel, 2013).

The other study in U.S identifies congestion as an issue of significant concern to many employers and quantifies the magnitude of this impact. The amount is significant, annually estimated to cost about $5.3 billion in shipping delays and $76 billion in employee day-to-day business travel delays. (Hartgen et al, 2014).

According to (Rogers, Martin, 2002) determined the cost of congestion in United States of America as a function of delay time and wasted fuel cost. Accordingly, the congestion cost for extra time and fuel for 439 urban areas were 24 Billion, 58 Billion and 115 Billion for the years

1982, 2000 and 2009 respectively; 3.9 Billion gallon of fuels wasted and 4.8 Billion person-hours of extra time wasted.

Somuyiwa, et al. (2015) revealed that 15.6% of variation in workers' productivity is accounted for by traffic congestion. They reflected that traffic congestion and workers productivity inversely associated where increased rate of traffic congestion leads to low productivity.

Few studies also examine cases in Addis Ababa and showed that traffic congestion at cross intersections and roundabouts brought vehicle extra fuel consumption cost; and time loss by passengers and drivers.

Mitiku, N (2015) estimated the cost of fuel lost and time lost depending on the waiting time of vehicles at road junctions approximately as ETB 2,900,000 per year. The cost of fuel lost and time lost rapidly increase if vehicles are waiting much time at the junction but the cost of time lost is greater than cost of fuel lost.

Kefyalew,T (2017) study on the North-South corridor of Addis Ababa also reported that total congestion cost including delay, wasted fuel and operating cost of passenger vehicles and truck vehicles at each road segments on average is about Birr 53.2 million per year. In addition, congestion increased pollutants emission to the environment.

2.5 Economic Cost of Traffic Congestion Estimation

Increasing traffic congestion does impose costs not only on travelers but also on the whole economic activities and finally affects national income. It has been difficult to develop and apply empirical measures of the extent of those economic costs.

Researcher Sanowear,H (2017)were conducted study at signalized intersection of Demak Ijo, Godean Street, Sleman, Yogyakarta to estimate traffic congestion cost According to the theory of TzedakisA (1980).

Theory of Tzedakis, A 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;

(i). Total Congestion Costs

The total congestion cost mathematically estimated as follow:

$$\mathbf{CC = N\left[VC * Va + \left(\frac{Va}{Vi}\right)V'\right]QT}$$

Where:

CC = cost of congestion (IDR per hour)

N = volume of vehicle queues (pcu/hour)

VC = vehicle operating costs (IDR/veh.km)

Va= actual speed (km/h)

Vi = ideal (design) speed (km/h)

V'= value of time per vehicle (IDR/hour)

QT = queue time (hours)

(ii).Estimating Vehicle Operating Cost

Vehicle operating costs (VOC) refer to travel costs that vary with vehicle usage and are based on vehicle kilometer traveled.

The five main factors they can affect vehicle Operating Costs are as follows:

1. Vehicle Type: Operating costs vary by vehicle size, class, and other characteristics. Trucks will typically have higher vehicle operating costs than cars.

2. Vehicle Speed: Vehicle speed is the dominant factor affecting vehicle operating costs. Typically operating costs decrease with increasing speed to a certain point, and then begin to increase with increasing speed.

3. Speed Changes: Changes in speed (also known as speed cycles) increase vehicle operating costs. This added cost is higher when speed cycling occurs at higher speeds.

4. Gradient: Grades can be either positive (uphill) or negative (downhill). Positive grades are more demanding on vehicle engines and require greater fuel consumption. This leads to an increase in operating costs. Negative grades may reduce operating costs, but may also increase wear on brakes. Wear on the vehicle's tires, leads to an increase in operating costs.

5. Road Surface: the roughness of the road surface can affect vehicle operating costs by affecting rolling resistance. Rough surfaces can reduce speed, require greater fuel consumption, increase wear on tires, and increase maintenance costs.

The main components of vehicle operating costs are Fuel costs (per liter),Tire wear (per piece), Maintenance labor costs (per hour),Lubricating oil consumption (per liter),Crew wages (per hour),Overhead Interest rate (%),Passenger working time (per hour), Passenger non-working time (per hour),Cargo time cost for goods vehicles, Annual working hours and Average vehicle life by vehicle type. Simon,G (2017).

2.6 Intersections

Intersections are crossroad at any place where two or more than two roads intersect or meet each other at grade. Intersections may be signalized or non-signalized, may or may not have a roundabout. The efficiency of an intersection is defined based on how well an intersection accommodates the needs of all road users.

2.6.1 Signalized intersection

Traffic signals are automatic traffic control devices which could alternately direct the traffic to stop and proceed at intersections using red and green traffic light signals as per the pre-

determined time settings. The main objectives are to provide sufficient intersection capacity and to minimize overall delay. The performance of a signalized intersection is judged on the basis of its signal timing.

Signal control are effective because they separate traffic in time however ,the separation introduces a mandatory delay in all traffic stream. Installing signal should be based on engineering study of the roadway,traffic and other condition.Proporley design signals can increase capacity,reduced frequency and severity of certain crashes and provide orderly movement.

Poorly designed signals can lead excessive delay,disobedience and significant collisions. At a signalized intersection, three signal indications are seen: green, yellow, and red. The red indication may include a short period during which all indications are red, referred to as an all-red interval, which with the yellow indication, and forms the change and clearance interval between two green phases.

There are three types of traffic signal controllers.

• Pre timed, in which a sequence of phases is displayed in repetitive order. Each phase has a fixed green time and change and clearance interval that are repeated in each cycle to produce a constant cycle length.

• Fully actuated, in which the timing on all of the approaches to an intersection is influenced by vehicle detectors. Each phase is subject to a minimum and maximum green time, and some phases may be skipped if no demand is detected. The cycle length for fully-actuated control will vary from cycle to cycle.

• Semi-actuated, in which some approaches (typically on the minor street) have detectors, and some of the approaches (typically on the major street) have no detectors. While these equipment-based definitions have persisted in traffic engineering terminology, the evolution of traffic control technology has complicated their function from the analyst's perspective. (HCM 2010 2010).

2.6.2 Roundabout

A roundabout is a circular intersection designed to reduce delay, reduce crossing conflicts and promote an efficient and safe traffic flow. Roundabouts are designed to accommodate vehicles of all sizes, including emergency vehicles, buses, trucks and trailer combinations. In a roundabout, drivers enter the intersection by navigating a gentle curve. And it reduced head on collision. A roundabout works as best and most efficient when the volume of traffic is balanced, an unbalanced traffic at roundabout leads to delays and queues.Three main features of roundabouts are illustrated (Figure 2-1), the central island, the circulating roadway, and the splitter island.

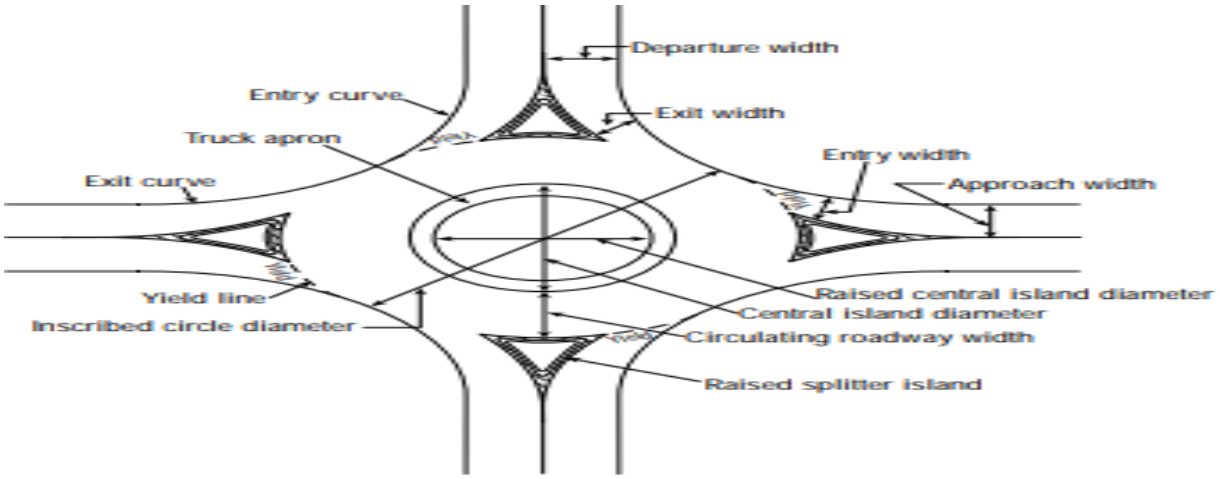

Figure 2- 1: Basic roundabout geometrics

The common characteristics that define a roundabout are the following.

• Vehicles entering a roundabout are required to yield to vehicles within the circulating roadway. Traffic circles sometimes employ stop or signal control or give priority to entering vehicles.

• The circulating vehicles are not subjected to any other right-of-way conflicts and weaving is kept to a minimum. This provides the means by which the priority is distributed and alternated among vehicles. A vehicle entering as a subordinate vehicle immediately becomes a priority vehicle until it exits the roundabout. Some traffic circles impose control measures within the circulating roadway, or are designed with weaving areas to resolve conflicts between movements.

• The speed at which a vehicle is able to negotiate the circulating roadway is controlled by the location of the central island with respect to the alignment of the right entry curb and the circulating roadway cross section. It is important that the speeds of vehicles on the roundabout are low. This feature is responsible for the improved safety record of roundabouts. Some large traffic circles provide straight paths for major movements or are designed for higher speeds within the circulating roadway. Some small traffic circles do not achieve adequate deflection for speed control because of the small central island diameter.

• No parking is allowed on the circulating roadway. Parking maneuvers, if allowed, would prevent the roundabout from operating in a manner consistent with its design. Some larger traffic circles permit parking within the circulating roadway.

• No pedestrian activities take place on the central island. Pedestrians are not intended to cross the circulating roadway. Some larger traffic circles provide for pedestrian crossing to, and activities on, the central island.

• All vehicles circulate counterclockwise (in countries with a drive right policy), passing to the right of the central island. In some small traffic circles (sometimes called mini-traffic circles) left-turning vehicles are expected to pass to the left of the central island.

• Roundabouts are designed to properly accommodate specified design vehicles. Some smaller traffic circles are often unable to accommodate large vehicles usually because of right-of-way constraints.

• Roundabouts have raised splitter islands on all approaches. Splitter islands are an essential safety feature, required to separate traffic moving in opposite directions and to provide refuge for pedestrians. Some smaller traffic circles do not provide raised splitter islands.

• When pedestrian crossings are provided for on the approach roads, they are placed approximately one car length back from the entry point. Some traffic circles accommodate pedestrians in other places, such as the yield point.

• The entry deflection is the result of physical features of a roundabout. Some traffic circles rely on pavement markings to promote deflection.(HCM 2010 ,2000).

2.6.3 Turbo Roundabout

Turbo roundabouts are a particular road intersection layout, designed to increase the safety of double-lane roundabouts, while maintaining their excellent capacity.

The primary objective of the Turbo roundabout design is to improve the safety performance of multilane roundabouts by reducing the number of conflict points. The basic Turbo roundabout only has 10 conflicts points, due to the elimination of weaving in the roundabout and lane changing at the roundabout exits.

The main features of turbo-roundabouts are-: nested spiral lane at one or more entries, yield to no more than two lanes (deviation might be possible), smooth spiral markings, raised and mountable lane dividers, at least one lane offers a choice for direction, at least two exit legs have two exit lanes, approach legs are aligned perpendicularly to the circulatory lanes, and roundabout signage cuts off the horizon for optimal recognition. Aprons in central island and armpit are established to keep narrow lane width for passenger vehicles but provide additional driving surface for HGVs

There are Different Layouts of turbo roundabout based on approach legs (Figure 2-2).For the intersection three or four approach legs the Basic turbo roundabout, Spiral roundabout, Knee roundabout and Rotor roundabout type of layouts were suitable but less suitable for three-leg junctions. For the Three legs only Stretched-knee roundabout and Star roundabout layouts were suitable.

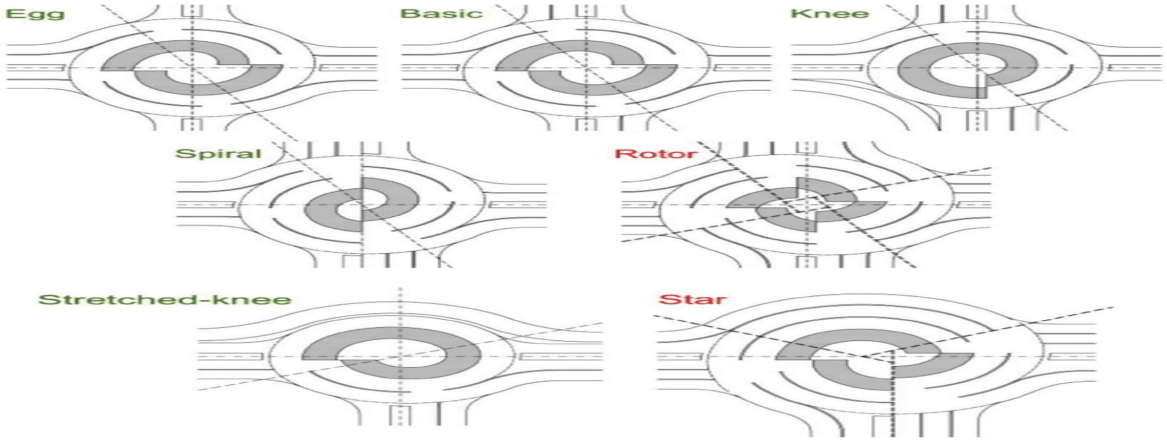

Figure 2- 2: Different Layouts of Turbo Roundabout

2.7 Roundabout Signalization

The proper operation of roundabout depends on there being a reasonable balance between the entry flows. An uninterrupted but not very intense stream of circulating traffic can effectively prevent much traffic from entering at a particular approach. The capacity of roundabouts is particularly limited if traffic flows are unbalance. This particularly the case if one entry has very high flow and the entry immediately before it on roundabout has light flow so that the heavy flow proceeds virtually uninterrupted. This produced continues circulating traffic which therefore prevents traffic from entering on subsequent approaches.

Roundabout Signalization Roundabouts are developed to get rid of signals and to reduce delay time at an intersection. But when an unbalanced flow occurs with a heavy flow it increases delay time at an intersection and in such situations. Unbalanced traffic flow is limiting the capacity of the roundabout. If the traffic flow is very heavy and unbalanced, it is not suitable to build up a roundabout. The main goal with roundabouts is to reduce delay time at an intersection and it has fewer conflict points than signalized intersection, which is reducing collisions.

However, a heavy unbalanced flow increases the delay time at an intersection and in this situation, signals are used to reduce flocking in the traffic flow and even balance the capacity. Integration of signalized roundabouts helps to decrease violation of traffic rules and to balance the flow. Although signalization defeats the nature of a roundabout's true purpose, they may provide solutions in situations such as an unbalanced flow of traffic. The benefits that signalization of roundabout can provide are shorter delays, reduced queue lengths, an increase in capacity and safety. (Charles R. Stevens, 2005)

Federal Highway Administration's roundabout informational guide state that signalizing roundabouts to improve capacity be considered only when it is the most cost-effective solution. Traffic signals at fully signalized rotaries should be timed carefully to prevent queuing on the circulatory roadway by ensuring adequate traffic progression of circulating traffic and especially critical movements.

2.7.1 Advantages of Traffic Signal Control

According to (Hallworth 1992).there are four main benefits to signalizing or metering a roundabouts, including shorter delays, reduced queue lengths, increase in capacity, and safety.

Shorter Delays- Delays at non-signalized roundabouts increase due to unbalanced flows or interactions with other intersections. Signals and meters can be used to balance delays and can reduce delays among a coordinated network. With the aid of the signals the delay can be more balanced in the roundabout and decrease the delay in coordinated networks through balancing flows**.**

Reduced Queue Lengths-With unbalanced flow, queues can become excessive, sometimes backing up into other intersections or roadways. This situation is most likely to take place on frontage road off-ramps. By using signals for metering, the queues can be handled and prevent that they block for example nearby intersections and can reduce queues by allowing queued traffic the right-of-way once a critical queue is detected.

Increase in Capacity - if an excessive amount of traffic due to growth or new developments is entering a roundabout, traffic may not be able to circulate freely and can sometimes lock up. In situations where traffic is excessive, traffic signals may improve operations. It should also be noted that additional improvements to the roundabout design may be needed to supplement the addition of signals.

Safety - With the need for weaving and merging within a roundabout, internal circulatory speed can increase and hinder the ability of entering traffic to accept a gap. Traffic signals and meters better regulate the entry and sometimes exit of the roundabout, slowing the speeds of weaving and merging traffic, giving more time for drivers to react, and increasing safety at a roundabout.

2.8 Performance measures

Performance measures can be based on empirical observations/data measurements of existing conditions or may be outputs of models that estimate or predict the performance of potential future scenarios, programs or alternative strategies. There are four measures which are used to describe the performance of two-way stop controlled intersections. These are

2.8.1 Delay

A critical performance measure on interrupted flow facilities is delay. There are several types of delay, but this study uses control delay as the principal service measure in evaluating level of service at signalized and un-signalized intersections. Although the definition of control delay is consistent among signalized and un-signalized intersections, its application, including LOS threshold values, differs for these facilities. Control Delay involves movements at slower speeds and stops on intersection approaches, as vehicles move up in the queue or slow down upstream of an intersection Drivers frequently reduce speed when a downstream signal is red or a queue is present at the downstream intersection approach. Control delay requires the determination of a realistic average speed for each roadway segment. It is implied in the estimates of the average travel speed on urban streets. (HCM 2010)

2.8.2 Level of Service

Level of service (LOS) is a qualitative measure used to relate the quality of traffic service. LOS is used to analyze highway by categorizing traffic flow and assigning quality levels of traffic based on performance measure. The HCM 2010 defines LOS for signalized and un-signalized intersections as a function of the average vehicle control delay (Table 1.1).LOS may be calculated per movement or per approach for any intersection configuration but LOS for the intersection as a whole is only defined for signalized and all way stop configuration.

Table 2- 1: Level of Service Criteria (HCM 2010)

LOS	Signalized intersection	Un signalized intersection
A	≤ 10 sec	≤ 10 sec
B	10-20 sec	10-25 sec
C	20-35 sec	15-25 sec
D	35-55 sec	25-35 sec
E	55-80 sec	35-50 sec
F	>80 sec	>50 sec

Roundabouts can reduce delays for pedestrians compared to traffic signals, because pedestrians are able to cross during any safe gap rather than waiting for a signal. During peak flows when large gaps are infrequent, the slower speed of traffic entering and exiting can still allow crossing,

despite the smaller gaps. The primary measure which is used to provide an estimate of level of service (LOS) is control delay. This measure can be estimated for any movement on the minor (i.e., the stop controlled) street. By summing delay estimates for individual movements, a delay estimate for each minor street movement and approach can be achieved. (HCM 2010).

2.8.3 Travel Time

Travel time is the time taken by a vehicle to traverse a given section of a highway. A travel time study determines the amount of time required to travel from one point to another on a given route. In conducting such a study, information may also be collected on the locations, durations, 13 and causes of delays. When this is done, the study is known as a travel time and delay study. Data obtained from travel time and delay studies give a good indication of the level of service on the study section. These data also aid the traffic engineer in identifying problem locations, which may require special attention in order to improve the overall flow of traffic on the route.

2.8.4 Queue

When demand exceeds capacity for a period of time or arrival time headway is less than the service time at a specific location, a queue is formed. A queue is also formed when arrivals wait at a service area for service. This service can be the arrival of an accepted gap in a major street traffic stream, the collection of tolls at a tollbooth, the payment of parking fees at a parking garage and so forth. The term back of queue refers to the number of vehicles that are queued at an approach of a signalized intersection depending on the arrival patterns of vehicles during the red phase and vehicles that do not clear the intersection during a given green phase. To mathematically predict the characteristics of a queuing system, it is necessary to specify the following system characteristics and parameters

Arrival pattern characteristics including average rate of arrival and the statistical distribution of time between arrivals, Service facility characteristics including service time average rates and distribution and the number of customers that can be served simultaneously or number of channels available and Queue discipline characteristics, such as the means by which the next customer to be served is selected.

Oversaturated queues are those in which the arrival rate is higher than the service rate and under saturated queues are those in which the arrival rate is less than the service rate. The length of an under saturated queue may vary but will reach a steady state with the arrival of vehicles. The length of an oversaturated queue will, however, never reach a steady state but will continue to increase with the arrival of vehicles. (Hcm, 2000)

2.8.5 Volume to Capacity Ratio

The volume to capacity ratio is the degree of utilization of the capacity of a segment, intersection or approach. The volume to capacity ratio is not defined over 1.0. Under those conditions it is considered to be a demand to capacity ratio. A lower ratio indicates smooth operations and minimal delays.As the ratio approaches 1.0, congestion increases and performance is reduced. At 1.0 the capacity is fully utilized. For example, when v/c equals 0.85, 85 percent of a highway's capacity is being used; 15 percent of the capacity is still theoretically available. However, as the v/c ratio approaches1.0, flow becomes unstable, speeds decrease, and bottlenecks can easily occur.

Volume is a measure of the rate of flow of traffic expressed as the number of vehicles passing a given point on a roadway over a specified time period, such as vehicles per hour or day.Capacity is the supply side measure of the ability of a facility to carry traffic. It is the maximum number of motorized vehicles per hour that can travel on a particular stretch of roadway under relatively ideal conditions such as proper lane widths, no parking, no bus blockages, etc.

Table 2- 2: LOS by V/C and Control delay (HCM 2010)

Control Delay (S/Veh)	LOS by Volume-to-Capacity Ratio	
	V/C<=1.0	V/C>1.0
0-10	A	F
>10-15	B	F
>15-25	C	F
>25-35	D	F
>35-50	E	F
>50	F	F

2.9 Saturation Flow Rate

Saturation flow rate is defined as the flow rate per lane at which vehicles can pass though a signalized intersection. The saturation flow rate represents the number of vehicles per hour per lane that can pass though a signalized intersection if the green signal were available for the full hour, the flow of vehicles were never halted, and no large headways occurred. Saturation flow rate for signalized intersection is computed using head difference and but for roundabout is very complicated to do an experiment (head difference due to stop and go movement).

$$S = \frac{3600}{h}$$

Where: S = saturation flow rate,(veh/h,) and h = saturation headway, (sec)

HCM 2010 uses a default base saturation flow rate of 1900 pc/h/ln. This value may be increased or decreased based upon local field measurements. Approaches with lower approach speeds (less than 50 km/h) often have lower base saturation flow rates, on the order of 1800 pc/h/ln. Approaches with higher approach speeds (greater than 80 km/h) may have base saturation flow rates higher than 1900 pc/h/ln.

2.10 Spot Speed Studies

Speed is an important transportation consideration because it relates to safety, time, comfort, convenience and economics. Spot speed studies are used to determine the speed distribution of a traffic stream at a specific location. The data gathered in spot speed studies are used to determine vehicle speed percentiles, which are useful in making many speeds related decisions.

Spot speed studies are conducted to estimate the distribution of speeds of vehicles in a stream of traffic at a particular location on a highway. The speed of a vehicle is defined as the rate of movement of the vehicle; it is usually expressed in miles per hour (mi/h) or kilometers per hour (km/h). A spot speed study is carried out by recording the speeds of a sample of vehicles at a specified location. Speed characteristics identified by such a study will be valid only for the traffic and environmental conditions that exist at the time of the study.

2.10.1 Traffic Spot Speed Study Sample Size

For a spot speed study at a selected location, a sample size of at least 50 and preferably 100 vehicles is usually obtained (Ewing 1999). Traffic counts during a Monday morning or a Friday peak period may show exceptionally high volumes and are not normally used in the analysis; therefore, counts are usually conducted on a Tuesday, Wednesday, and Thursday.

The larger the sample size, the greater the probability that the estimated mean is not significantly different from the true mean. It is therefore necessary to select a sample size that will give an estimated mean within acceptable error limits.

2.10.2 Speed Percentiles

Speed percentiles are tools used to determine effective and adequate speed limits, and the three speed percentiles used on this study are 15^{th}, 50^{th}, and the 85^{th} percentiles.

The 15^{th} percentile is the speed at which 15% of the observed vehicles are traveling at or below. This percentile is used in calculating all red clearance intervals (ar).

The 50^{th} percentile is the median speed of the observed data set. This percentile represents the speed at which half of the observed vehicles are below and half of the observed vehicles are above. The 50th percentile of speed represents the average speed of the traffic stream.

The 85^{th} percentile is the speed at which 85% of the observed vehicles are traveling at or below. This percentile is used in calculating yellow interval and evaluating/recommending posted speed limits based on the assumption that 85% of the drivers are traveling at a speed they perceive to be 17 safe (Homburger W.S et al. 1996). In other words, the 85th percentile of speed is normally assumed to be the highest safe speed for a roadway section.

A frequency distribution table is a convenient way to determine speed percentiles. There are five columns to determine the speed percentiles, the first column the recorded speed from smaller to larger, the second column for frequency of the recorded speed (the number of vehicles recorded at each speed), the third column for The cumulative frequency (the total of each of the numbers (frequencies) on column two added together row by row), the fourth column for percentage of the cumulative frequency, the fifth column for speed percentile (50% and 85%).If 50th and 85th percentiles falls at exact in the cumulative percent column we can take directly the speed in that

row as 50th and 85th speed percentiles but the exact 50% and 85% (50th and 85th percentiles) are not found in the cumulative percent column. To reach these exact percentages, a calculation is completed using percentages and speeds from the distribution table using the equation below.

$$\boldsymbol{VD = (PD - Pmin)/(Pmax - Pmin)\ (Vmax - Vmin) + Vmin}$$

Where: V_D= the exact 50^{th} or 85^{th} percentile of speed

P_D= 50% or 85%

P_{min}= minimum percentile V_{max}= maximum percentile speed

P_{max}=maximum percentile V_{min}= minimum percentile speed

Average speed is the arithmetic mean of all observed vehicle speeds (which is the sum of all spot speeds divided by the number of recorded speeds).

$\bar{u} = (\sum(fi * ui)/(\sum fi)$ Where: $\bar{U}$= arithmetic mean

fi= no of observations on each speed group

ui= midvalue for the ith speed group

2.10.3 Methods for Conducting Spot Speed Studies

Spot speed data are gathered using one of three methods:

(1) Stopwatch method

(2) Radar meter method

(3) Pneumatic road tube method

Stopwatch method

The stopwatch method can be used to successfully complete a spot speed study using a small sample size taken over a relatively short period of time. The stopwatch method is a quick and inexpensive method for collecting speed data.

A stopwatch spot speed study includes five key steps:

1. Obtain appropriate study length.

2. Select proper location and layout.

3. Record observations on stopwatch spot speed study data form.

4. Calculate vehicle speeds.

5. Generate frequency distribution table and determine speed percentiles.

2.11 Traffic Volume Studies

Traffic volume studies are conducted to collect data on the number of vehicles and/or pedestrians that pass a point on a highway facility during a specified time period. This time period varies from as little as 15 minutes to as much as a year depending on the anticipated use of the data.

Intersection counts are taken to determine vehicle classifications, through movements, and turning movements at intersections. These data are used mainly in determining phase lengths and cycle times for signalized intersections, in the design of channelization at intersections, and in the general design of improvements to intersections.

2.11.1 Method of Traffic Volume Count

Two methods are available for conducting traffic volume counts:

1) Manual Counting Method

Manual counts are typically used to collect data for determination of vehicle classification, turning movements, direction of travel, pedestrian movements, or vehicle occupancy. This method of data collection can be expensive in terms of manpower.

Manual counts are typically used for period of less than a day, normal intervals for manual counts are 5, 10 and 15 minutes. Traffic count during Monday morning rush hour and Friday evening rush hour may show exceptionally high volumes and are not normally used in analysis. Therefore, counts are usually conducted on Tuesday, Wednesday or Thursday. Manual counts

are recorded using one of three methods: tally sheets, mechanical counting boards, or electronic counting boards. (Traffic study, 2002).

2) Automatic Counting Method.

The automatic count method provides a means for gathering large amounts of traffic data. Automatic counts are usually taken in 1-hour intervals for each 24-hour period. The counts may extend for a week, month, or year. When the counts are recorded for each 24-hour time period, the peak flow period can be identified. Automatic counts are recorded using one of three methods: portable counters, permanent counters, and videotape.

- **Portable Counters**

Portable counting is a form of manual observation. Portable counters serve the same purpose as manual counts but with automatic counting equipment. The period of data collection using this method is usually longer than when using manual counts. The portable counter method is mainly used for 24-hour counts. Pneumatic road tubes are used to conduct this method of automatic counts.

- **Permanent Counters**

Permanent counters are used when long-term counts are to be conducted. The counts could be performed every day for a year or more. The data collected may be used to monitor and evaluate traffic volumes and trends over a long period of time. Permanent counters are not a cost-effective option in most situations.

- **Videotape**

Observers can record count data by videotaping traffic. Traffic volumes can be counted by viewing videotapes recorded with a camera at a collection site. A digital clock in the video image can prove useful in noting time intervals. (Traffic study, 2002).

2.12. Vehicle time value

Value of travel time is the monetary value the person will be ready to pay for a unit travel time reduction. Generally, travelers prefer to choose the route of less travel time, even at long distance

and high running cost of the vehicle. Since travel time has a value, but the value of travel time depends on many factors, each of varying importance depending upon the traveler, the purpose of travel, the amount of time available, the reliability of having the time to use etc. Hence, data collection should include the factors affecting their travel journey of different rod users.

There are two distinct approaches in the economic evaluation of travel time those are Wage rate approach and preference approach.

I. Wage rate approach

Wage rate approach is the common and simple approach to ascertain the passengers travel time cost. This approach estimates the average wage rate of the road user and to treat it as the time value of the travel. As the trip characteristics changes from work time journey and leisure time journey, the value of travel time for trips also may vary. A major disadvantage of the wage rate approach is that, it does not account the trip characteristics of the passengers and is difficult to find the travel time value for unemployed road users.

II. Preference approach.

In preference survey approach, the travelers are asked to value the price they would pay for reduced travel durations. The actual rating of travelers would depend upon their wage rate, personal choice, trip characteristics and purpose of the trip, it is the most scientific way to estimate the value of travel time. There are two type of preference approach .This are revealed preference (RP) and stated preference approach (SP).

RP approach method uses data collected on real life choices, the choices as made by individual decision makers are bound by the real constraints confronted by those same decision makers.

SP approach method permits generation of multiple observations per respondents and are also asked to consider a number of situations in a set of option to maximize their utility in this choice of transport system. It is considered as a better method for value of travel time estimation because the travelers themselves evaluate different trade off possibilities between travel time and travel cost.(munera c,2018).

2.13 Microscopic Traffic Simulation Model

PTV Vissim was first developed in 1992. PTV Vissim is the world most advanced and flexible traffic simulation software. This software is used to model multilane roundabout (three lane approaches) and intersections with and without traffic signal timing and provide a result likes control delay, level of service and queue length. Developing road network, node and link development, route decision, signal timing and phase diagram sequencing was used to model the intersections.

PTV Vissim is the leading software program for traffic and transport analyses and forecasts worldwide and allows for GIS-based data management in the field of private and public transport. Vissim is a program for computer-aided transport planning, which serves to analyze and plan a transportation system. A transportation system includes private and public transport supplies (PrT and PuT) and travel demand. Vissim supports planners to develop measures and determines the impact of these measures. (PTV Vissim 2021 Manual).

CHAPTER 3: METHODOLOGY

In this section, I described the study area including the road segments, the sources of the data, the data collection strategy, the study design, and statistical analytical methods employed. Both quantitative and qualitative study methods were applied.

3.1 Study Area

The study is conducted in Addis Ababa, the capital city of Ethiopia and one of the largest urban centers in sub-Sahara Africa. It is located 80 49'55.929" and 90 5'53.853" North Latitude and between 380 38'16.555" and 380 19.547" East Latitude with an altitudinal zone ranges from 2054 to 3023 meters above sea level. The mean annual maximum and minimum temperatures is 22.8 and 10.6 degree centigrade respectively. The mean annual rainfall of the city is 1180.4mm.The city covers an area of about 519.5 km2 of land. (Addis Ababa City Administration Integrated Land Information, Atlas 2014.). Map of study area including the nine sub city of Addis Ababa is shown in Figure 3.1.

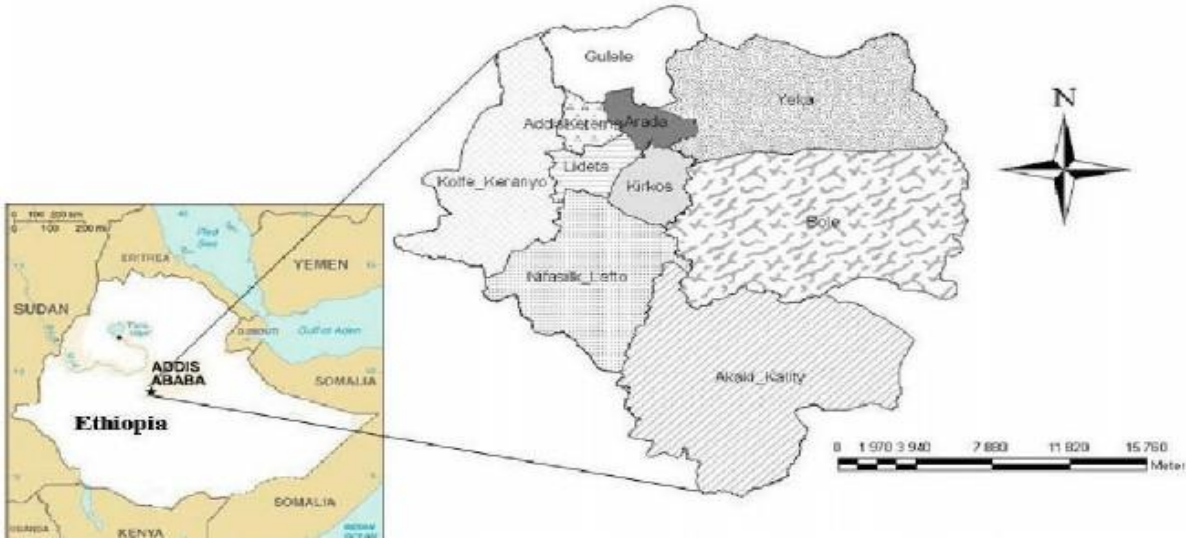

Figure 3- 1: Study map

3.2 Description of Study Corridor

The study focused on Welete to total road segment, south entrance of Addis Ababa city due to covering the whole Addis Ababa is very large. The road segment is about 6.5km. The welete-

total road segment was constructed during Addis Ababa- Jimma road Construction project by the joint venture of DRAGADOS J&P since 1992 EC. The road is important that serves the main road to connect Addis Ababa and major many town of Ethiopia such as Jimma, Waliso, Welkite, Worabe, Butajera and etc., and also import and export carried out area. This specific road segment is quite congested route and more when in peak hours. From the total road segment, welete to Mobil (near to Ayertena intersection from Kara approach) road has only one lane in each direction this worse the congestion due to minimum road capacity. From the selected road segment, I took the three major intersections namely Ayertena signalized intersection, Zenebework roundabout, and Total (3kuturmazoriya) turbo roundabout (Figure3-2).

Figure 3- 2: Study corridor

3.2.1 Ayertena signalized intersection

As shown in Figure 3-3, ayertena intersection is the signalized major intersection on the selected road segment (welete- total). This intersection has four approaching legs. Those are Kara, Betel, Jemo and Ayertena. Kara approach has three entry and exit lanes with 40cm curbstone median. Betel approach has 4 entry and 4 exit lanes with five-meter median. Jemo approach has 4 entry and 4 exit lanes with 40cm double curbstone median. Ayertena approach has eight lanes with 4 entry and 4 exits in each direction. A Jemo and Ayertena approach is directly linked to ring road.

Figure 3- 3: Ayertena signalized intersection

3.2.2 Zenebework Roundabout

As presented in Figure 3-4, Zenebework roundabout is the second roundabout. This study section has three legs with three circular lane and 22 m of circular inscribed diameter.

The approach legs are Total, zenebework and wera. The two major approach legs are total and zenebework that are directly linked to ring road. Total approach and zenebework approach have three entry and exit lanes and wera approach has two entry and exit lanes.

Figure 3- 4: Zenebework Roundabout.

3.2.3 Total Roundabout

Total round about is the third selected intersection (Figure 3-5).Turbo roundabout has three legs and three circulating spiral lane with raised lane divider. Raised lane separators on the ring required drivers to choose the lane before entering the intersection. The approach legs are Torhayloch, Bsrate gebreal and Total. All approaches have three entry and exit lanes and all approaches had channelized right turn. Torhayloch and Total approaches legs directly linked to ring road with raised median width of 1 meter.Bisrate gebreal approach has median of 1.2 meter width.

Figure 3- 5: Total (3 kutur mazoriya3kuturmazoriya) Turbo Roundabout

3.3 Study design

Quantitative and qualitative research approaches was considered. The quantitative methods were used to determine congestion cost, traffic volume analysis, spot speed analysis, signal design and level of service of urban segments. A direct field measurement was the main sources of quantitative data. A qualitative research methodology covers questionnaire and secondary data review. The qualitative and qualitative data from questionnaire were used to assess the cause, impact and solution of traffic congestion.

.

3.4 Type and source of data

Both primary and secondary data source were used. Records of road traffic congestion situations which occurs during peak hours and the questionnaire is administering to general peoples, experts and drivers who formed the population from which samples were selected for this study using simple random sampling techniques. The primary data were collected by using questionnaire, traffic counts, spot speed measure, and field measure.

The secondary data was collect from already collected and analyzed source Thus; secondary data provide second hand information and include both raw data and published ones. It includes books, journal articles, newspapers, report and publications of various associations and organization as well as other documentary reviews from internet. Vehicle time value was the secondary data in this study to estimate the total congestion cost.

3.5. Data collection equipment and methods

Primary and secondary data was used. Questionnaires, Spot speed study, vehicle traffic volume and intersection geometry study were applied to collect the data. Vehicle time value was the secondary data for this study. The necessary field visit and data collections were made on study area. The detailed description for the data collection methods and collected data are as follows.

3.5.1 Questionnaires

In this study, the questionnaires were designed and distributed to the respondents on a face-to-face basis in order to gather information about cause, impact and proper measures to minimized the current traffic congestion in Addis Ababa specially welete-total road segment.

The questionnaires comprised four sections to gather detail information on the perception of respondents regarding traffic congestion cause, impact and solution. Questionnaire was distributed to general peoples, experts and drivers who formed the population using purposively and simple random sampling techniques. Drivers are those who drive any type of vehicle on welete- total road segment. Experts included those who had knowledge about the selected road segment but they don’t utilize it on a daily base. They worked on Addis Ababa transport bureau of that area while ordinary peoples are those who utilized the selected road segment for their day-to-day trip.

Sample size: Sample is the part of the population that helps us to draw inferences about the population. Collecting research of the complete information about the population is not possible and it is time consuming and expensive. Thus, we need an appropriate sample size so that we can make inferences about the population based on that sample.

Addis Ababa is the capital and biggest city of Ethiopia. It consists of a population of 3,384,569 as per the 2007 population enumeration, with yearly growth rate of 3.8%. Total area is covered 122.08 square kilometer. The population density of Addis Ababa is 5165 persons per square kilometer.

Rough guides by Ronán Conroy develop a table for sample size based on number of population respect to required margin of error. 95% confident level were taken for the large population with 10% margin of error, sample size =96 ~100 sample respondents. By purposively sampling technique Addis Ababa transport bureau kolfe keraniyo sub city district for experts and Repi 2 condominium were selected for driver and ordinary peoples to make the sample represent the population. The target population compromise commuters those used the selected road segment day to day basis and Driver, whose operate on the selected road segment daily and experts whose have knowledge about the segment.

The total sample size considered was100 respondents because of time and budget constraint. By using simple random sampling technique, 10 experts who worked in Addis Ababa transport bureau kolfe keraniyo sub city district and 20 driver and 70 ordinary peoples who lived in Repi one condominium house and also used the selected road segment for their daily basis were selected. The simple random sampling techniques used to minimize study biases by giving an equal independent chance of being selected.

For this study the researcher prepared questionnaires used to analyze the cause, social impact and solution of congestion (descriptive analysis) and mean analysis using excel sheet and SPSS software.

3.5.2 Spot speed study on approach legs

Spot speed study was conducted on each approaching legs of those three intersections. According to hand book of traffic studies, sample size of studying spot speed study was 50 up to

100 vehicles. Video recording techniques was used. First marked appropriate study length was applied then record a video to capture the marked point. In video graphic method, video camera was placed at proper place at the top of the building to capture the two ends of the marked section and record video to obtain the travel time taken by each vehicle. By replaying the recorded video and noting down the time taken to the entry and exit time of the vehicle in the section. The researcher try to get vertical reference point that can represent the marked pointes it was helpful to differentiate the start and end point of the study length simply during replying the video. A sample of 100 vehicles for each approach legs and choose study length based on traffic stream average speed was considered as indicated in table3-1.

Table 3- 1: Recommended Spot Speed Study Length (Traffic Studies, 2002)

NO	Traffic Stream Average Speed			Recommended Study Length	
	Mph	ft/s	Km/h	Feet	Meter
1	< 25	< 37	< 40	88	27
2	25-40	37-60	40-64	176	54
3	> 40	> 60	> 64	264	80

Spot Speed Study Steps: firstly obtain appropriate study length and mark start and end point or choose vertical reference that can represent those points. Then Select best position to video recording on the top of the building (to capture start and end point of the study length). Record the time taken used by each vehicle to travel the study length by replaying the recorded video (by pause and play the video); the time was there in the video. Calculate vehicle speed (distance travel/time taken) then Generate frequency distribution table and determine speed percentiles.

3.5.3Traffic Volume Study

Traffic volume count was conducted for three consecutive days (Tuesday, Wednesday and Thursday) on the selected study areas for 12hr of a day from 6:30 am to 6:30 pm. According to the Traffic volume count guide, Traffic count during Monday and Friday may show exceptionally high volumes and are not normally used in the analysis, therefore, counts are usually conducted on Tuesday, Wednesday and Thursday.

Fifteen minute traffic count was conducted to represent one hour traffic volume count and to determine peak hour for different vehicle type for each movements (R.turn, L.turn, Through and

U-turn). Three major intersections were selected for traffic volume analysis as show table 3-2 below.

Table 3- 2: Time of data collection of intersections

NO.	Intersection Name	Type of Intersection	Time of Data Collection
1	Ayertena	4 leg Signalized	06:30AM-06:30PM
2	Zenebework	3 leg Roundabout	06:30AM-06:30PM
3	Total 3 kutur mazoriya	3 leg Turbo Roundabout	06:30AM-06:30PM

Eight vehicle classifications (car, minibus, midbus, bus, truck, truck trailer, three wheeler and motor) were used for traffic volume study and analysis. In order to conduct traffic volume, it is necessary to convert different type of vehicles to common unit called passenger car unit. This study utilizes passenger car unit required from ERA manual as indicated in Table 3-3 to covert each vehicle type in to passenger car.

Table 3- 3: Passenger car unit's value for vehicles ERA manual

	PCU Values for different terrain type		
Vehicle type	**Level**	**Rolling**	**Mountainous**
Bicycle	0.5	0.5	NA
Motorcycle	0.5	1	1.5
Passenger car	1	1	1.5
Buses	2	4	6
Light good vehicles	1	1.5	3
Medium good vehicles	2.5	5	10
Heavy good vehicles	3.5	8	20

3.5.4 Geometric data of the road segment

Field measurements considered to collect the geometric data. The data collected were phase time of signalized intersection, Approaching road gradient (road profile), approaching Lane width (carriage way), number of approaching lanes and legs, number of circulating lanes, inscribed circle diameter, exit and entry radius. Methods used to collect those data were visual observation, Google-earth map and manual tape. Geometric study is vital for computation of saturation flow

rate, for allocation of traffic signal timing and for vissim input and model. The collected data of ayertena signalized intersection phase time and total turbo roundabout field data summarized as shown in table 3-4 and table 3-5 respectively.

Table 3- 4: Ayertena intersection phase time

Time	Signal time(sec)	Approaches			
		Ayertena	Kara	Betel	Jemo
06:30AM-04:00AM	Green	30	60	45	15
	yellow	3	3	3	3
	All red	2	2	2	2
10:00AM-03:00PM	Green	40	40	40	30
	yellow	3	3	3	3
	All red	2	2	2	2
03:00PM-06:30PM	Green	60	40	40	40
	yellow	3	3	3	3
	All red	2	2	2	2

Table 3- 5: Total turbo roundabout

Element		Dimension(m)
Inner Lane	Inner radius	12
	Outer radius	17.15
Outer Lane	Inner radius	17.45
	Outer radius	22.45
Inner Lane	Start width	5.30
	End width	5.00
	Average width	5.15
Outer Lane width		5.00
Lane divider width		0.3
Distance between outer center points		5.35
Distance between inner center points		5.05

3.6 Performance analysis of intersections

The performance analysis was analyzed by using VISSIM 9 software. It considered delay, vehicle queue, and LOS. The criteria accounted to the minimum queue length and delay, but the highest LOS and calibration wasn't taken as an issue for the purpose.

3.6.1 VISSIM Simulation Modeling

PTV Vissim is the world most advanced and flexible traffic simulation software. Developing road network, insert background image capture from Google earth, set a scale, node and link development, route decision, vehicle speed decision and reduced speed area, conflict area, vehicle input, signal timing and phase diagram sequencing was used to model the intersections. For this study vissim (9)software was used to model multilane roundabout (three legs approaches) and intersections with traffic signal timing and provide a result likes control delay, level of service and queue length to determine the performance of the intersections. After extracting the delay, queue and LOS result of intersections model other alternative to modify intersections performance.

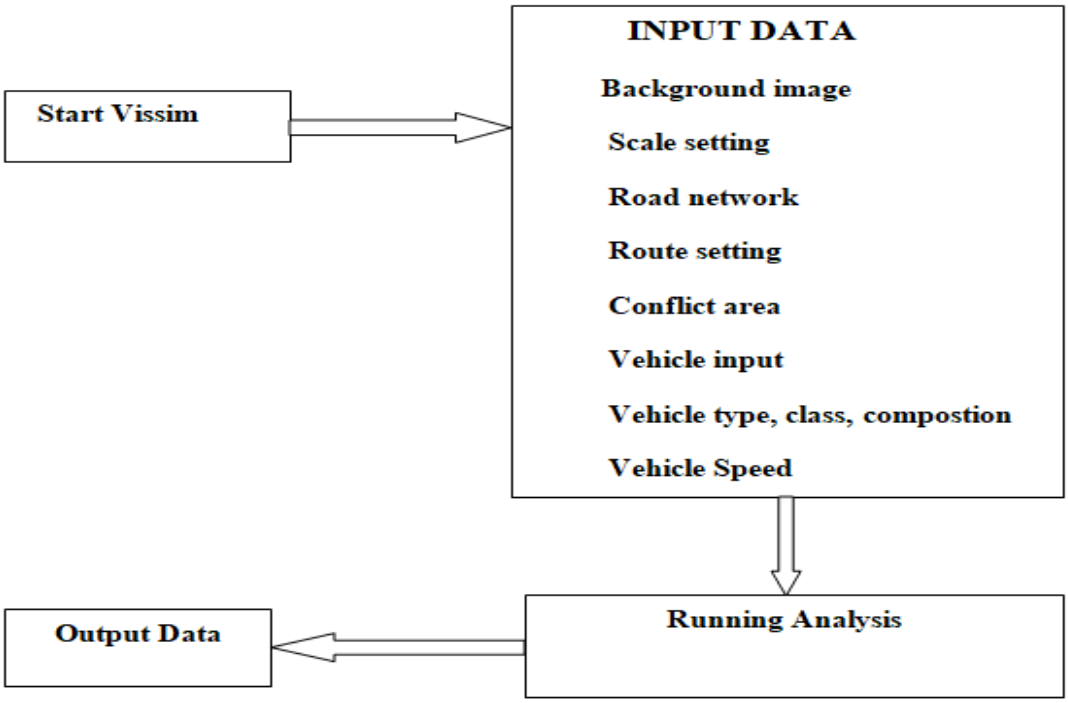

Figure 3- 6: Stage of modeling using software Vissim 9

3.7 Estimating total congestion cost

Tazadakis (1980) formula were used to estimate the total congestion cost

(i). Total Congestion Costs

Based on tazadakis total congestion cost written mathematically as:

$$\mathbf{CC = N\left[VC * Va + \left(\frac{Va}{Vi}\right)V'\right]QT}$$

Where:

CC = cost of congestion (ETB per hour)

N = volume of vehicle queues (Veh/hour)

VC = vehicle operating costs (ETB/veh.km)

Va= actual speed (km/h)

Vi = ideal (design) speed (km/h)

V'= value of time per vehicle (ETB/hour)

QT = queue time (hours)

(ii). Vehicle Operating Cost (VOC)

Simon,G (2017) tried to estimate road users cost in Addis Ababa by taking road segment from Ministry of Mines– Torhayloch (coca cola) it depends on vehicle operating cost, accident cost and value of time cost per vehicle type. He calculated road user cost by using HDM-4 Version 1.1 and manually and take the average of HDM & manually calculated value.

The input data used for the calculation were collected from road users by using interview method and questionnaires and others essential data like vehicle price, new tire price, crew wages, annual overhead costs were collected from road agencies like AACRA, EARA and WT consulting. And the researcher estimate vehicle operating cost by considering crew, depreciation, interest on capital invested, cargo holding, fuel, lubricating Oil, repair& maintenance, tyre consumption and overhead costs.

For this study used, final result of vehicle operating cost from Simon,G (2017) study for different truck type of Small Truck, Medium Truck, Large 2 axle Truck,3-axled Truck,4-axled Truck,5-axled Truck and 6-axled Truck grouped into one as truck it can represent all type by taking the average value of them and the same for truck trailer type for the simplification of the

calculation. And update his estimated VOC result in to recent year (2021).When updating the VOC value, the formula introduced in the AASHTO Red Book is applied, shown below. Jaehyun, C (2020).

$$\textbf{VOT for the selected year} = \left(\frac{\textbf{CPI for Selected Year}}{\textbf{CPI in Base Year!}}\right) \times \textbf{VOT in Base Year}$$

According to Central Statistics Agency of Ethiopia report CPI value for Addis Ababa in 2017=100 and CPI value = 237.7 in 2021.

3.7.1 Value of time

Simon,G (2017) tried to estimate the value of time per vehicle type. He depended on passenger travel time (working passenger hours and non-working passenger hours and finally annual average passenger working and nonworking passenger hours) calculated by using HDM-4 Version 1.1 and manually then used the average value of them. For this study update VOT estimated value by Simon,G (2017) to recent year(2021) by using CPI value of both years. The estimated and Adjusted VOT value per vehicle type was summarized below table 3-6.

Table 3- 6: Value of time per vehicle type

	2017 Semon. G , estimated value	Adjusted value(2021)
Vehicle type	VOT ETB/Vehicle type	VOT ETB/Vehicle type
Car	2.9095	6.9159
pick up/4-wheel drive	2.6464	6.2906
Minibus	6.9250	16.4607
Microbus	6.7000	15.9259
Bus	14.9850	35.6193
Truck	0.0101	0.0241
TruckTrailer	0.0126	0.0300

3.8 Saturation Flow Rate

Saturation flow rate is the flow in vehicles per hour that could be accommodated by the lane group assuming that the green phase were displayed 100 percent of the time g/C= 1, in which “g” is vehicular green time and “C” is cycle length.

A saturation flow rate for each lane group is computed according to Equation 1. The default base saturation flow rate value of 1900 pc/h/ln is used From HCM 2010.

Saturation flow rate factors is calculated based on the formula indicate in table3-7. Therefore those calculated factors used for Saturation flow rate computation for roundabout approaches.

S= So*N*fW*fHV*fg*fp*fbb*fa*fLU*fLT*fRT*fLpb*fRpb…… Equation (1)

Where: S = Saturation flow rate for the subject lane group, expressed as a total for all lanes in the lane group (veh/h)

So = Base saturation flow rate per lane (1900pc/h/ln)

N = Number of lanes in the lane group

f_W = Adjustment factor for lane width (3.6m is base condition)

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

fg = Adjustment factor for approach grade

fp = Adjustment factor for the existence of parking lane and parking activity adjustment to the lane group.

fbb = Adjustment factor for the blocking effect of local buses that stop within the intersection area

fa = Adjustment factor for area type

f_{LU} = Adjustment factor for lane utilization

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

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

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

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

For total roundabout adjustment factors of the three approaches were calculated based on the formula as indicated in table3-7. For the lane width adjustment factor (fw) determination 3.5meter lane width was used for all approaches and for approach grade adjustment (f_g) (-3%), (+1%) and (-5%) % grade were determine from Google earth for lane group of torhayloch, total and b.gebreal approaches respectively.

For parking lane adjustment factor there was absence of parking vehicle data but from filed visit the parking volume is small so, taken HCM 2010 value for some parking vehicle = 50 veh/hr. For heavy vehicle adjustment factor used heavy vehicle proportion of all approach from data collected for traffic volume analysis. For total approach (19.74%), bisrate.g (12.77%) and for torhayloch approach (19.5%) HV proportions were used.

For bus stop adjustment factor (f_{bb}) determination, number of bus stop per hour was required, to get this value the researcher considered heavy vehicle proportion of each approach of the roundabout only as a bus due to at peak hour there is restriction of heavy good vehicle movement and by multiply the total parked vehicles (50veh/hr) by each approach heavy vehicle proportion and get the same 10 bus/hr at total and torhayloch approaches and 6 bus/hr at b.gebreal approach. For area adjustment factor take default value of 1 for non CBD area and also 1 for f_{lu}.

For left turn adjustment factor the left turn vehicle proportion was need those value were taken from peak hour volume survey data as (72%) for total approach, (32%) for b.gebreal and (37%) for torhayloch approach. For right turn adjustment factors shared lane formula was used for total and b.gebreal approach the input data for this calculation was proportion of right turn value it was get from peak hour volume data as b.gebreal (64%) and torhayloch (34%).And for total approach take 1 due to the absence of right turn movement.

Table 3- 7: Formula for saturation flow rate adjustment factors (HCM 2010)

Factor	Formula	Definition of variables	Notes
f_{LT}	protected phasing Exclusive lane $f_{LT}=0.95$ Shared lane $fLT=1/1+0.05P_{LT}$	P_{LT}=proportion of LT in lane group P_{RT}=proportion of RT in lane group A_{PbT}=permitted phase adjustment P_{LTA}=proportion of LT protected green over total LT green P_{RT}=proportion of RT in lane group P_{RTA}=proportion of RT protected green over total RT green	
f_{RT}	Exclusive lane $f_{LT}=0.85$ Shared lane $f_{RT}=1-(0.15)p_{RT}$ Single lane $f_{RT}=0.9-(0.135)p_{RT}$		
fLpb	Left turn adjustment $fLpb=1-P_{LT}(1-ApbT)(1-P_{LTA})$ Right turn adjustment $f_{RTA}=1-P_{RT}(1-A_{PbT})(1-P_{LTA}$		
fw	$fw=1+(W-3.6)/9$	W=lane width(m)	W>2.4
f_{HV}	$f_{HV}=100/100+\%HV(ET-1)$	%HV=% heavy vehicle for lane group volume	If w.4.8 two lane analysis may be considered
fg	fg=1-%G/200	%G=% grade on a lane group approach	6≤%G≤+10
fp	fp=N-0.1-18Nm/3600/N	N= number of lane in lane group Nm=number of parking maneuvers per hour	0≤Nm≤180 fp≥0.05 fp=1 for no parking
fbb	fbb=N-14.4NB/3600/N	Nm=number of parking maneuvers per hour NB= number of bus stopping per hour	0≤Nb≤250 fbb≥0.55
fa	fa=0.9 in CBD	Vg=un adjusted demand flow rate for the lane group veh/h VgL= un adjusted demand flow rate on the single lane in the group with the highest volume and N= number of lanes in lane group	
	fa=1 in all other areas		
f_{LU}	$f_{Lu}=Vg/Vg-N$		

3.9 Signal Timing (HCM Method)

Traffic signal timing design was done on this study to have traffic control on total turbo roundabout sections during morning peak hour time. To allocate traffic signal timing vehicular green time, clearance interval (all red interval), transition interval (yellow interval) are essential. And it is critical to check pedestrian green time requirement. Formulas used for traffic signal timing designed are detailed as follow.

I. Equivalent Factor for Left and Right Turn Vehicles

Demand volumes would be converted to equivalents based on all of the traffic and roadway factors to estimate an appropriate cycle length and to split the cycle length into appropriate green times for each phase, it is necessary to find the critical-lane volume for each discrete phase. Left and right turn vehicles converted to equivalent through vehicle unit (tvus) by using factors as shown in Table and Table respectively.

Table 3- 8: Through Vehicle Equivalents for Left-Turning Vehicles, ELT (HCM 2010)

Opposing flow Vo(veh/h)	Number of opposing lanes No		
	1	2	3
0	1.1	1.1	1.1
200	2.5	2	1.8
400	5	3	2.5
600	10.0*	5	4
800	13.0*	8	6
1000	15.0*	13.0*	10.0*
≥ 1200	15.0*	15.0*	15.0*
ELT for all protected left turns=1.05			

* Indicates that LT capacity is only available through "sneakers."

Table 3- 9: Through Vehicle Equivalents for Right-Turning Vehicles, ERT (HCM 2010)

Pedestrian Volume in conflicting cross walk ped/h	Equivalent
None(0)	1.18
Low(50)	1.21
Moderate (200)	1.32
High(400)	1.52
Extra(800)	2.14

II. Clearance Interval (all red intervals; ar)

The all red interval is the time to clear off vehicles already in the intersection, must provide sufficient time for the vehicle to cross the intersection clear it back bumper past the far cross walk line before conflicting vehicles are given green.

There are different formulas for different cases of pedestrian traffic volume. The cases are there is no pedestrian traffic, significant pedestrian traffic exists and some pedestrian traffic exists. For this study pedestrian volume data was not available but from filed visit there are some pedestrian.

For cases in which some pedestrian traffic exists

$$\max[\left(\frac{W+L}{1.47*S15}\right),(\frac{P}{1.47*S15})]$$

Where: ar = Length of all red phase, s w = Distance from the departure STOP line to the far side of the farthest conflicting traffic lane, ft

p = Distance from the departure STOP line to the far side of the farthest conflicting crosswalk, ft

L = Length of a standard vehicle, usually taken to be 18-20 ft.

S_{15} = 15th percentile speed of approaching traffic or speed limit, as appropriate, mi/h

III. Change Interval (Yellow Interval, y)

Amber time interval warns a driver the end of a green time it given after green time and allows a vehicle that one is safe stopping distance away from the stop line when the green is withdrawn to continue at the approach speed and enter the intersection legally on yellow.

$$Y = t + \frac{1.47 * S_{85}}{2a + (2\mathrm{g} * 0.01G)}$$

Where: y = Length of the yellow interval, s t = Drivers reaction time, s

S_{85} = 85th percentile speed of approaching traffic or speed limit, as appropriate, mi/h

a = Deceleration rate of vehicles, ft/s^2

G = Grade of approaches, %

g = Acceleration rate due to gravity, which is $32.2ft/s^2$

IV. Cycle Length (Cdes)

The time taken to complete one cycle or it is the period of time required for one complete sequence of signal indication. The max sum of critical lane volume that could be handled by a signal was manipulated to find a desirable cycle length as equation1.

$$C_{des}=\frac{L}{1-[\frac{V_c}{S*PHF*(\frac{V}{C})}]}$$ ……...Equation (1)

Where: C_{des} = Desirable cycle length, s L = Total lost time per cycle, s/cycle

PHF = Peak hour factor V/c =Target v/c ratio for the critical movements in the intersection

S = Saturation flow rate veh/h/ln

V. Effective Green Time (g_i)

Total available green time in the cycle must be divided for each phase. Total available green time in the cycle is found by deducting the lost time per cycle from cycle length. Total effective green time can be calculated by equation 2.

$$g_{TOT}=C-L$$ ……..Equation (2)

$$g_i=g_{TOT}*(\frac{V_{ci}}{V_c})$$

Where: g_i = Effective green time for phase i s g_{TOT} = Total effective green time in the cycle, s

Vci = Critical lane volume for phase or sub-phase i, (veh/h) Vc = Sum of the critical lane volumes, (veh/h) C = Cycle length, s L = Lost time per cycle, s

VI. Pedestrian Green Time (G_p)

During signal design allocate minimum green time requirement for pedestrian using equation below.

$G_{p=}3.2 + \left(\frac{L}{S_P}\right) + (2.7 * \frac{N_{ped}}{W_E})$ For $W_E > 10ft$

And $G_{p=}3.2 + \left(\frac{L}{S_p}\right) + (0.27 * N_{ped} For\ W_E < 10ft$

Where G_P = Minimum pedestrian crossing time, s

L = Length of the cross walk, ft

S_P = Average Walking speed of pedestrians, ft/s

N_{ped} = Number of pedestrians crossing per phase on a single crosswalk, peds

W_E = Width of cross walk, ft

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Characteristics of the participants

Here I described the socio demographic, socioeconomic and travel-related characteristics of the 100 participants responded to the questionnaire.

Gender profile

Data collected from 100 respondents, of whom 55% of the respondents were males, with generally no big difference in the respondents by the sex distribution noted.

Table 4- 1: Respondents distribution by sex

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	55	55	55	55
	Female	45	45	45	100
	Total	100	100	100	

Age profile

Wider age groups respondents were included in the study, here I classified in to six groups. Majority of the respondents (39%) were within the age range of 30 to 39 years, followed by 31% from 21 to 29 years. The very young (less than 20) and the very old (above 60) age groups were only included 5% and 4%, respectively, of the respondents, which might be unrepresented in this study.

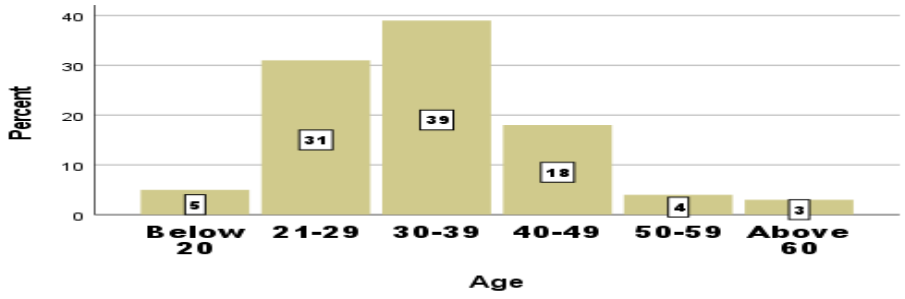

Figure 4- 1: Respondents distribution by age

Marital status

Marital status was among the socio-demographic questions provided to the respondents, for which 69% were married, 27% were single or divorced, and 4% were widowed.

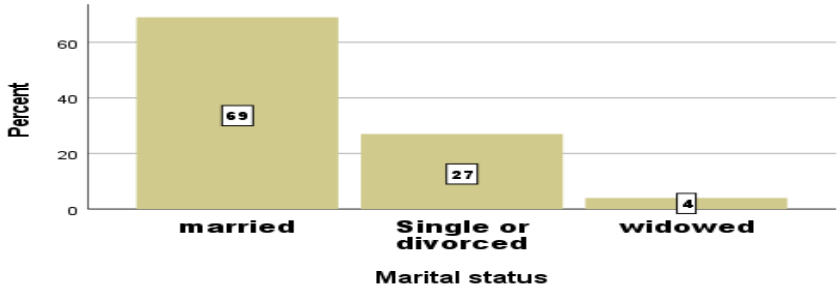

Figure 4- 2: Marital status of the respondents.

Educational Status

In relation to educational status, 33% of the respondents had secondary education, 22% had primary education and 45% of the respondents had higher education which encompasses diploma, undergraduate degree, masters and PhD.

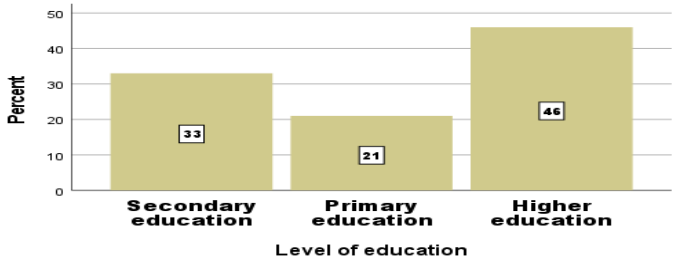

Figure 4- 3: Level of education of the respondents.

Type of Employment

The study finding indicates that 6% of the respondents were students, 47% of the respondents were self employed, 19% were employed in private organization, 23% were employed in public organization and only 5% were unemployed. From the total of 100 respondents the highest (47%) were self employed.

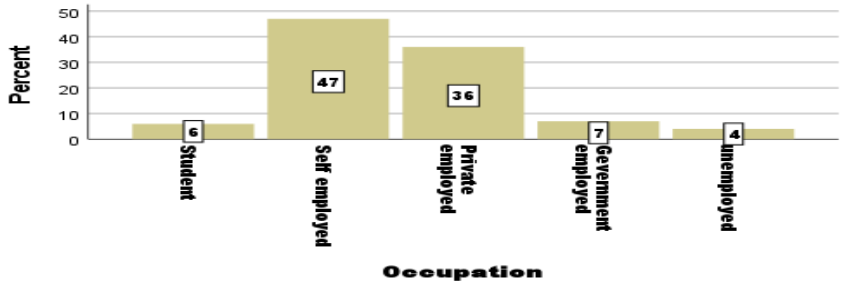

Figure 4- 4: Distribution of the respondents by occupational status

Mode of travel

For the question about the mode of travel, 81% of the respondents were public transport users, 17% of the respondent used their private vehicle, and only 2% of the respondents used fright transport.

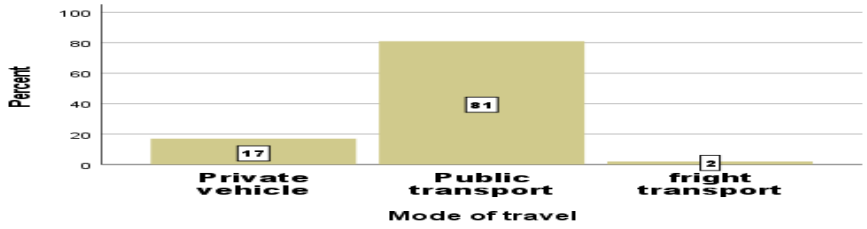

Figure 4- 5: Mode of travel of the respondents

Departure and arrival time from/to home

Majority of the respondents leave there houses between 1:00 and 2:00 AM and return to home between 1:00 and 3:00 PM. Very few respondents leave their house after 3 AM and return after 3 PM.

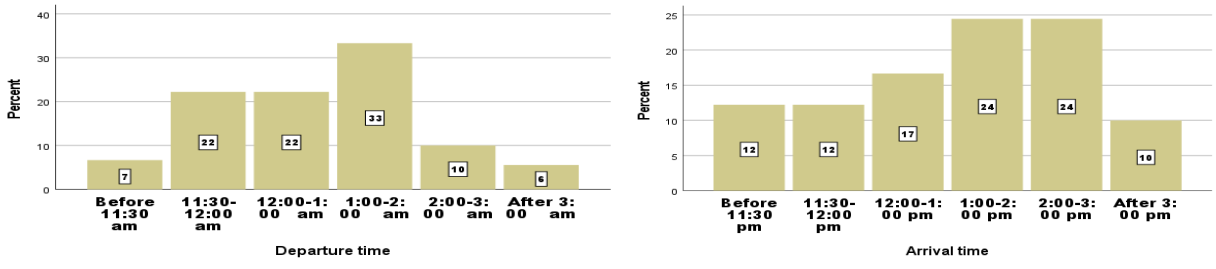

Figure 4- 6: Departure and arrival time of the respondents.

Distance from home to workplace

Research finding indicate that almost half percent (46%) of the respondents were travel daily 10 to 20km. 32%, 18% and only 4% of the respondents were travel 1-10km, 20-40kmand more than 40km respectively daily for different purpose.

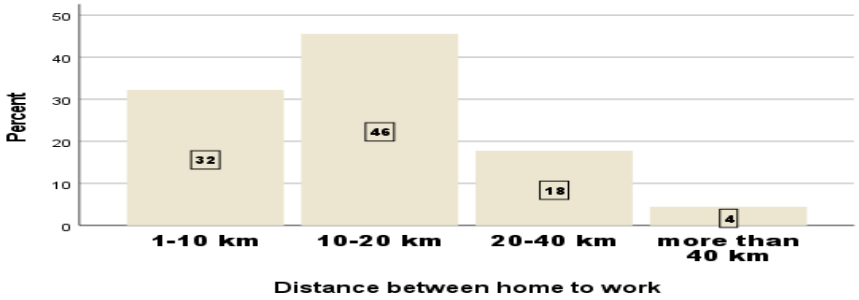

Figure 4- 7: Distribution of the respondents by the distance of their workplace and home.

Do you change your departure time to avoid traffic congestion?

Assuming the traffic jam around pick hours, respondents were asked whether they change their house departure time to avoid the traffic congestions, and 87% responded yes.

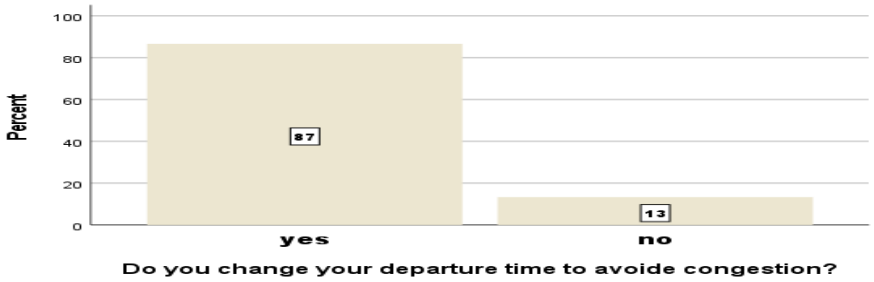

Figure 4- 8: Respondents' response to departure time change to avoid congestion question.

Do you change your normal route to avoid traffic congestion?

For the question related to change of route, 69% of the respondents agreed with the change of rout to minimize the traffic congestions.

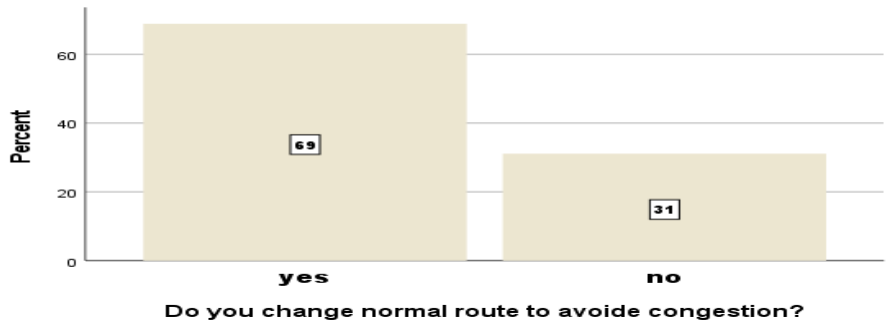

Figure 4- 9: Respondents' response to change of route to avoid congestion question.

4.2Cause of Traffic Congestion

From the field visit the researcher was mention ten Potential contributors of traffic congestion at welete-total road segments on a questioner. To know the degree of agreement of the general peoples, drivers and experts on the cause of traffic congestion of the selected road segments, the researcher distributed the questioner on face to face basis. The statement of cause of traffic congestion was based on likert scale, whereby a mean value of 1 meant that respondents strongly agreed, while a mean of 5 meant that the respondents strongly disagreed with the statements.

4.2.1Mean Analysis

Table 4- 2: Mean Analysis of Cause of Traffic Congestion.

Causes	N	Mean
Poor traffic management system	100	2.64
Inadequate road capacity	100	1.18
Illegal parking	100	2.18
Traffic accident	100	2.67
Aggressive behavior of driver	100	2.25
Large number of pedestrian	100	2.49
Increasing number of private car	100	2.37
Illegal road side marketing	100	2.06

presence of large vehicles	100	2.29
Poor design of the road	100	1.54

Using the sample size of 100, the mean value of 2.64, 2.18, 2.67, 2.25, 2.49, 2.37, 2.06 &2.29 for 'Poor traffic management system', 'Illegal parking', 'Traffic accident', 'Aggressive behavior of driver', 'Large number of pedestrian', 'High number of private car', 'Illegal road side marketing' and 'Presence of large vehicles' respectively indicate that respondents on average agree that traffic congestion partly caused by these factors. The two most contributors of the traffic congestion, according to the respondents, were 'In adequate road capacity' (1.18) and 'poor road design' (1.54).

4.3 Social Impact of Traffic Congestion

One objective of this study was assessing the social impact of traffic congestion on the community. The researcher reviewed some papers worked on this topic, made field visit and as one of the member of that community identify about ten social impact of traffic congestion on the community. The total respondents of this part of the questioner were 90 include ordinary peoples and driver but exclude experts given the earlier two were the main population groups affected by the traffic congestion.

I. Health Problem

Table4-3 shows the health implication of traffic congestion on commuters and drivers in the study area. About 31% of the respondents, responded strongly agreed with congestion impact on health, while 42% agreed, and 15% were neutral, 11% disagreed and only 1% strongly disagreed. The results indicate that health impact of traffic congestion on the commuters and drivers exists and should be considered when evaluating policy alternatives for addressing traffic congestion in the study area. Previous studies reveal that traffic congestion has serious health effects to the people particularly those public transport drivers and users as they are exposed to transmitted diseases like; TB, flue and skin diseases.

Table4- 3: Level of respondents' agreement to health implication of traffic congestion.

		Frequency	Percent
Valid	Strongly Agree	28	31
	Agree	38	42
	Neutral	13	15
	Disagree	10	11
	Strongly Disagree	1	1
	Total	90	100

II. Increase Stress And Fatigue

According to Table 4-4, it is revealed that traffic congestion increase stress and fatigue on drivers and commuters. Out of 90 respondents (59%) strongly agree, (34%) agree, (6%) disagree and only 1% strongly disagree. Regarding this result congestion affect the performance of the respondents The study noted that most of the respondents about 51% departure from home early (before 1:00am) and 58% back to home after 1:00am.Getting home after passing through heavy traffic makes peoples tired and stressed. And due to this they can't concentrate well in family life, get angry quickly and become mentally weak.

Table 4- 4: Level of respondents' agreement to stress and fatigue associated with traffic congestion.

		Frequency	Percent
Valid	Strongly Agree	53	59
	Agree	31	34
	Disagree	5	6
	Strongly Disagree	1	1
	Total	90	100

III. Constraint Social Relation

As shown table 4-5 out of 90 respondents 48(53%) strongly agree, 38(42%) agree and the same 2(2%) for neutral & disagree that traffic congestion constraint social relation. The study reveals

that most of the respondents about 64% travel about 10-40km daily and they also have to wake up early to pass the segment before traffic jam, both of which may contribute to social life disruption of peoples.

Table 4- 5: Level of respondents' agreement to social relation disruption secondary to traffic congestion.

		Frequency	Percent
Valid	Strongly Agree	48	53
	Agree	38	42
	Neutral	2	2
	Disagree	2	2
	Total	90	100

IV. Late Arrival and Early wakeup

Table 4-6 shows percent and frequency of respondents' degree of agreement on congestion cause early weak up and late arrival .the study result show that from the total respondents 59(66%)strongly agree,28(31%)agree and 3% neither agree nor disagree. This result implies people wake-up early and arrived late to home affect family life parents can't control their children's and students become dizzy can't be actively participate in school due to insufficient sleep.

Table4- 6: Level of respondents' agreement to disruption of sleep wake up and home arrival time due to traffic congestion.

		Frequency	Percent
Valid	Strongly Agree	59	66
	Agree	28	31
	Neutral	3	3
	Total	90	100

V. Increase Accident and Incident

Finding from table showed that 47% of the respondents strongly agree that traffic congestion increase traffic accident and incident and about 34% agree, 4% neutral, 11% disagree and 3%

strongly disagree. This result indicates due to traffic jam accident and incident could be increased particularly rear-end and side-to-side collision of cars and incident to pedestrian and motorist are common.

Table4- 7: Level of respondents' agreement to incident of accident due to traffic congestion.

		Frequency	Percent
Valid	Strongly Agree	42	47
	Agree	31	34
	Neutral	4	4
	Disagree	10	11
	Strongly Disagree	3	3
	Total	90	100

VI. Increase Transportation Cost

As indicated table 4-8 out of 90 respondents 70% strongly agree, 20% of the respondents agree, 2% disagree and 8% are neutral with that traffic congestion cause transportation cost to increase. At study area transportation cost increase during morning and evening peak hour is common due to the drivers used local roads to pass congested areas or intersections this may minimized travel time of the commuters so, they are willing to pay more than normal cost.

Table4- 8: Level of respondents' agreement to increase transportation cost due to traffic congestion.

		Frequency	Percent
Valid	Strongly Agree	63	70
	Agree	18	20
	Neutral	7	8
	Disagree	2	2
	Total	90	100

VII. Difficulty To Estimate Travel Time

The result table4-9 shows that most of the respondents fail to estimate travel time due to the traffic jam. From the total of 90 respondents, 52(58%) strongly agree, 28(31%) agree, 7(8%)

disagree and 3% of them neither agree nor disagree on the statement. The study result implies commuters and driver fail to predict their travel time due to congestion.

Table4- 9: Level of respondents' agreement to difficulty in managing travel time due to traffic congestion.

		Frequency	Percent
Valid	Strongly Agree	52	58
	Agree	28	31
	Neutral	3	3
	Disagree	7	8
	Total	90	100

VIII. Missing Appointment And Late Delivery of Good

Findings from Table 4-10 reveal that due to traffic jam, people get late in their appointments and delivery of good. Among the respondents, about 71% strongly agree, 26% agree, 2% disagree and only 1% neutral. Late deliveries of goods due to congestion have impact on productivity and economic growth of the country by losing productive hours and missing appointment also gives people mental stress.

Table4- 10: Level of respondents' agreement to interruption of appointments and delivery of goods due to traffic congestion.

		Frequency	Percent
Valid	Strongly Agree	64	71
	Agree	23	26
	Neutral	1	1
	Disagree	2	2
	Total	90	100

IX. Block The Movement of Emergency Vehicles

One of the necessary services affected by traffic congestions are emergency vehicles movements including Ambulances and fire trucks. For the question related to implications of traffic congestion on emergency vehicles movement, 66% and 34% were "strongly agreed" and agreed,

respectively as indicated on table4-11. Among few things affected by such blocked emergency vehicle movements, complications to pregnant women and patients are common one.

Table4- 11: Level of respondents' agreement to interruption of emergency vehicles movement due to traffic congestion.

		Frequency	Percent
Valid	Strongly Agree	59	66
	Agree	31	34
	Total	90	100

X. Diversion To The Local Road

The views of the respondents on diversion to the local road due to traffic congestion shown table4-12 were as follows: 51 (57%) strongly agree, 35(39%) agree, 3% &1% neutral disagree. The study result implies most of vehicle divert to the local road to avoid traffic jam, this exposed children play on the local road to traffic incidents and also destruct the road early before its design period because the local road design and construct by consider only local road users.

Table 4- 12: Level of respondents' agreement to diversion of local road due to traffic congestion

		Frequency	Percent
Valid	Strongly Agree	51	57
	Agree	35	39
	Neutral	3	3
	Disagree	1	1
	Total	90	100

4.3.1 Mean analysis

The statement that question about the impact of traffic congestion was based on Likert scale, whereby a mean value of 1 meant that respondents strongly agreed, while a mean of 5 meant that the respondents strongly disagreed with the statements. As shown in table4-13 below the sample size was only 90 by exclude 10 of the experts from the total respondents. The questioner used for the expert removed this part intentionally because the researcher believe that the experts were not

a member of the community and they are not used the selected road segment for their daily trip so it couldn't have no effect on them.

As shown in the below table, almost all of the impacts of traffic congestions were a major concern of the road users, with all below 2.1 mean value of Liker scales. "Late arrival and early wake-up", "missing appointments and late arrival", "increased transport cost", "missing appointment and late delivery" and "block for emergency vehicles" were the top impacts of the traffic congestions according to the respondents.

Table4- 13: Mean Likert scale value for the common implication of traffic congestion using data from 90 respondents.

	N	Mean
Health problem	90	2.09
Increase stress and fatigue	90	1.56
Constraint social relation	90	1.53
Late arrival and early wakeup	90	1.38
Increase accident and incident	90	1.90
Increase transport cost	90	1.42
Difficulty to estimate travel time	90	1.61
Missing appointment and late delivery	90	1.34
Block for emergency vehicle	90	1.34
Diversion to local road	90	1.49

4.4 Spot Speed Study and Analysis

For spot speed study a sample of 100 vehicles taken from each approach legs of the intersections. Those speed data were used to determine the speed characteristics of the whole population of vehicles traveling on the study site. To calculate speed, first record travel time data by replaying video record and note each time taken to travel the determined length of 54 meter for 100 sampled vehicles. Put the recorded time result in excel spread sheet then divided the selected travel distance by each vehicle travel time to get speed.

First step in the preparation of frequency distribution table is put the calculated speed in column one, in column two put number of frequencies of vehicle (the number of vehicles recorded at each speed), column three the cumulative frequency (the total of each of the numbers

(frequencies) added together row by row from lower to higher speed), the fourth column is percentage of the cumulative frequency and the last column for speed percentile to determine the 50th and 85th speed percentile.

Table4- 14: Spot Speed Study Analysis at Total turbo Roundabout, Total Approach.

Speed(km/hr)	Frequency of vehicles	cumulative frequency	Cumulative percent	Speed percentile
12.96	4	4	4%	
13.89	7	11	11%	
14.95	2	13	13%	
16.20	5	18	18%	
17.67	9	27	27%	
19.44	18	45	45%	50%
21.60	17	62	62%	
24.30	23	85	85%	85%
27.77	8	93	93%	
32.40	5	98	98%	
38.88	2	100	100%	

For the average Speed which is the arithmetic mean of all observed vehicle speeds (which is the sum of all spot speeds divided by the number of recorded speeds). It is given as follows

$$\bar{u} = (\sum(fi * ui)/(\sum fi)$$

4.5 Traffic Volume Study

Traffic count study on the three intersections were for three days(Tuesday, Wednesday and Thursday) from 6:30 am up to 6:30 pm. Traffic volume study at Ayertena signalized intersection shown in fig below indicate that there was small variation of traffic volume between the three days throughout the day. There was also no large variation between morning and evening peak hour volume from another time of the day, and there was high traffic volume throughout a day. From the three days, Wednesday was the highest peak period for the traffic volume.

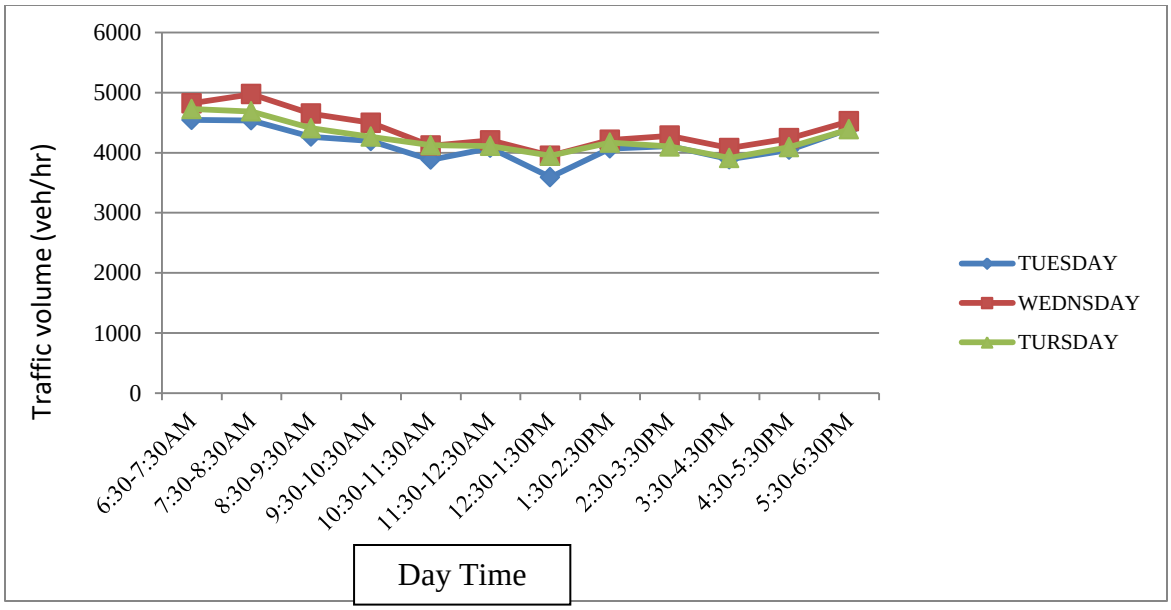

Figure 4- 10: Traffic volume flow by the time of the day over three days for Ayertena signal intersection.

When we see the situation in Zenebework roundabout, the traffic volume increased continuously as we go from morning to night in all three days, and this might not be a surprise given the location found in the residential area and most of people used this road segment for making home to work and back trip.

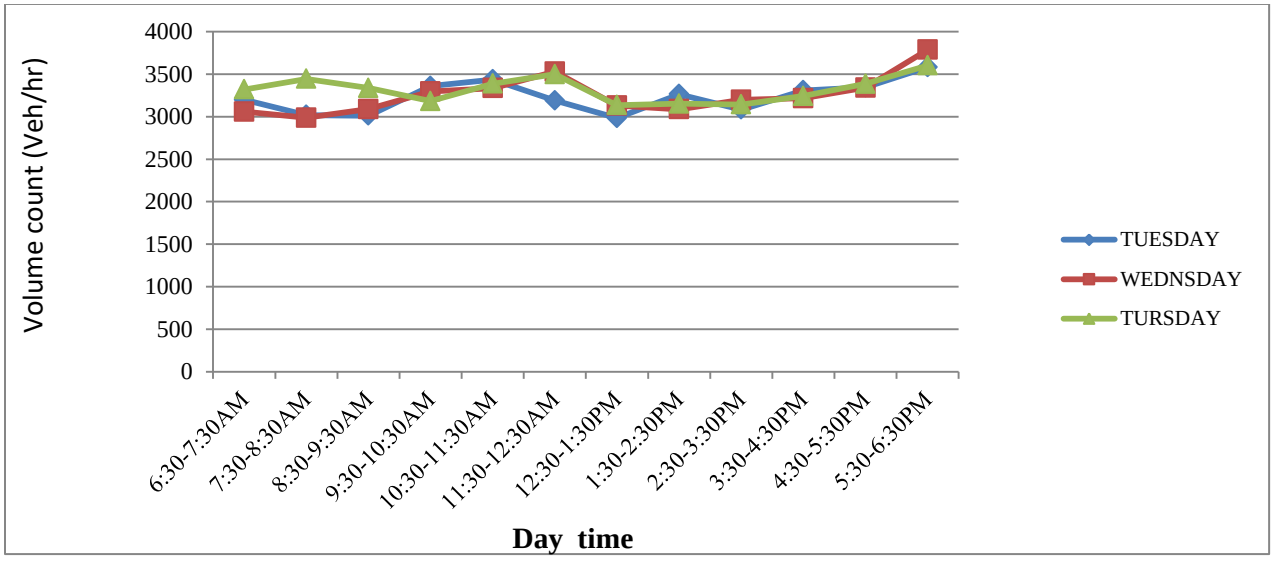

Figure 4- 11: Traffic volume flow by the time of the day over three days for Zenebework roundabout.

During the time of study conducted at Total turbo roundabout as shown in Figure4-13 there is some variation between the three days of traffic volume survey relative to the other roundabouts. In this roundabout, there were peak traffic volumes at the early morning and late PM of the day while the traffic volume dropped continuously in between these two peaks. This study area was the most congested area relative to the two intersections because this roundabout accepts traffic flows from Zenebework roundabout, and as it also a residential place there was inflows of travelers from the nearby places.

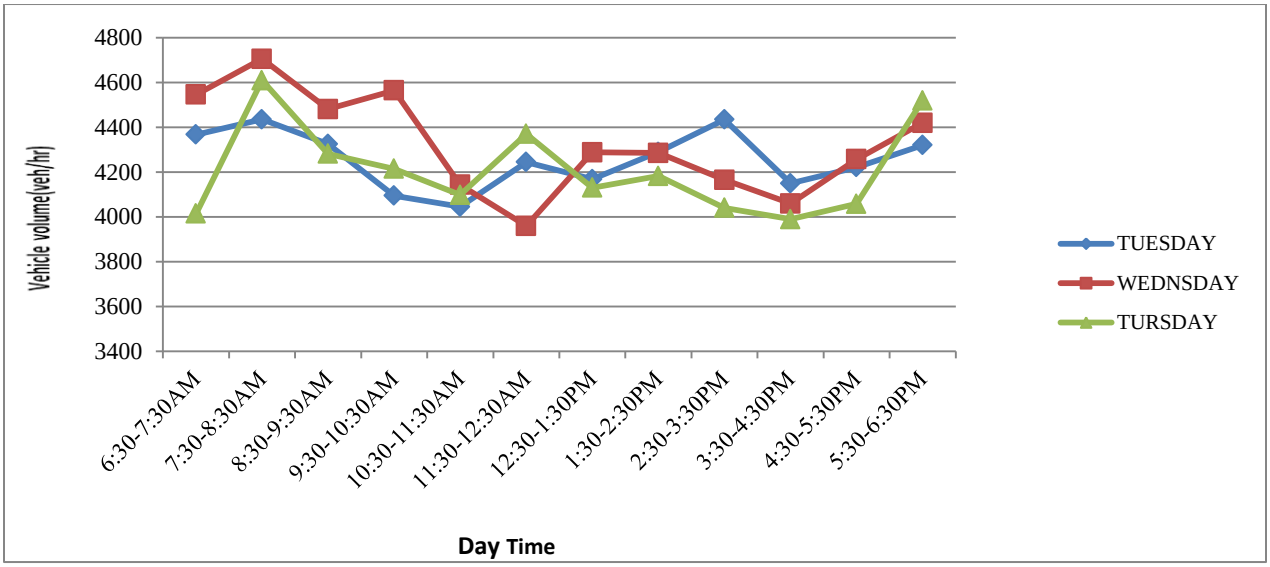

Figure 4- 12: Traffic volume flow by the time of the day over three days for Total roundabout.

4.5.1 Peak Hour Factor (PHF)

The peak hour factor (PHF) is the hourly volume during the maximum volume hour of the day divided by the peak 15-minute flow rate within the peak hour. It is also a measure of traffic demand fluctuations within the peak hour. Table4-15 below shows the morning peak one hour traffic volume data collection and peak hour factor value for those three roundabouts. All three roundabouts peak hour factor approximate to one, which means one hour traffic volume data variability is for each 15 minutes period was minimum, it leads to equal amount of traffic volume was observed for one hour peak period. Demand fluctuation at Zenebework roundabout is relatively high due to minimum peak hour factor value when we compare to the other intersections.

Table4- 15: Peak hour factor per intersections.

INTERSECTION	Time	Car	Mini bus	Mid Bus	Bus	Truck	Trailer Truck	Three wheeler	Motor cycle	TOTAL		PHF
Ayertena Signal	7:30-7:45AM	609	377	32	80	74	16	31	68	1287	4974	0.95
	7:45-8:00AM	632	404	26	58	74	10	23	78	1305		
	8:00-8:15AM	591	370	18	62	85	11	27	66	1230		
	8:15-8:30AM	565	341	23	40	82	8	25	68	1152		
Zenebework Roundabout	7:30-7:45AM	515	282	16	48	12	0	24	38	935	4161	0.89
	7:45-8:00AM	570	275	25	51	11	0	12	41	985		
	8:00-8:15AM	605	278	18	62	33	0	26	52	1074		
	8:15-8:30AM	636	331	20	47	36	10	32	55	1167		
Total Roundabout	7:30 - 7:45AM	787	297	41	55	51	1	2	34	1268	4705	0.93
	7:45 - 8:00AM	669	285	23	48	40	2	7	47	1121		
	8:00 - 8:15AM	715	218	19	22	59	4	11	63	1111		
	8:15 - 8:30AM	717	298	15	36	60	5	5	69	1205		

The three intersections peak hour traffic count summarized detailed on figure4-14 below. On this figure vehicles generalized in to four vehicle classification categories: cars (car, three-wheeler &minibus), Bus (bus&midbus), HGV (truck& truck trailer) and Motor. As shown in the figure, cars had the highest proportion than the other vehicle category in all intersections. Relatively, Zenebework roundabout had high proportion of cars than the other intersections. Ayertena signalized intersection relatively had high proportion of HGV (truck & tuck trailer) than the other intersections.

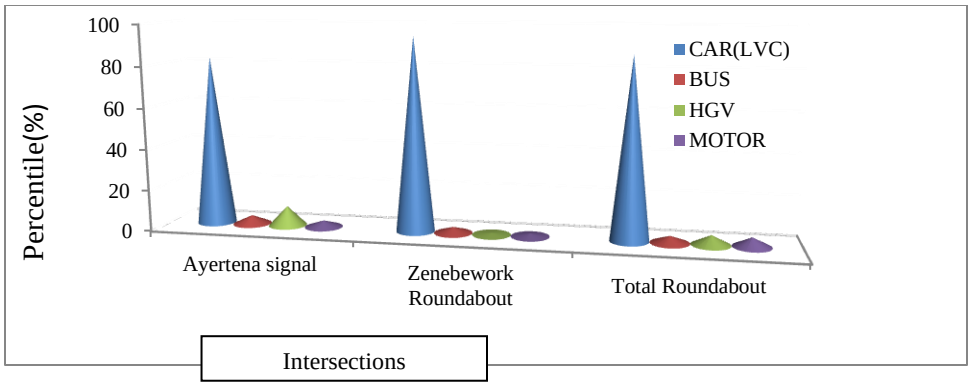

Figure 4- 13: Traffic volume flow over the pick hour for different vehicles types at the three intersections

Peak hour traffic turning movement (through, right turn and left turn) percentile proportioning per approach at Ayertena Signalized intersection detailed on Figure4-15. In figure through vehicle take the highest portion of turning movement at each approach. Even though right turn movement have high proportion at Ayertena approach due to the presence of passenger car station in that area, all approaches left and right turn movements are almost equivalent. (For the rest of the study areas refer Appendix B).

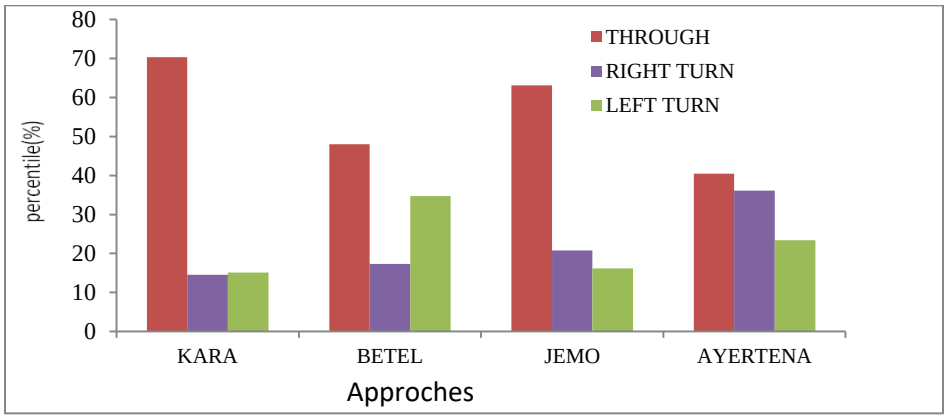

Figure 4- 14: Peak hour traffic turning movement.

I also compared the peak hour traffic volume among the major and minor road approaches as summarized in the figure4-16 below. Kara approach has higher AM peak hour traffic volume and less proportion of PM peak hour traffic volume proportion than Ayertena approach, this could be due to most of the trip makers were choose the earlier for going to work and the latter for returning to home. From the minor road approaches, Betel approach has higher AM peak

volume than PM peak but Jemo approach has higher PM peak hour volume than AM peak hour volume.

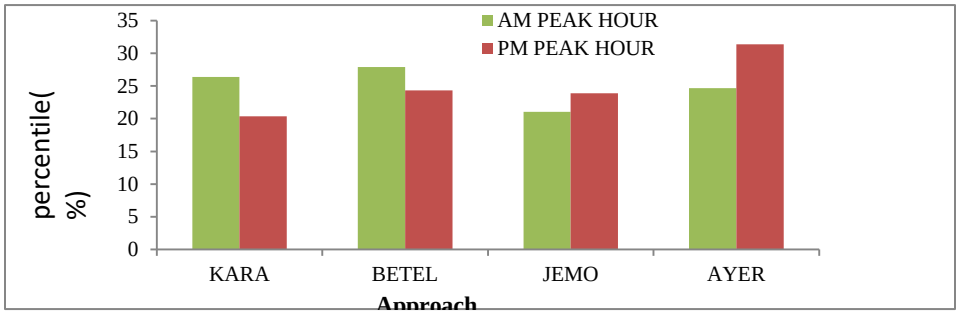

Figure 4- 15: AM & PM Peak Hour Traffic Count Comparison per Approach at Ayertena signalized intersection.

The figure4-17 below indicates the considerable significant variability in percentile of traffic volume among the AM and PM peak hours at the three roundabouts. Zenebework approach had highest proportion of AM peak hour traffic volume while the Total approach had the highest proportion of traffic volume at PM peak hour. The discrepancy could be due to the travelers who used the Zenebework and Total approaches make home to work and back trip, respectively. Wera approach had almost equivalent AM and PM peak hour volume.

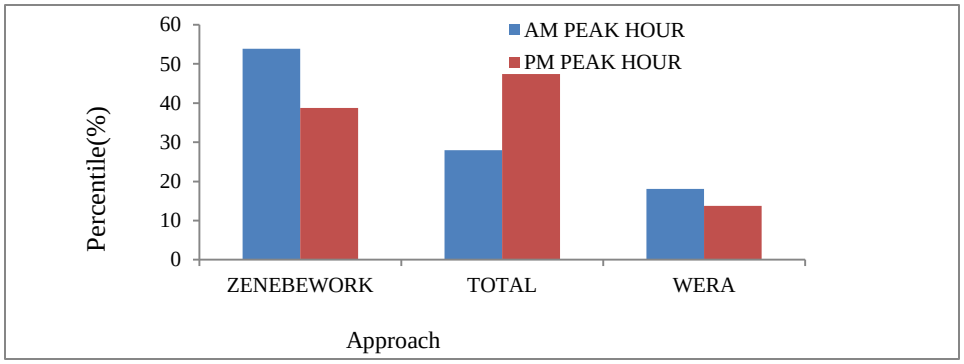

Figure 4- 16: AM and PM Peak Hour Traffic Count Comparison per Approach at Zenebework roundabout.

Total roundabout percentile of AM and PM peak hour traffic count per approaches summarized detailed on figure4-18 below. On this figure the highest AM and PM peak hour traffic volume was on Torhayloch approach. Highest AM peak hour volume could possibly be due to high number of U-Turn vehicles on this approach, some of those vehicles were diverted to the local road from Zenebework roundabout to ignore congestion of total roundabout at Total approach.

Highest PM peak hour of Total approach could be due to the selected route was at residential area and most of the road users' who usually leave home for different purpose should pass this roundabout to return their home due to absence of alternative route and also it is the main road used as the exit from Addis Ababa to neighbors city.

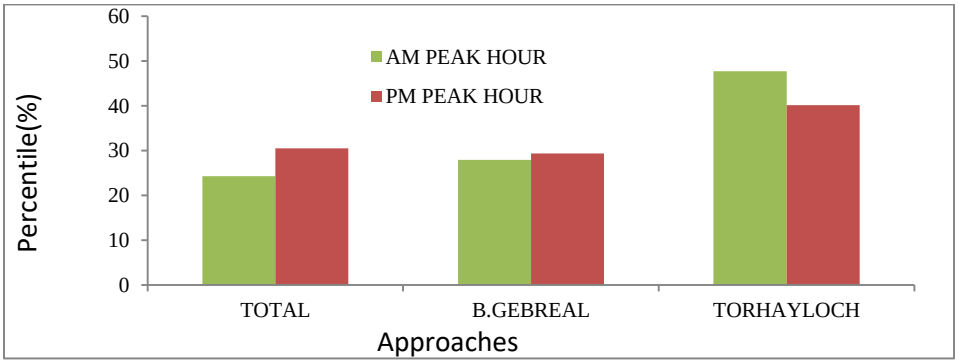

Figure 4- 17: AM & PM Peak Hour Traffic Count Comparison per Approach at total roundabout.

4.6 Performance Analysis

In order to analyze the performance of the intersections traffic modeling (stimulation) were performed by using vissim 9 software. Traffic volume (Morning peak hour), cycle time (for signalized intersection), geometric data, road condition, vehicle composition, vehicle speed were utilized as an input data for traffic modeling/simulation by using software Vissim 9. However, default values were taken for other input data.

4.6.1 Ayertena Signalized Intersection

In order to develop the model/simulation in vissim9 links and connectors were drawn into the model using an aerial image of the study area obtained from Google Maps. The vehicle volumes and the turning movements obtained from the video record data were loaded into the model at the intersections as shown in figure4-19. In this simulation model signal heads were also coded for each travel lane individually at the location of the signal stop line for each correspondent signal group based on AM peak phase time plane data coded on signal controller as indicated in figure 4-20.

Vissim distributed the volumes based on the routing decisions and this was based on the turning volume percentage as shown table4-16. The vehicle composition can also be altered, and was

based on a percentage of the total vehicles (table). Vissim applies desired speed distribution to each vehicle entering the model and reduced speed areas were also defined for turning movements.

4.6.2 Input Data

Eight traffic vehicle types categorized in to four groups based on their weight and length, Car (car, minibus and three wheelers), Bus (Bus and midbus), HGV (Truck and Truck trailer) and Motor.

Table 4- 16: Vissim input data of the three intersections AM peak hour traffic vehicle composition and RF.

AM Peak Hour Vehicle Composition and Relative flow					
Ayertena Signalized Intersection					
Time	**Car**	**Bus**	**HGV**	**Motor**	**Total**
7:30-8:30AM	4094	240	360	280	4974
RF	0.82	0.05	0.07	0.06	1.00
Zenebework Roundabout					
Time	**Car**	**Bus**	**HGV**	**Motor**	**Total**
7:30-8:30AM	3259	99	33	53	3444
RF	0.95	0.03	0.01	0.02	1.00
Total Roundabout					
Time	**Car**	**Bus**	**HGV**	**Motor**	**Total**
7:30-8:30AM	4109	161	222	213	4705
RF	0.87	0.03	0.05	0.05	1.00

Table 4- 17: AM peak hour vehicle input and route relative flow for the three intersections

AM Peak hr Vehicle Input and vehicle Route Relative flow				
Ayertena Signalized Intersection				
Approaches	Vehicle Input		Movement	RF
	Kara	1312	Through	0.7
			Left.T	0.15
			Right.T	0.15
	Betel	1388	Through	0.48
			Left.T	0.35
			Right.T	0.17
	Jemo	1046	Through	0.63
			Left.T	0.16
			Right.T	0.21
	Ayertena	1228	Through	0.36
			Left.T	0.23
			Right.T	0.4
Zenebework Roundabout				
Approaches	Vehicle Input		Movement	RF
	Zenebework	1856	Through	0.72
			Left.T	0.28
	Total	964	Through	0.72
			Right.T	0.28
	Wera	624	Right.T	0.66
			Left.T	0.34
Total Roundabout				
Approaches	Vehicle Input		Movement	RF
	Total	1188	Through	0.28
			Left.T	0.72
	Bisrate.G	1230	Left.T	0.33
			Right.T	0.67
	Torhayloch	2190	Right.T	0.29
			Left.T	0.38
			U.Turn	0.33

Table 4- 18: AM peak hour signal timing per phase at ayertena signalized intersection

	Signal Time			
Intersection	Approaches	Green (sec)	Yellow (sec)	All red(sec)
Ayertena Signal	Kara	60	3	2
	Ayertena	30	3	2
	Betel	45	3	2
	Jemo	15	3	2

Figure 4- 18: Ayertena intersection vissim model

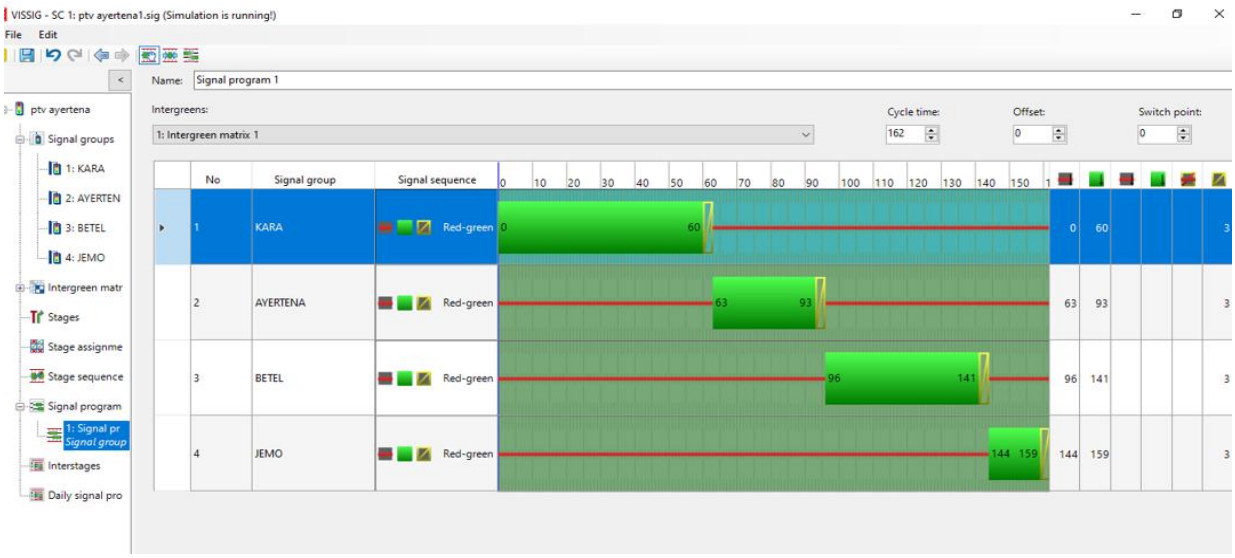

Figure 4- 19: Ayertena intersection AM peak signal program

4.6.3 VISSM Output Result

The output resulted of Ayertena intersection from simulation using software Vissim 9 is as shown in Table 4-19. It can be seen from the table that the average vehicle control delay occurred was 315 second, the longest queue length was 260 meter at Betel Approach and the overall level of service is F (very bad).

Table 4- 19: Ayertena signalized intersection vissim9 output

Time Interval	Approach	Movement	QLen (m)	Qlen Max (m)	Vehs (All) (veh)	LOS (All)	LOS Val (All)	Veh Delay (All) (sec)	Stop Delay (All) (sec)	Stops (All) (Veh)
0-3600	Kara	Through	119.56	154.68	808	F	6	117.45	95.51	2.33
0-3600		Right.T	10.68	168.5	165	F	6	102.63	79.77	2.46
0-3600		Left.T	119.56	154.68	159	F	6	123.46	100.3	2.62
0-3600	Ayertena	Through	139.52	164.69	206	F	6	320.75	283.79	5.38
0-3600		Right.T	139.52	164.69	78	F	6	350.74	310.47	5.53
0-3600		Left.T	139.52	164.69	145	F	6	385.9	343.02	6.45
0-3600	Betel	Through	192.49	230.89	363	F	6	338.99	279.16	8.23
0-3600		Right.T	112.62	260.35	95	F	6	348.75	291.22	8.24
0-3600		Left.T	192.49	230.89	267	F	6	316.13	262.3	7.51
0-3600	Jemo	Through	184.77	230.98	397	F	6	509.92	461.59	7.26
0-3600		Right.T	167.23	229.04	94	F	6	357.85	314.87	6.38
0-3600		Left.T	184.77	230.98	98	F	6	515.03	459.74	8.38
0-3600	Average		141.89	260.35	2875	F	6	315.63	273.48	5.90

The performance evaluation of Zenebework roundabout was done with the help of PTV VISSIM software, analysis for 3600 seconds time interval for stimulation. As indicated in table 4-20, the overall LOS of the roundabout is B (Good) with the max queue length is 95.67 meters and the Max total vehicle delay per approach is 65.49 seconds at Zenebework approach.

Table 4- 20: Zenebework Roundabout vissim9 output

Time Interval	Approach	Movement	QLen (m)	Qlen Max (m)	Vehs (All) (veh)	LOS (All)	LOS Val (All)	Veh Delay (All) (sec)	Stop Delay (All) (sec)	Stops (All) (Veh)
0-3600	Zenebework	Through	41.53	55.87	625	LOS_E	5	46.7	27.21	2.66
0-3600		Left.T	25.23	55.87	228	LOS_C	3	18.59	10.51	1.15
0-3600	Total	Through	9.86	95.67	1226	LOS_A	1	9.89	1.61	0.54
0-3600		Right.T	9.86	95.67	323	LOS_B	2	11.05	2.3	0.8
0-3600	Wera	Left.T	0.33	21.16	179	LOS_A	1	9.31	3.71	0.69
0-3600		Right.T	0.28	35.74	400	LOS_A	1	4.26	0.15	0.14
0-3600	Average		14.52	95.67	2981	LOS-B	2	16.63	7.58	1.00

The output resulted of total roundabout from traffic simulation using software Vissim 9 is as shown in Table 4-21. It can be seen from the table that the maximum vehicle delay occurred was 203.07 seconds, the maximum queue length is 165.78 meter, and the overall level of service is D (bad).

Table4- 21: Total roundabout from traffic simulation using software Vissim 9.

Time Interval	Approach	Movment	QLen (m)	Qlen Max (m)	Vehs (All) (veh)	LOS (All)	LOS Val (All)	Veh Delay (All) (sec)	Stop Delay (All) (sec)	Stops (All) (Veh)
0-3600	TOTAL	Through	71.09	163.02	224	LOS_F	6	55.4	38.24	2.25
0-3600		Left.T	139.85	163.02	571	LOS_F	6	203.07	101.64	15.28
0-3600	B.Gebreal	Right.T	56.04	165.78	794	LOS_B	2	12.44	4.97	0.5
0-3600		Left.T	108.18	165.78	338	LOS_F	6	190.33	111.71	12.44
0-3600	Torhayloc	Right.T	0	0	637	LOS_A	1	1.7	0	0
0-3600		Left.T	31.29	118.13	822	LOS_C	3	21.16	4.4	1.68
0-3600		U.Turn	31.29	118.13	670	LOS_C	3	24.03	4.76	1.89
0-3600	Average		62.53429	165.78	4056	LOS-D	4	72.59	37.96	4.86

4.7 Estimating Total Congestion Cost

Firstly, Vehicle operating costs estimated by Simon, G (2017) adjusted in to recent year (2021).When updating the VOC value, the formula introduced in the AASHTO Red Book is applied, and Central Statistics Agency of Ethiopia report CPI value for Addis Ababa in 2017=100 and CPI value = 237.7 in 2021 were used. To obtain total congestion cost of this study take the average VOC adjusted year value of all vehicles type. And also for VOT value take the average of the adjusted year value per vehicle type indicted in the previous chapter as 11.6095 ETB/hr.

VOC adjusted value was summarized in table4-22 below.

Table 4- 22: Summarized VOC value

	Estimated value by Semon. G , 2017	Adjusted value(2021)
Vehicle type	VOC ETB/Vehicle type	VOC ETB/Vehicle type
Car	8.8988	21.1524
pick up/4-wheel drive	10.7936	25.6563
Minibus	9.1400	21.7258
Microbus	10.4600	24.8634
Bus	12.0800	28.7142
Truck	21.2115	50.4198
TruckTrailer	26.4672	62.9126

Table4-23 below summarizes calculated total congestion cost by using equation proposed by Tezedakis study, discuss on the pervious chapter. The total traffic congestion costs were **721,666.682, 4020.674 and 154,281.096 ETB** per hour for Ayertena signalized intersection, Zenebework roundabout and Total roundabout respectively**.** The Actual average speeds per approach used for the calculation were from spot speed analysis before and design speed for urban road was 50km/hr from ERA manual 2013. The total congestion cost of the three intersection of the selected road segment during morning peak hour was calculated as **879,968.45 ETB** per hour.

Table 4- 23: Total congestion cost of the three intersections.

AYERTENA INTERSECTION	**APPROCHES**	Queue time (hours)	Queue volume (veh/hr)	Actual Speed (km/h)	Design speed (km/h)	VOT (ETB/hour)	VOC (ETB/veh.km)	Congestion Cost(ETB/hr)
	KARA	0.030939	2298	20.28	50	11.61	33.63	48831.58
	AYERTENA	0.095219	2610	21.75	50	11.61	33.63	183064.25
	BETEL	0.089289	3595	19.4	50	11.61	33.63	210899.80
	JEMO	0.139014	3278	18.07	50	11.61	33.63	278871.04
ZENEBEWORK ROUNDABOUT	APPROCHES	**Total congestion cost for Ayertena Signalized Intersection**						**721666.68**
	ZENEBEWORK	0.006917	660	23.55	50	11.61	33.63	3640.91
	TOTAL	0.000694	771	20.9	50	11.61	33.63	378.98
	WERA	0.000208	6	18.54	50	11.61	33.63	0.78
TOTAL ROUNDABOUT	APPROCHES	**Total congestion cost for Zenebework Roundabout**						**4020.67**
	TOTAL	0.051783	2877	21.57	50	11.61	33.63	108832.38
	BSRATE.G	0.044783	1025	21.95	50	11.61	33.63	34123.45
	TORHAYLOCH	0.008636	1487	26.04	50	11.61	33.63	11325.26
		Total congestion cost for Total Roundabout						**154281.10**

4.8 Measures That Can Reduce Traffic Congestion.

The researcher was revised many literatures and identified around ten measures that potentially minimize traffic congestion of the selected road segment, and then a questionnaire prepared accordingly were distributed to general peoples, drivers and experts. Then, the degree of agreement of the respondents was measured using five points Likert-scale, and the analysis was done using SPSS software.

4.8.1Mean Analysis

Table 4- 24: Mean value of solutions to minimize traffic congestion.

	N	Mean
Expand the capacity of the road	100	1.12
Introducing better traffic management system	100	1.96
Ban good vehicles movement during peak hour	100	2.16
Redesign the intersections	100	1.79
Ban road side marketing	100	1.92
Allocate different travel time for student	100	2.36
Design pedestrian lane	100	1.45
Parking restriction	100	1.47
Constructing alternative road network	100	1.14
Increase green time at signalized intersection	100	2.17

The statements “Solution to traffic congestion” in the questionnaires was based on Likert scale where a mean of 1 represent strongly agree and a mean of 5 represents strongly disagree. The most weighted solution for the traffic congestion problem were “expanding the capacity of the road”, “constructing alternative road network”, “designing pedestrian lane”, and “putting parking restrictions’, with each had mean Likert scale value of 1.12, 1.14, a.45 and 1.47, respectively. As shown on table4-24, the mean value of “banning good vehicle movement during peak hour”, “allocating different travel time for the student” and “increasing the green time of signalized intersection” were 2.16, 2.36 and 2.17, respectively. These signify that respondents, on average, agree that these measures could reduce traffic congestion of the selected segment.

4.8 Turbo Roundabout Signalization

Total 3kutur mazoriya roundabout changed in to turbo roundabout recently, about three years only even tough, safety of that area increased because of the star type turbo roundabout design but it couldn't minimize the highest traffic congestion of the area especially during morning and evening peak hour. To minimize the unbalance traffic flow of total turbo roundabout at AM peak hour the researcher design signal to signalized the turbo roundabout as it is without reconstruct the intersection infrastructure.

4.8.1 Saturation Flow Rate

Saturation flow rate for signalized intersection was computed using head difference and but the roundabout was very complicated to do an experiment (head difference due to stop and go movement), so base saturation flow rate 1900pc/h/ln with adjustment factors were used in this study.Table4-25 indicates the calculated saturation flow rate adjust factors of each approach of total roundabout.

Table4- 25: Saturation Flow Rate Adjustment Factor of total roundabout.

Saturated Flow Rate Adjustment Factors			
Approaches	Total	B.Gebreal	Torhayloch
N	3.0000	3.0000	3.0000
fw	0.9889	0.9889	0.9889
fHv	0.8351	0.8868	0.8368
fg	0.9950	1.0250	1.0150
fp	0.8833	0.8833	0.9333
fbb	0.9867	0.9920	0.9867
fa	1.0000	1.0000	1.0000
fLU	1.0000	1.0000	1.0000
fLT	0.9652	0.9844	0.9756
fRT	1.0000	0.8977	0.9488
fLpb	1.0000	1.0000	1.0000
fRpb	1.0000	1.0000	1.0000

As shown in table4-26 the saturation flow rate value was decrease significantly from base saturation flow rate value (1900pc/h/ln) due to adjustment factors stated table above. Due to the presence of heavy vehicle proportion at Torhayloch and Total approach, high proportion of right

turn vehicle at Bisrate.g and Torhayloch approach and minimum approaching grade of total approach leg the saturation flow rate values was decreased significantly.

Table 4- 26: The saturation flow rate value

Total Turbo Roundabout		S (pc/hr/ln)
Approaches	Total	1314
	Bisrate.G	1323
	Torhayloch	1360

4.8.2 Signal Timing Design

To minimize traffic congestion due to the unbalance traffic flow of total turbo roundabout this study used traffic signal time allocation as solution. From traffic signal timing design at turbo roundabout total cycle time of 160 sec was calculated. Table4-27 indicates split signal phase sequence timing results of total roundabout includes green time, yellow interval and all red intervals.

Vehicular green time interval and all red interval on Total and Torhayloch had relatively high, the green time was due to high traffic volume of morning peak hour and the all red interval increment was due to lengthy roundabout geometry to turn from one approach to the other far side and 15th percentile speed decrement leads to have highest all red values.

Table 4- 27: traffic signal timing result summary at total roundabout

Signal cycle Parameters	Total Turbo Roundabout		
	Total	Bisrate.G	Torhayloch
Phasing	Ø1	Ø2	Ø3
Green Time(sec)	56	33	49
Yellow Interval(sec)	3	2	3
All red interval(sec)	5	3	6

4.8.2.1 Pedestrian Green Time Requirement

During designing traffic signal timing checking pedestrian green time requirement is crucial for safety. In computation of pedestrian green time pedestrian walking speed was taken to be 4 ft/sec and Due to time and budget constraint pedestrian volume count was not done but from filed visit the researcher can see pedestrian volume was small so used 200ped/hr default value for moderate pedestrian volume from HCM 2010. The length of the cross walk equals to 10.5 meter (34 ft) and the width of the cross walk equals 3 meter (9.8ft) , so used the formula for W_E <10ft below. One cycle length was 160 sec from signal design, so in one hour (3600sec) there could be 23 number of cycle this indicted that from the total number 200 pedestrians per hour only nine of them cross the road per cycle. Therefore using 34 ft length, 4ft/sec travel speed of pedestrian and nine pedestrian per cycle pedestrian green time become 14.13 seconds for all approaches

$$G_{p=}3.2 + \left(\frac{L}{S_p}\right) + (0.27 * N_{ped}) For\ W_E < 10ft$$

Because all streets have equal width and equal cross walk width and some pedestrian volume in all cross walk, minimum pedestrian green time requirement is the same for each phase. As shown table4-28 the signal safely accommodates all pedestrians no change for signal timing for vehicular need is required.

Table 4- 28: pedestrian green time requirement

Total Turbo Roundabout					
Vehicular green time(sec)		Pedestrian green time (sec)		Formula	Check Requirement
GVTO	56	GPB	14.13	GPB(14.13)≤GVTO +YVTO(64)	OKEY
GVB	33	GPTR	14.13	GPTR(14.13)≤GVB + YVB(38)	OKEY
GVTR	49	GPTO	14.13	GPTO(14.13)≤GVTR + YTR(58)	OKEY

4.8.3 Performance Analysis

This study provides shared lane and split phase sequencing as one input for total roundabout signalization modeling as shown in figure4-20. Splitting signal phases sequence used for modeling roundabout signalization due to the roundabout geometry. Total turbo roundabout with

traffic signal at peak hour is evaluated using VISSIM simulation modeling tool. Figure4-21 indicates, roundabout signalization modeling at total turbo roundabout. To evaluate the signalized total turbo roundabout performance considers delay, vehicle queue and level of service (LOS) output results from simulation using Vissim 9 software.

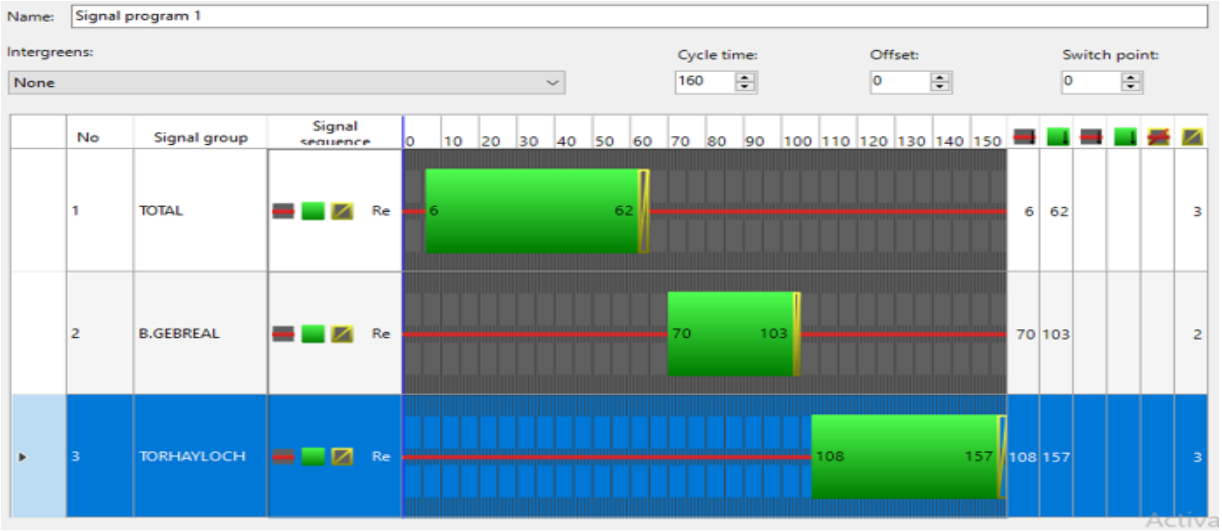

Figure 4- 20: Signal timing of total roundabout

Modeling signalizing turbo roundabout channelized right turn for the two legs (Bisrate.G and Torhayloch) and through movement for total approach legs due to roundabout geometry and channelization structure allowing them to bypass traffic signal.

Figure 4- 21: vissim model of total signalized roundabout.

Based on the analysis, signalizing is the good option for improving intersection performance. It reduced delay, shortened vehicle queue time, reduced queuing volume of vehicles as well as increased the LOS at total roundabout. The table (4-29) comparison results showed that the average vehicle delay was reducing from 72.59 seconds to 17.84 seconds, Average queue length from 62.53(m) to 19.01(m), Maximum queue length from 165.78 (m) to 137.24(m) vehicle queuing time from 360.47 seconds to 141.75 seconds, vehicle queue volume from 5,389 veh/hour to 1596 veh/hour and roundabout LOS increased from D to B. It means that the signalizing the turbo roundabout can reduce the congestion and improve the roundabout performance significantly.

Table 4- 29: comparative results

Parameters	Total Turbo Roundabout (existing)	Total Turbo roundabout signalized (modified)
level of service(LOS)	LOS-D	LOS-B
Average Vehicle Delay(sec)	72.59	17.84
Average queue length(m)	62.53	19.01
Maximum queue length(m)	165.78	137.24
vehicle queue volume(veh/hr)	5389	1596
vehicle queue time(sec)	360.47	141.75

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Based on the findings of this study the following major conclusions are derived:

- The traffic flow is very high on the selected road segment throughout the day and highly congested at morning and evening peak hours. This is due to the road is a main entrance to Addis Ababa from the southern gate and is residential area too.
- Major social impacts of traffic congestion were increase stress and fatigue, constraint social relation, late arrival and early weak up, increase accident and incident, increase transport cost, difficulty to estimate travel time, missing appointment and late delivery, block for emergency vehicles, diversion to the local road, and health problem.
- The three major intersections of selected road segment studied was modeled in VISSIM 9 microscopic simulation for performance evaluation by considering delay, vehicle queue and level of service as the important parameters from software outputs. Performance analysis result shows the overall level of service value of Ayertena signalized intersection and Total Turbo roundabout is very bad (LOS-F) and bad (LOS-D) respectively but Zenebework roundabout level of service is good (LOS-B).
- The total traffic congestion cost per peak hour at Ayertena Signalized Intersection, Zenebework Roundabout and Total Turbo Roundabout are 721,666.7, 4020.674 and 154,281.1 ETB respectively.
- To improve traffic conditions at welete-total road segment focused on total turbo roundabout by using vissim simulation for performance analysis. The modification of the total turbo roundabout was the addition of traffic lights while maintaining infrastructure of the current turbo roundabout. This modification can reduce delay from 72.59 seconds to 17.84 seconds, maximum queue length from 165.78 m to137.24m, and increase LOS-D to LOS-B.

5.2. Recommendations

The recommendations were made based on the result and engineering judgments to minimize socio-economic impact of traffic congestion. The recommendations help the government to look into the matter and put optima efforts reduce the traffic congestion at study area. Overall, the following specific recommendations are proposed based on the result of this study.

I. Expand the Capacity of the Road

The road from welete to total road segment is obviously performed at its overcapacity particularly the segment from welete to ayertena intersection is narrow carriageway width of 7m with 1.5m pedestrian lane even if there is high number of pedestrian in this area they used the main road together with traffic other than the pedestrian lane it is because the pedestrian lane almost destructed it is not comfortable to users and also lane used by road side marketers.

II. Constructing Alternative Road Networks

The strategy of constructing alternative road networks is recommended as a long-term solution and can help in reducing traffic congestion by diverting some of the traffic flow of the existing route. The implementation of this recommendation is very expensive although it sounds a positive one, the government body institutions need design a serious deal towards initiation ahead.

III. Construct Pedestrian Lane and Restrict Illegal Parking and Road Side Marketing

Based on the field visit the absence of properly constructed pedestrian lane, illegal parking and roadside marketing worsen the traffic congestion of the study area. Construct modern pedestrian lane and put restriction on illegal parking and roadside marketing as short term solution to minimize traffic congestion and accident in study area.

IV. Redesign the Intersections

Signalizing total turbo roundabout without changing the existing infrastructure increase the level of service and reduced delay and queue as shown before so, this indicate that it could be good recommendation for improving unbalance traffic flow of turbo roundabout.

REFERENCES

1. Admasu, N. (2017) 'Estimating Total Traffic Congenstion Costes for Selected Road of Addis Ababa (A case Study : Mekanisa - Jemo Road)'.

2. Aftabuzzaman, M (2007) Institute of Transport Studies, Monash University, Melbourne, Victoria, Australia.

3. Alaa,G, Ahmed,S and Sherif,B(2018) Economic Impact of Urban Traffic Congestion on the main routes in mansoura city, Egypt.

4. Allan, R. (2013) what really cause traffic congestion? nberke [at] sheeps head bites [dot] com.

5. Charles R. Stevens (2005) 'Signals and Meters at Roundabouts' Texas Transportation Institute

6. ELISONGUO, A. D., 2013, the Social-Economic Impact of Road Traffic Congestion, Darussalam.

7. Ewing, R. (1999) Traffic Calming Impacts. In Traffic Calming: State and Practice. Institute of Transportation Engineers, Washington, D.C.

8. Transport Systems Improvement Project' (2016), Ethiopia

9. Federal Highway Administration (FHWA)(2015) "Modern Roundabouts, an Informational Guide". Research and Technology. Retrieved 15 September 2015

10. Grant-Muller, SM and Laird, JJ (2007) Costs of Congestion: Literature Based Review of Methodologies and Analytical Approaches. Scottish Executive, Edinburgh.

11. Hallworth, M.S. (1992), Signaling Roundabouts, Traffic Engineering and Control 33.6, pp. 354–363.

12. Handbook of Simplified Practice for Traffic Studies; TR-455, (2002).

13. Harriet, T. and Emmanuel, A. K. (2013) 'An Assessment of Traffic Congestion and Its Effect on Productivity in Urban Ghana', 4(3).

14. "Highway capacity manual" (HCM 2010) transportation research board 2000, executive committee.

15. "Highway capacity manual" (HCM 2010), Transportation research board 2010, executive committee.

16. Homburger, W.S (1996). Spot Speed Studies, Institute of Transportation Studies, University of California, Berkeley

17. Jaehyun, C (2020). Road User Costs for Highway Construction Projects Involving a Lane Closure

18. Kefyalew, T. (2017) Analysis of Traffic Congestion and its Economic Cost in Addis Ababa A Case Study of Meskel Square to Kality Interchange.

19. Mercylee N. (2018) SOCIO-ECONOMIC EFFECTS OF TRAFFIC CONGESTIONON URBAN MOBILITY ALONGJOGOO ROAD, NAIROBI CITY COUNTY-KENYA.

20. Munera, c. (2018) Economic impact of traffic congestion- estimation and challenges. ***Available from:*** *https://www.researchgate.net/publication/326235494*

21. Md, Sanowear Hand Moudud, A (2017), Traffic Scheduling Simulation: The Case of Dhaka City available at: https://www.researchgate.net/publication/322050091

22. Noor .M, Rizkie. A and Muchlisin (2018) Analysis of congestion cost at signalized intersection using Vissim 9 (Case study at Demak Ijo Intersection, Sleman) Indonesia

23. PTV Visum Manual (2021) PTV AG, Karlsruhe, Germany info@vision.ptvgroup.com www.ptvgroup.com and www.vision-traffic.ptvgroup.com

24. Program, C. H. (2001) Economic Implications of Congestion.

25. Rogers, Martin (2002). Highway engineering. Oxford, UK: Blackwell Science. ISBN 978-0-632-05993-5

26. Ronán .C, Sample size a rough guide available at: http://www.cmh.edu/stats/size.asp

27. Simon,G.(2017) Urban Road Users Cost Allocation: A Case Study On Addis Ababa.

28.Solomon, S (2015) Segmental Assesment of Level of Traffic Congestion on Kality Ring Road to Dukem Bridge.

29. Somuyiwa, A. O., Fadare, S. O. and Ayantoyinbo, B. B. (2015) 'Analysis of the Cost of Traffic Congestion on Worker's Productivity in a Mega City of a Developing Economy', pp. 644–656.

30. Tzedakis, A, Different Vehicles Speeds and Congestion Costs. Journal of Transport Economics and Policy XIV, 1, 81-103 (1980)

31. Weisbrod, G. Vary D. and Treyz, G (2003). Measuring the Economic Costs of Urban Traffic Congestion to Business, Available at: HYPERLINK "http://www.edrgroup.com/pdf/

32. Sileshi,S (2019)Assessing Socio-Economic impact of Road Traffic Congestion in Addis Ababa City in Case of Megenagna to CMC Michael Road Segment.

33. Sugiyanto, G, Biaya Kemacetan(2008) (Congestion Cost) Mobil Pribadi di Central Business District

34. Jaehyun, C (2020). *Road User Costs for Highway Construction Projects Involving a Lane Closure*

Appendix A: Spot Speed

a) Spot Speed Analysis at Ayertena Signal ,Kara Approach

Speed (km/h)	Frequency of vehicles	cumulative frequency	Cumulative percent	Speed percentile	50^{th} &85^{th} percentile speed(km/hr)
10.80	1	1	1%		
11.44	2	3	3%		
12.15	1	4	4%		
12.96	3	7	7%		
13.89	8	15	15%		
14.95	9	24	24%		
16.20	5	29	29%		
17.67	10	39	39%		
19.44	10	49	49%	50%	19.55
21.60	20	69	69%		
24.30	15	84	84%	85%	24.48
27.77	15	99	99%		
32.40	1	100	100%		

b) Spot Speed Analysis at Ayertena Signal ,Ayertena Approach

Speed (km/h)	Frequency of vehicles	cumulative frequency	Cumulative Percent	Speed percentile	50^{th} &85^{th} percentile speed(km/hr)
6.94	1	1	1%		
10.80	1	2	2%		
11.44	1	3	3%		
12.15	1	4	4%		
12.96	1	5	5%		
13.89	3	8	8%		
14.95	1	9	9%		
16.20	10	19	19%		
17.67	15	34	34%		
19.44	13	47	47%	50%	21.27
21.60	12	59	59%		
24.30	19	78	78%	85%	25.92
27.77	15	93	93%		

32.4	5	98	98%		
38.88	1	99	99%		
48.6	1	100	100%		

c) Spot Speed Analysis at Ayertena Signal ,Betel Approach

Speed (km/h)	Frequency of vehicles	cumulative frequency	Cumulative percent	Speed percentile	50^{th} &85^{th} percentile speed(km/hr)
9.26	1	1	1%		
9.72	1	2	2%		
10.80	2	4	4%		
11.44	1	5	5%		
12.15	1	6	6%		
12.96	1	7	7%		
13.89	4	11	11%		
14.95	11	22	22%		
16.20	12	34	34%		
17.67	16	50	50%	50%	17.67
19.44	19	69	69%		
21.60	13	82	82%	85%	22.4
24.30	10	92	92%		
27.77	2	94	94%		
32.40	4	98	98%		
38.88	1	99	99%		
48.60	1	100	100%		

d) Spot Speed Analysis at Ayertena Signal ,Jemo Approach

Speed (km/h)	Frequency of vehicles	cumulative frequency	Cumulative percent	Speed percentile	50^{th} &85^{th} percentile speed(km/hr)
6.94	1	1	1%		
7.78	1	2	2%		
8.84	2	4	4%		
10.80	2	6	6%		
12.15	3	9	9%		
12.96	2	11	11%		
13.89	4	15	15%		
14.95	10	25	25%		
16.20	17	42	42%	50%	16.94
17.67	16	58	58%		
19.44	14	72	72%	85%	21.20

21.60	16	88	88%		
24.30	8	96	96%		
27.77	3	99	99%		
32.40	1	100	100%		

e) Spot Speed Analysis at Zenebework Roundabout, Zenebework Approach

Speed (km/h)	Frequency of vehicles	cumulative frequency	Cumulative percent	Speed percentile	50^{th}&85^{th} percentile speed(km/hr)
11.44	1	1	1%		
12.96	2	3	3%		
13.89	2	5	5%		
14.95	3	8	8%		
16.20	7	15	15%		
17.67	7	22	22%		
19.44	9	31	31%		
21.60	17	48	48%	50%	21.83
24.30	24	72	72%		
27.77	13	85	85%	85%	27.77
32.40	11	96	965%		
38.88	3	99	99%		
48.60	1	100	100%		

f) Spot Speed Analysis at Zenebework Roundabout, Wera Approach

Speed (km/h)	Frequency of vehicles	cumulative frequency	Cumulative percent	Speed percentile	50^{th}&85^{th} percentile speed(km/hr)
11.44	2	2	2%		
12.15	1	3	3%		
12.96	5	8	8%		
13.89	8	16	16%		
14.95	7	23	23%		
16.20	18	41	41%	50%	17.15
17.67	14	55	55%		
19.44	25	80	80%	85%	20.52

21.60	10	90	90%		
24.30	3	93	93%		
27.77	4	97	97%		
32.40	2	99	99%		
48.60	1	100	100%		

g) Spot Speed Analysis at Zenebework Roundabout, Total Approach

Speed (km/h)	Frequency of vehicles	cumulative frequency	Cumulative percent	Speed percentile	50^{th}&85^{th} percentile speed(km/hr)
12.96	2	2	2%		
13.89	6	8	8%		
14.95	4	12	12%		
16.20	7	19	19%		
17.67	15	34	34%	50%	18.76
19.44	26	60	60%		
21.60	10	70	70%		
24.30	14	84	84%	85%	24.62
27.77	11	95	95%		
32.40	3	98	98%		
38.88	2	100	100%		

h) Spot Speed Analysis at Total Roundabout, B.Gebreal Approach

Speed (km/h)	Frequency of vehicles	cumulative frequency	Cumulative percent	Speed percentile	50^{th} & 85^{th} percentile speed(km/hr)
12.96	2	2	2%		
13.89	1	3	3%		
14.95	7	10	10%		
16.20	4	14	14%		
17.67	12	26	26%		
19.44	16	42	42%	50%	20.46
21.60	17	59	59%		

24.30	21	80	80%	85%	25.46
27.77	15	95	95%		
32.40	4	99	99%		
38.88	1	100	100%		

i) Spot Speed Analysis at Total Roundabout, Torhayloch Approach

Speed (km/h)	Frequency of vehicles	cumulative frequency	cumulative percent	Speed percentile	50^{th} & 85^{th} percentile speed(km/hr)
13.89	1	1	1%		
14.95	3	4	4%		
16.20	9	13	13%		
17.67	6	19	19%		
19.44	15	34	34%		
21.60	9	43	43%	50%	23.05
24.30	13	56	56%		
27.77	11	67	67%	85%	31.74
32.40	21	88	88%		
38.88	8	96	96%		
48.60	4	100	100%		

Appendix B: Traffic Count Analysis

Figure1. Zenebework Roundabout AM Peak Traffic Turning Movement

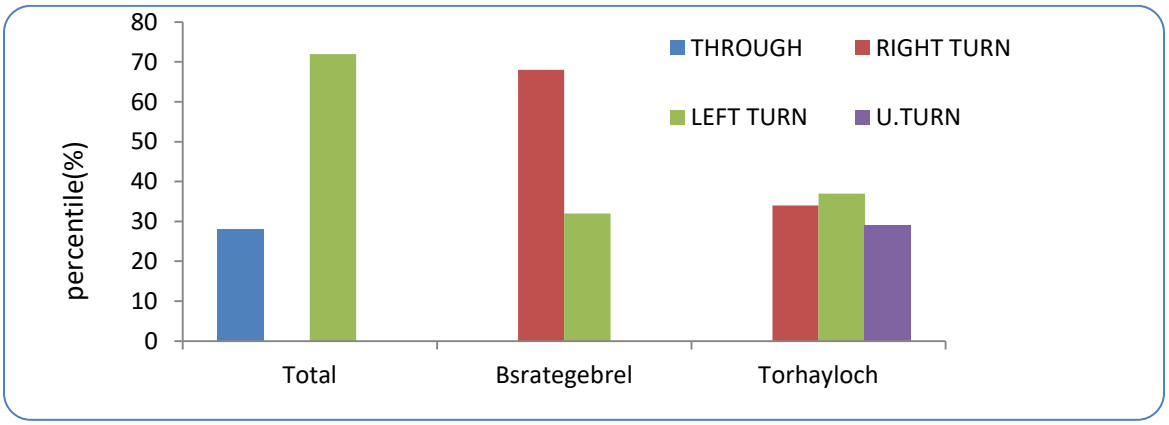

Figure2. Total Roundabout AM Peak Traffic Turning Movement

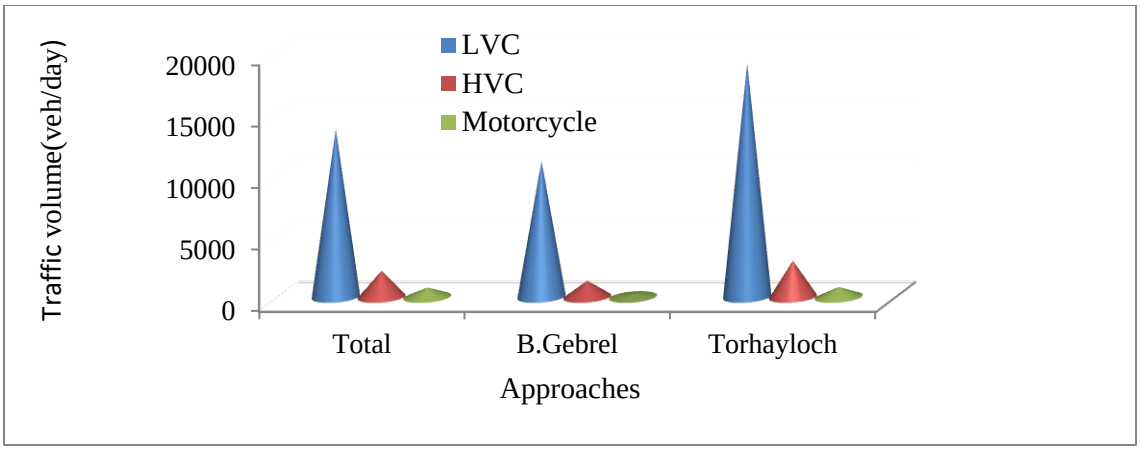

Figure 3.Traffic Count Summary at Total Roundabout, Wednesday

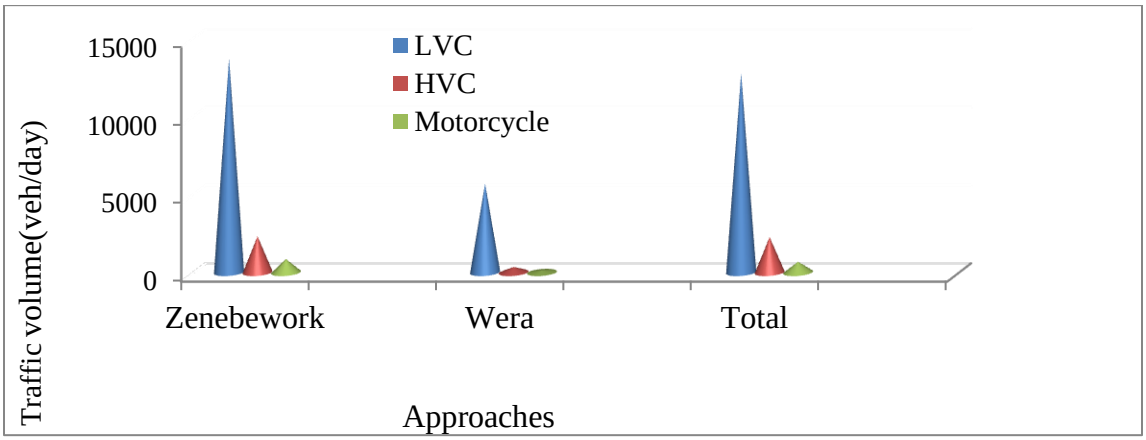

Figure 4.Traffic Count Summary at Zenebework Roundabout, Wednesday

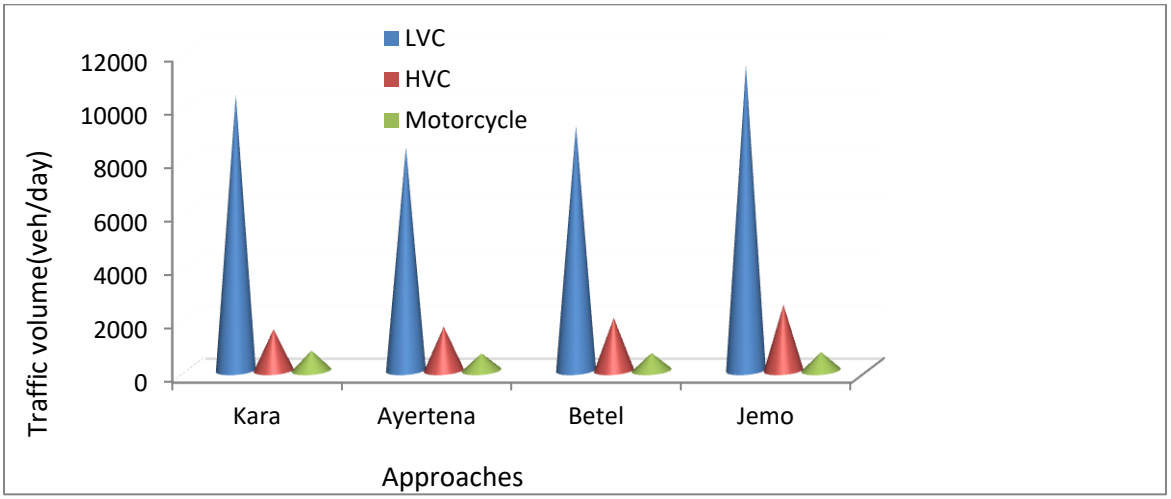

Figure 5.Traffic Count Summary at Ayertena Signal, Wednesday

Appendix C: VISSIM

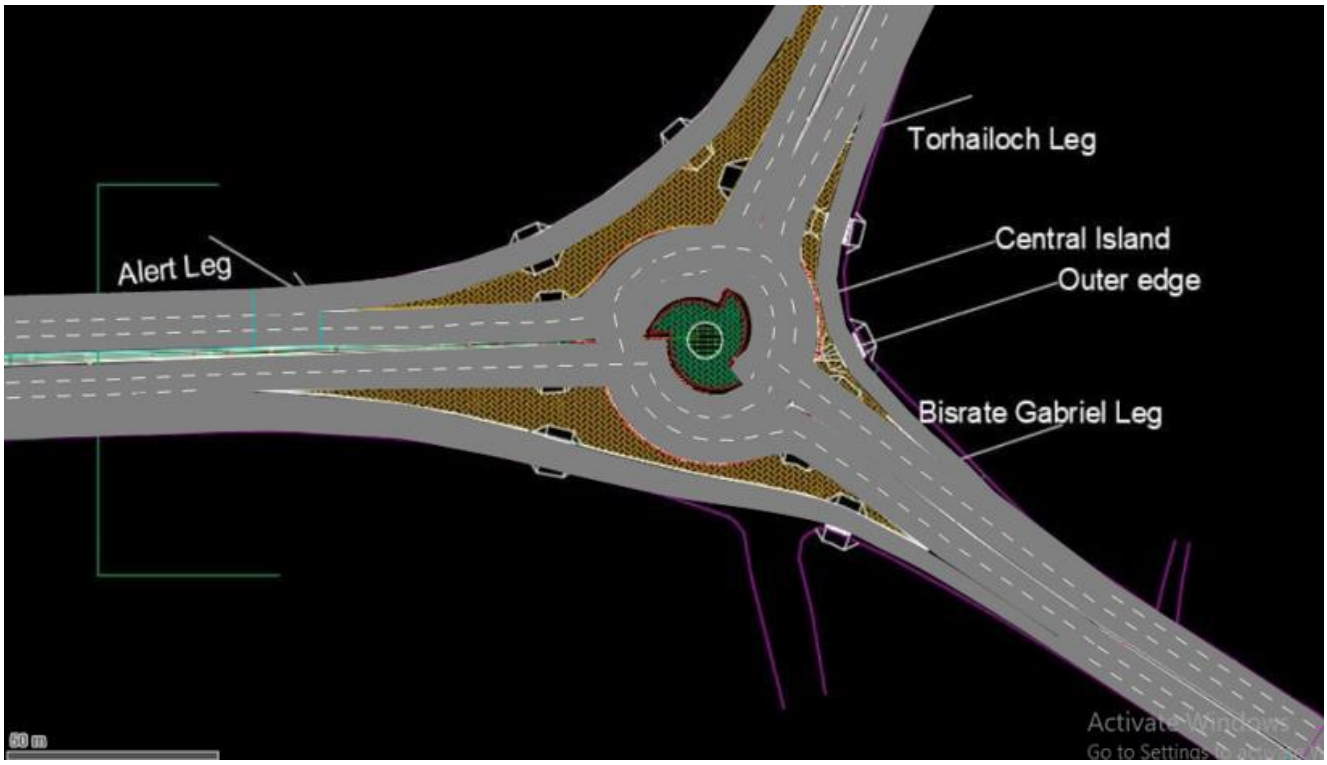

Figure6. Total Roundabout Vissim Model

Figure7. Zenebework Roundabout Vissim Model

Appendix D: Question nary

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

Road & Transport Engineering

Appreciate you taking the time to answer the following question. This questionnaire is intended to collect information about the Traffic Congestion under the title "Assessment of the socio-economical impact of traffic congestion in Addis Ababa A Case Study of Welete-Total. This questionnaire will only be used for research at and will not be used for any other purpose.

Sincerely yours.

Instruction: Please answer all questions by putting an "☑" mark on your choice and write your opinion for others. Write your opinions on some of the questions you are requested. You do not need to write your name.

Section A: Personal details

1. Gender:

☐ Male ☐ Female

2. Age Group (Years):

☐ Under 20 ☐ 40 to 49 ☐ 21 – 29 ☐50 to 59 ☐30 – 39 ☐ Above 60

3. Marital status

☐ Single ☐ Married ☐ Divorced ☐ Widowed

4. Level of education:

☐ None ☐ Secondary Education ☐ Primary Education ☐ Higher Level Education

Other: Please specify ……

5. Your occupation:

☐ Student ☐ Private employed

☐ Self-employed ☐ Public employed ☐ Retired

Other: Please specify……

Section B: Question

1. What is the mode of travel you most often use in your day to day activity?

☐ Personal/private vehicle ☐ Public transport ☐ Freight Vehicles

Other: Please specify……

2. What is your usual departure time from home?

☐ Before 11:30am ☐ 11:30-12:00am ☐ 12:00-1:00am

☐ 1:00-2:00am ☐ 2:00-3:00am ☐ after 3:00am

Other: Please specify……

3. What is your usual arrival time to home

☐ Before 11:30pm ☐ 11:30-12:00pm ☐ 12:00-1:00pm

☐ 1:00-2:00pm ☐2:00-3:00pm ☐ after 3:00pm

4. What is the distance between your home and workplace?

☐ 1-10 kilometers ☐ 10-20 kilometers

☐ 20- 40 kilometers ☐ more than 40 kilometers

Other: Please specify……

5. Do you change your departure time to avoid possible traffic congestion?

☐Yes ☐ No

6. Do you change your normal route to avoid possible traffic congestion?

☐ Yes ☐ No

Section C: Cause and Effect

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
What are the causes of congestion?					
Poor traffic management					
Inadequate Road capacity					
Illegal Parking					
Traffic incidents/accidents					
Uncivil driver behavior					
presence of too many pedestrians					
Increasing no of private vehicle owners					
Illegal road side marketing					
Presence of more large truck (good vehicle)					
Poor road design					
What are the effects of congestion?					
Health Risk					
Increase stress levels and fatigue					
Constrain societal relations					
Early wake up and late arrival					
Increased accidents and incidences					

The cost transport increases with the increase in traffic congestion					
Inability to estimate travel times					
Missing appointments and late delivery of goods and services.					
Blocks the way for emergency vehicles and increase response time					
Diversion on the local road networks					

Section D: Solution

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Solution to traffic congestion					
Expand the capacity of the road					
Increase no of public transport					
Introduce better traffic management system					
Ban good vehicles movement during peak hour					
Redesign the intersections					
Ban illegal road side marketing					
Allocate different travel time for student					
Design pedestrian lane					
Parking restriction					

Construct alternative road network					
Increase green time at signalized intersection					

Please specify if you have any other opinion, to mitigate the problem of traffic congestion along Welete - Total road segment? .....

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Thank you very much!!