ASSESSEMENT ON THE CHALLENGES AND EFFECTIVENESS OF PEAK HOUR TRAFFIC MANAGEMENT IN ADDIS ABABA: A CASE STUDY FROM MEGENAGNA TO AYAT ROAD

MSc. THESIS

ASTEWAY MEKONNEN TENAW

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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ASTEWAY MEKONNEN TENAW

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ADVISORS' APPROVAL SHEET

This is to certify that the thesis entitled **"ASSESSEMENT ON THE CHALLENGES AND EFFECTIVENESS OF PEAK HOUR TRAFFIC MANAGEMENT IN ADDIS ABABA: A CASE STUDY FROM MEGENAGNA TO AYAT ROAD"** submitted in partial fulfillment of the requirements for the degree of **Masters of science** with specialization in **Road and Transport Engineering,** the Graduate Program of the **Department of Civil Engineering,** and has been carried out by **Asteway Mekonnen** (ID. No. **GPRoTrR/003/11),** under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Prof. J.P Narayan	____________________	_________________
Name of Major Advisor	Signature	Date
Mrs. Tigist Assefa (MSc.)	____________________	_________________
Name of Co-advisor	Signature	Date

EXAMINERS' APPROVAL SHEET

We, the undersigned, members of the Board of Examiners of the final open defense by Asteway Mekonnen have read and evaluated his thesis entitled **"ASSESSEMENT ON THE CHALLENGES AND EFFECTIVENESS OF PEAK HOUR TRAFFIC MANAGEMENT IN ADDIS ABABA: A CASE STUDY FROM MEGENAGNA TO AYAT ROAD"**, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

Prof. J.P Narayan	________________	________________
Name of Advisor	Signature	Date
Dr. Moltot Zewde	________________	________________
Name of Internal Examiner	Signature	Date
Dr. Robeam Solomon	________________	________________
Name of External Examiner	Signature	Date
Mr. Daniel Chufamo (MSc.)	________________	________________
Name of Chair Person	Signature	Date
____________________	________________	________________
SGS Approval	Signature	Date

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I hereby declare that this MSc thesis entitled **"ASSESSEMENT ON THE CHALLENGES AND EFFECTIVENESS OF PEAK HOUR TRAFFIC MANAGEMENT IN ADDIS ABABA: A CASE STUDY FROM MEGENAGNA TO AYAT ROAD"** is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name: **Asteway Mekonnen**

Email: astemak234@gmail.com

Phone: +251-912-89-61-45

Hawassa University, Ethiopia

Signature: _______________

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ABBREVIATIONS

AALRT:	Addis Ababa Light Rail Transit
CBD:	Central Business District
DHV:	Design Hourly Volume
DDHV:	Design Demand Hourly Volume
EOT:	Extension of Time
FTA:	Federal Transport Authority
HCM:	Highway Capacity Manual
LOS:	Level of Service
PCU/E:	Passenger Car Unit / Equivalent
PHF:	Peak Hour Factor
V/C:	Volume to Capacity Ratio
VMT:	Vehicles Miles Travelled

ABSTRACT

Beside the construction of a high quality road network, managing operational performance of the highway system directly increases a nation's economic output by reducing travel time and costs. The Addis Ababa Traffic Management Agency tries to implement different remedial measures on the city arterials which aim to improve their operational performance; especially during the day's peak period. Measuring the challenges and effectiveness of those management practices in the capital is the focus and novelty of this research. Due to its representative nature with two ways and an eight lane geometric feature, the route from Megenagna to Ayat is selected as a cases study. Observations like congestion pattern, video recording, direct field measurements and secondary data were the main sources for the analysis. Volume to capacity ratio analysis method was used to measure the existing operating performance of the route. The method of queue and delay analysis in working zone areas was used to quantify the delay on the route. Results from the performance analysis shows that, congestion is a concept beyond the serving capacity of roadway facilities. Even though the maximum traffic flow exhibited is only 80% of the road segments capacity, results from the queue analysis shows 255 veh-hr vehicles in waiting to traverse the segment. The delay analysis also shows a need of extra 13.74 minutes to clear the queued vehicles. Interruption from pedestrians and diverted vehicles, bottleneck geometrical features and safety conditions are the main identified challenges of the traffic management practice. Implementing the reversible lane as a remedy helps in diverting up to 21.22% of the peak traffic to the less congested direction and decreased the time loss by 1.67 minutes. Regulating the random crossing pattern of pedestrians, cycle time increment of traffic light on specific segments and restricting usage of on street parking during peak periods are proposed recommendation to improve the traffic flow.

Key words: Traffic congestion, Directional distribution, Peak hour, Reversible lane.

1. INTRODUCTION

1.1 Background of the Study

Transportation is an essential element in the economic development of a society. Without good transportation, a nation or region cannot achieve the maximum use of its natural resources or the maximum productivity of its people. Progress in transportation has a great influence both in human lives and environmental damage, and it is the responsibility of the transportation engineer working with the public body to develop high quality transportation consistent with available funds and social policy and to minimize damage (Garber and Hoel, 2009).

A high urbanization rate in combination with the intense desire for car ownership in developing countries causes a rapid growth of motorization. When the economy continues to develop and private car ownership grows, persistent daily congestion has been exponentially increasing during recent years, especially along major corridors. The volume can be at, near or even beyond capacity during extended periods, or in some cases, the entire day (Gakenheimer, 1999). This rapid growth in the traffic movement may leads to congestion and required for a transport management system on the roadway network. Traffic congestion continues to remain a major problem in most cities around the world, especially in developing regions resulting in massive delays, increased fuel wastage and monetary losses. Due to the poorly planned road networks, illegal use of roads a common outcome in many developing regions is the presence of small critical areas which are common hot-spots for congestion; poor traffic management around these hotspots potentially results in elongated traffic jams (Subramanian, 2012).

The main purpose of implementing the traffic management practices are improving the safety and flow of traffic, reducing traffic emissions and improving the capacity of the roadway arterials to utilize effectively. Globally, the strategies to deal with traffic congestion can be categorized into supply-side and demand-side (Downs, 2004). The supply-side strategies consist of building new roads or expansion of existing roads to increase carrying capacity of the network. The demand-side strategy focuses on improving efficiency of public transport and non-motorized traffic, and harnessing advanced traffic management and traffic control.

For many decades, building more capacity was essentially the default response to traffic congestion. It is a simple response to the problem of demand exceeding supply. However, by the 1990s criticism of this approach began to mount as increases in the roadway capacity often, in the medium to long term, led to even greater increases in demand for road space, calling into question its overall effectiveness as a strategy (Downs, 2004).

Worldwide the most common practice for reversible lane operation is manual or mixed-time control. While in the first case it is particularly difficult for a human operator to evaluate the costs incurred by the transition period, in the second case, typically, a static problem of lane reversal is solved. These types of operation very often result in too early or too late reversal which have a negative effect on system performance. A number of real-time tidal flow strategies have been proposed for urban arterials, for motorways or in interrupted facilities, or both. Currently, many sites employ tidal flow operations including the A38(M) Aston Expressway (Birmingham, UK), A15 Canwick Road (Lincoln, UK), A61 London Road (Sheffield, UK) (Wolshon and Lambert, 2006).

Addis Ababa the capital and major economic center of Ethiopia has a large concentration of motorized vehicles. The capital experiencing continued growth and change. But due to the fact that a greater numbers of the vehicles are operated in the city, traffic congestion becomes crucial issues. Traffic congestion has been a long standing problem in many routes of the city, but it poses particular problem in roads that highly served the commuting activity (Hagere, 2014). Measuring the challenges and effectiveness of tidal traffic management practice in the capital is the main objective of the research.

The study tried to investigate how the selected street is operating during peak hours by taking appropriate field survey on the traffic volume and try to assess the challenge of the remedy in a way to achieve the expected goal. The selected route highly used by the commuter community. Since the commuting activity mainly holds during the morning and afternoon peaks the roadway segment congested especially during those periods. Wide residential settlement, presence of construction activities, commercial building presences, the presence of governmental and non-governmental institutions around the roadway and business activities involved on the route are highly influence the mobility on the area.

1.2 Statement of the Problem

In urban areas, the morning peak traffic is typically inbound towards the central business district of the city with relatively low outward-bound flows, whereas the afternoon peak is in the reverse direction. A road is expected to accommodate the major flow in both directions by providing appropriate design flow parameters and a better traffic management system. Especially for developing countries like Ethiopia, where their economic development not allow rapid expansion of roadway network, managing urban traffic has a vital role in their economic improvement. In comparing with other cities of the nation, the large numbers of motor vehicles are found in Addis Ababa with a total share of 63.19% (FTA, 2016). Despite the intensive road network expansion in Addis Ababa, road traffic congestion during peak hours has been a major problem in the city. In order to overcome these difficulties, the Addis Ababa Traffic Management Agency tries to implement different remedial measures on the city arterials. One of the solutions taken is applying the reversible flow lane concept to distribute the traffic in opposite lane of the road segment during the peak hour flows that aims to decrease the congestion on the selected route (i.e. from Megenagna to Ayat). Besides measuring the challenge and effectiveness of the remedy, the study tried to propose recommendations based on the finding results. This help to manage peak hour flows in the selected lanes and also makes the remedial measure an attractive alternative for solving peak periods traffic congestion.

1.3 Objectives of the Study

1.3.1 General objective

The general objective of the study is assessment on the challenges and effectiveness of peak hour’s traffic management practice in Addis Ababa.

1.3.2 Specific objectives

- To evaluate the existed performance of the route with and without the congestion management practice;
- To assess the challenges of peak hours traffic congestion management practice in the selected route;
- To evaluate the effectiveness of peak periods traffic congestion management practice in the selected route.

1.4 Research Questions

The study tries to answers the following questions:

- How the congestion trend and the directional distribution differ between the two ways during the stated peak and off peak periods?
- What are the challenges facing the reversible flow lane operation in improving peak hour performance of the roadway?
- How the applied mitigation measure helps in improving the capacity and decreasing delay on the roadway?

1.5 Significance of the Study

Despite assessing the challenges and effectiveness of the peak hour's traffic management practice implemented in the selected road segment, the study will tries to provide insights for the future strategy to the improvement plan of traffic management system on the capital. At the end, the major finding of the study helps in, providing a tangible information on the existing performance of the selected route which guide the policy makers and concerned professionals in driving the solution, identifying the challenges and their improvement method for the implemented congestion remedial measure, providing the trend change on traffic congestion and the need for EOT in the reversible lane, determining the level of pedestrian crossing and geometric features impact on the directional distribution system and giving an insight on areas which require further investigation whether in revising or improving an act of the traffic management practice on the city.

1.6 Scope of the Study

Even though Addis Ababa has a number of arterials which have a great congestion problem, due to time limitation and budget constraints the study will mainly focuses on the selected route (i.e. Megenagna to Ayat). The selected route has representative nature with two way multilane geometric feature and accessed widely by the commuter community towards the CBD of the capital. Furthermore, the analysis was segment based rather than area wide or regional study. Hence, it focuses mainly on the road segments the relative effect of consecutive intersection was not discussed. The selected route is divided into three segments in order to assess the existed capacity and its increment by the reversible lane. Even though, the scope of the research is limited to specific locations, it is expected to provide the general idea to have convenient traffic management system in the city arterials. Time and budget constraints also limit scope of the study.

2. LITERATURE REVIEW

2.1 General Overview

One of the significance is the traffic congestion issue as a global phenomenon in the management of capital cities, giving the level of population and activity concentration. United Nations first reported the urban population dominance in 2010, revealing that urban areas are home to 3.5 billion nearly 50 percent of world's population and cities population is expected to increase to 5.2 billion in 2050 (Mahmassani et al., 2012). Thus, a review of various theories and empirical literature relevant to the assessment on mitigating road traffic congestion especially during peak periods were expected to done to get relevance information and conceptual frame in tackling the effect. Traffic management practices required to improve the movements of people and goods; to ensure efficient and safe access and distribution; alleviate traffic congestion and adverse traffic impacts arising from major land use developments. Traffic management could be regarded as a systematic and sustained effort on directing and controlling all traffics on our roads to make them free from negative effects of the transport system.

According to (Hagere, 2014) traffic management is considered as a means of optimizing the available road network in accord with specified objectives as dictated by the prevailing local issues. More recently the emphasis has moved away from simple capacity improvements to accident reduction, demand restraint, public transport priority, environmental improvement and restoring the ability to move around safely and freely on foot and by pedal cycle. Hence traffic management arose from the need to maximize the capacity of existing road networks within finite budgets and, with a minimum of new construction. To cope with the situation, it is imperative to ensure proper use of available facilities and develop infrastructure through optimum utilization of resources.

2.2 Definition of Traffic Congestion

The (European Conference of Transport Ministers, 2007) stated that, there is no single, broadly accepted definition of traffic congestion. One of the principal reasons for this lack of consensus is that congestion is both: a physical phenomenon relating to the manner in which vehicles impede each other's progression as demand for limited road space approaches full capacity. Conversely, congestion can be perceived as a relative phenomenon relating to user expectations from road system performance. Consequently, both operational and user perspectives are important in understanding congestion and its impacts. In this respect, they recommends that, transport policies should be developed on the basis that congestion is related to both the behavior of traffic as it nears the physical capacity of the road system, as well as the difference between road users' expectations of the system's performance and how the system actually performs.

Traffic congestion may be simply defined as the situation that arises when road and rail networks are no longer capable of accommodating the volume of movements that occur on them (Turton & Knowles, 1982). The location of congested areas within a town is determined by the physical transport framework and by the patterns of land use and their associated trip generating activities. The level of traffic over loading will also vary in time, with a particularly well–marked peak during the daily journeys-to-work periods (Afukaar, 2003).

According to (Turton and Knowles, 1982) although congestion on urban roads is largely attributable to overloading, there are other aspects of this basic problem that also require solutions. In industrialized nations increasing volumes of private car, public transport and commercial vehicle traffic have exposed the inadequacies of urban road systems, particularly in city centers where street patterns have often survived largely unaltered from the nineteenth century and earlier.

In evaluating level of traffic congestion on certain roads of Addis Ababa, (Solomon, 2007) discusses the critical parameters that mainly use in characterizing road way traffic congestions as: capacity, demand, level of service, service flow rate and performance measure.

2.3 Types of Traffic Congestion

The two types of congestion are outlined as recurrent congestion and non-recurrent congestion. These types are based upon the frequency and predictability of the congestion the factors which are capable to impact on driver behavior. The costs associated with each type of congestion are likely to be different. Non-recurrent congestion costs may be more difficult to quantify due to the inherent sparseness of adequate amounts of data needed. It may be argued that the costs could be higher as drivers have not been able to take the possibility of congestion into account in planning their journey or alternatively the costs not have come into play. Some routes are increasingly subject to non-recurrent congestion, for example with accident black spots. In these cases drivers may "learn‟ an expected cost in terms of likely delay and successful contingency routes (Laird et al., 2005).

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

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

2.4 Causes of Traffic Congestion

Traffic congestion is caused by different factors. According to (Schrank et al., 2014) the causes of traffic congestion are: movement of people and lots of freight at the same time, the slow growth in infrastructure supply and trips to be delayed by events that are irregular. However, frequent crashes, vehicle breakdowns, improperly timed traffic signals; special events and weather are factors that cause a variety of traffic congestion problems.

In addition, a research done by (Mahmud et al., 2012) summarizes the major causes of traffic congestion as follows:

- Narrow roads- Streets are not that wide spread, due to illegal possession on the road they are getting narrow and becoming a reason behind traffic jam. So, every possibility is there to expand the road as per their right- of- way to reduce traffic congestion. Moreover this will be less expensive and less time consuming due to land acquisition that won't be required in this process.
- Illegal Parking- Illegal parking on the road has been creating congestion every day. On-road parking of vehicles is one of the main reasons behind serious traffic congestion on different parts of the routes.
- Increasing number of population- All the areas under cities is facing an increasing number of populations which is a bad indicator for the traffic management and this could be a vital reason behind traffic.
- Higher purchasing power of the public - Due to the higher purchasing power of the citizen of cities, the popularity of private transportation is increasing and but existing roads and highways are not supportive or changing according to the increasing number of vehicle. As a result vehicle congestion is increasing at an alarming rate.
- Improper planning of city development- Development Plan has its long term city development planning. However, that planning is not proper. Most of the time it is seen that some illegally ceased roadside land, but due to the vague development plan these kinds of movements are going in vain.
- Improper lane management- Lane management is an important fact in managing the traffic. Many types of the vehicles try to overtake other vehicles even in the single undivided road. This is the main reason that the city roads are unequipped with the lane dividers which divide the lane into incoming and outgoing traffic.

2.5 Impact of Traffic Congestion

Congestion involves queuing, slower speeds and increased travel times, which impose costs on the economy and generate multiple impacts on urban regions and their inhabitants. Congestion also has a range of indirect impacts including the marginal environmental and resource impacts of congestion, impacts on quality of life, stress, and safety as well as impacts on non-vehicular road space users such as the users of sidewalks and road frontage properties. The impacts of traffic congestion can be viewed in three ways: impact on economy, impact on health, and impact on environment. Traffic congestion has great economic impact due the society losing money in four ways as shown below (Mahmud et al., 2012):

- ❖ Loosing man-hours;
- ❖ Extra transportation cost;
- ❖ Extra fuel consumptions;
- ❖ Vehicle operating cost; and
- ❖ Miscellaneous cost.

Traffic congestion mainly affects the following groups:

- ❖ General peoples- Most People are suffering some kind of physical or mental discomfort due to traffic congestion and some ways of suffering are listed as follows: Breathing problem, headache, mental stress, hearing problem, unexpected sweating, tiredness, and eye problem.
- ❖ Vehicle operators- The ways of sufferings for the vehicle operators are almost similar to other people. The main sufferings due to traffic congestion are: headache, pain in the body, and excessive sweating.

Traffic congestion impacts on the environment can be viewed it two ways as sound pollution and air pollution causes environmental pollution in two main ways. The effects of sound pollution are: students in the nearby school are disrupted their study by noise and to the nearby society causes headache difficulty in concentration and sleeping, bad tempers, and experiences hearing problems. So, air pollution increases as traffic becomes congested when vehicles stop for a longer periods of time and their engine is on operation, they highly emit greenhouse gasses which are lighter than air but very dangerous for our health and they even can cause death (Mahmud et al., 2012).

As a result of traffic congestion, the following classes of trips are affected according to United States National Cooperative Highway Research Program (NCHRP Reports 463, 2011)

- Commuting (Home-Work Car Trips);
- Regional Freight Delivery (Work-to-Work Internal Truck Trips);
- Interregional Freight Delivery (Work-to-Work External Truck Trips);
- Regional Service Delivery (Work-to-Work Non commodity Trips);
- Personal Travel (Home-Based Non-work Trips).

Congestion has different impacts within the society. Congestion involves queuing, slower speeds and increased travel times, which impose costs on the economy and generate multiple impacts on urban regions and their inhabitants. Congestion also has a range of indirect impacts including the marginal environmental and resource impacts of congestion, impacts on quality of life, stress, safety as well as impacts on non-vehicular road space users such as the users of sidewalks and road frontage properties (European Conference of Ministers of Transport, 2007). Congestion impairs us from moving freely and that it disrupts business activities in cities and reduces productivity. It affects a wide range of activities, services, goods, markets opportunities in the cities which can best be delivered through transport mobility. The report continues that 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.

2.6 Measuring Traffic Congestion

Mainly traffic congestion measures are grouped into five categories: Time-related measures, Volume measures, Congestion indices, Delay measures, and LOS measures (Williams et al., 2011). To measure the effectiveness of the tidal flow lane the capacity to volume computation and level of service measures are used (Mahmassani et al., 2012). Each of the categories and measures is described in more detail below.

2.6.1 Time related measures

Time-related measures, which include travel time and travel rate, are widely used to evaluate congestion. One key reason is that measurement of the time it takes to travel a particular distance can be done repeatedly and can apply to all modes of travel, including the movement of goods. Travel times are the primary means of measuring performance in several ongoing intelligent vehicle-highway system–related research projects including Houston's Real-Time Traffic Information System, which uses both cellular telephone reporting and automatic vehicle identification techniques to record travel times.

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

Origin-destination travel times is an output of the traffic assignment process of travel demand modeling, defined as the estimated time necessary to travel from an originating zone to a destination zone of a given highway network. These travel times can be estimated by calculating minimum time path skim trees.

Percentage of time average speed is below threshold value. This spot-speed measure uses information collected from automated speed monitoring equipment. The measure uses data that can be collected in a completely automated fashion, with an increase in the value of this measure corresponding unambiguously to an increase in the degree of congestion (Lomax et al., 1997).

2.6.2 Volume measures

The wide availability of traffic volume counts and vehicle miles traveled (VMT) data make volume measures attractive to use. Because volume is a representation of the level of demand, it is often compared with the available supply, and this relationship is typically expressed in terms of a volume to-capacity ratio (V/C). It should be noted that VMT, an important measure for the purposes of air-quality analysis, is not a strong measure of congestion by itself. Density, which is also a measure of congestion, is a function of both volume and speed on a roadway segment of a given length and is directly related to freeway LOS (Mahmassani et al., 2012).

2.6.3 Congestion index

This index is a system wide measure of congestion on the street and freeway system. The roadway congestion index uses daily VMT per lane mile of roadway for both freeways and principal arterial streets within an empirically derived formula. The index equation weighs the daily VMT per lane mile values for the two functional classes by their respective daily VMT, which is then normalized by daily VMT per lane miles representing the threshold of congestion (Rodrigure et al., 2006).

2.6.4 Delay measures

Delays of any type increase travel time and reduce travel speeds. As such, measures of delay are closely tied to time related measures. By focusing on delay as a performance measure, specific problem locations or areas can be identified whether they are recurring or nonrecurring. A number of recent studies, focused on nonrecurring congestion, have demonstrated the importance of incident-related delays and the benefits that can be derived from their reduction. Delay is the difference between desired or free flow and actual travel time is considered a good measure of congestion intensity on a roadway link or in an overall system. However, this measure does not give much insight into the specific causes of congestion. A minute mile of delay is the product of the length of a roadway segment and the difference between an acceptable travel rate and the actual travel ratio (where the actual travel ratio is equivalent to 60 minutes divided by the speed on the segment) (Schrank et al., 2014).

2.6.5 Level of service measure (LOS)

Highway Capacity Manual (HCM, 2010) defined "Level of Service" (L.O.S.) as a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience. Highway capacity manual (HCM) developed by the transportation research board of USA provides some procedure to determine level of service. It divides the quality of traffic into six levels ranging from level A to level F. Level of service A represents the zone of free flow. Here the traffic volume will be less; traffic will be experiencing free flow. Level of service B represents zone of reasonably free flow; free flow speeds are still maintained at this level of service. The drivers freedom to choose their desired speed is only slightly restricted. At level of service C, the presence of other vehicles begins to restrict the maneuverability within the traffic stream. At level of service D, the average speeds begin to decline with increasing flows. Freedom to maneuver within the traffic stream is noticeably restricted. Level of service E defines operation at capacity. At this level, the stream reaches its maximum density limit. Finally, Level of service F describes conditions in a queue that has formed behind a point of breakdown or disruption (Keeler, 1994). Traffic congestion impacts can be measured based on roadway volume to capacity ratios (V/C). A V/C less than 0.85 is considered under-capacity, 0.85 to 0.95 is considered near capacity, 0.95 to 1.0 is considered at capacity, and over 1.0 is considered over-capacity (Fasika, 2015). Congestion is a non-linear function, so as a road approaches its maximum capacity, small changes in traffic volumes can cause proportionately larger changes in congestion delays (HCM, 2000).

Moreover, according to (Lomax and et al., 1997) the road user's perception as a measure for "acceptable" or "Unacceptable" congestion can be taken as an indicator or a demarcation for classifying a road section or an intersection as congested or not. The assigned primary performance measure which is used to provide an estimate of level of service is density. The three measures of speed, density, and flow or volume are interrelated. When values for two of these measures are known, a value for the remaining measure can be computed. Level of Service (LOS) is a qualitative measure describing operational conditions with in a traffic stream, generally in terms of such service measures as speed and travel time, and comfort and convenience.

2.7 Traffic Congestion Mitigation Measures

Mainly traffic congestion is a consequence of disparity between transportation demand and supply. Demand for transportation in urban areas is an increasing phenomenon for the continuous increase in urban population and economic activities lagging behind the transportation supply. As a result, traffic congestion has already become a part of urban transportation system. Such traffic congestion not only causes problems to urban transportation activities but also causes degradation to natural environment by increasing the magnitude and intensity of air pollution. Efforts to eliminate traffic congestion completely from the transportation network may be unrealistic; rather the way to minimize traffic congestion is a challenge for stakeholders in the road transport sector.

United States Department of Transportation Federal Highway Administration (1998) stated that, the key strategies to address congestion are the following:

- Adding more capacity for highway, transit and railroads;
- Operating existing capacity more efficiently; and
- Encouraging travelers to use the system in less congestion-producing ways.

But, increase in road capacity by adding more lanes, grade separated intersection may not mitigate traffic congestion since it induces additional traffic. Traffic grows when roads are uncongested, but growth declines as congestion develop, reaching a self-limiting equilibrium. If capacity increases, traffic volumes grow again until they reach a new equilibrium (Grant-Muller and Laird, 2007).

In finding a way to coping with peak hour traffic congestion (Downs, 2004) asserted that, traffic congestion mitigation strategies fall into two broad categories: supply strategies and demand strategies. Supply strategies focus on increasing the supply of transportation capacity. Examples include expanding roadway capacity and expanding transit capacity. Demand strategies focus on influencing demand for capacity such as increasing residential densities, using toll ways, and using ramp metering.

2.7.1 Supply strategies

- **Expand roadway capacity**

Expanding roadway capacity is often the default action for dealing with traffic congestion by transportation agencies, politicians, and other decision makers. Proponents of this strategy often argue that increasing the capacity of roadways is the only effective solution for mitigating traffic congestion (Balacker and Staley, 2006). There is some evidence to indicate that expanding roadway capacity leads to a short-term reduction in the severity of traffic congestion. For instance, (Balacker and Staley, 2006) reported that Houston Texas reduced average annual travel delay per commuter by 50% between 1986 and 1992, while nearly quadrupling the number of freeway lane miles built during this period. Likewise (Derrick, 2013) reported that, average annual travel delay for San Francisco Bay Area commuters fell 32% between 2006 and 2009 as freeway capacity in the region increased during this period. However, both of these reports were merely observations by the authors. Neither report employed analysis techniques such as regression analysis to isolate what amount of the reduction that actually came from expanding capacity versus other factors such as the unemployment rate or the rate of population growth or decline in these cities. When regression analysis is applied, the results are less significant. For instance (Cervero, 2001) found that, a 10% increase in freeway lane miles increased freeway speeds by 4.2%. Furthermore, the benefits of expanded capacity can be quite small, relative to the costs of expansion. He explained that the relative ineffectiveness of reducing traffic congestion through roadway expansion is a consequence of induced demand. According to him, expanding roadway capacity in a congested corridor decreases travel times and increases travel speeds along that roadway during peak periods. However, these travel time and speed improvements attract more drivers to the corridor as the cost to the driver for entering the expanded roadway during peak periods declines.

- **Expand transit capacity**

Expanding transit capacity increases transportation supply in two ways. First, it expands the supply of public transportation system in terms of its ability to transport additional passengers. Second, it can increase roadway capacity by shifting some trips from the roadway onto public transportation instead. The latter is where the potential traffic congestion reduction comes into effect. In analyzing urban traffic volume (Kim et al., 2008) conducted a case study on Minneapolis-St. Paul, assessing traffic volumes eight years prior to the opening of a Light Rail Transit System in the metro area, and two years following the opening in 2004. The researchers found that the Twin Cities experienced a steady rise in traffic volumes of 4.65% annually, on major freeway systems in the metro area, in the ten years of study, but saw the rate of increase in traffic volumes fall by 2.1% in the first year and 4.3% in second year after the opening in 2004. Unfortunately, because the authors did not control for other factors that could have played a role in the reduction of traffic volumes increases such as the percentage of population over the age of 65, the unemployment rate, and population growth or decline. It is therefore difficult to discern the degree in which the expansion of the transit capacity attributed to the decline in traffic volumes increases in the metro area. However, using regression analysis to control for many of these factors (Duranton and Turner, 2011) found that, public transportation had no discernible effect on travel demand. Some of the studies on the effect of transit systems have attempted to estimate the difference in the severity of traffic congestion in a given areas if transit systems were shutdown. The often-cited annual studies by the Texas Transportation Institute try to estimate the costs of traffic congestion in the absence of public transportation systems. In developing a total peak period travel time (Shrank et al., 2014) estimated that, if transit systems were shut down nationwide traffic congestion would worsen considerably, with nearly a 17% increase in aggregate travel delay, equal to 796 million additional hours of delay. The study suggested that transit systems can reduce the severity of traffic congestion in an area, as some people who would ordinarily drive in the absence of transit systems choose to transit systems instead, but does not indicate whether expansion of existing transit systems would further reduce congestion.

2.7.2 Demand strategies

- **Use of toll ways**

Toll ways have received a lot of attention over the last couple of decades, particularly from economists, as an effective strategy to combat traffic congestion. In evaluating the impacts of value priced express lanes (Sullivan, 2000) studied one of the better-known toll ways, the SR-91 HOT lanes in California, over a five-year period after its opening in 1995. Sullivan found that within six months of the HOT lanes opening in 1995, evening peak period travel delay fell significantly from an average of 30-45 minutes to 5-10 minutes. The author noted, however, that towards the end of the study, in late 1999, evening peak period travel delay had risen to an average of 30 minutes, concluding that flexible pricing based on demand had failed to reduce this rise in delay.

Most of the studies regarding toll ways have focused on specific unit level analysis (e.g., looking at the impact of a toll way on a specific roadway or adjacent roadway). Both (Downs, 2004) and (Stopher, 2004) acknowledge the short-term effectiveness of toll ways, but raised concerns about the long-term effectiveness of the strategy. Downs argued that toll ways often do not raise toll prices sufficiently to mitigate traffic congestion in the long run, often because of political pressures. Similarly, Stopher contended that in the long run rising increases in wealth and demand from a growing population would likely erode any gains from toll ways without continued price increases. These concerns have been somewhat supported by (Sullivan's, 2000) study, which saw most of the reductions in travel delay, as a result of the SR-91 HOT lanes, erased within four years of their opening.

- **Use of ramp metering**

Ramp metering has offered a comparatively inexpensive way to manage freeway demand and assuage traffic congestion. There is strong evidence of the effectiveness of ramp metering in reducing congestion, but a somewhat limited amount of recent study on ramp metering. (Kang and Gillen, 1999) noted that, most ramp metering studies are outdated (many performed in the 1980s or before) and failed to account for cost associated with ramp metering, such as ramp queues backing up onto main streets and/or lost time waiting on ramps. For instance, in a series of case studies conducted by (Piotrowicz and Robinson, 1995) of eight cities with ramp metering, the authors found on average that ramp metering increased freeway throughput (vehicles per hour) by 17-25% and travel speeds by 16-62%, from peak period conditions, but failed to account for any costs resulting from the metering.

A more recent study by (Kwon et al., 2006), used regression analysis to isolate the effect of ramp metering on traffic congestion over a six month period on I-880 in the Bay Area. The authors found that when controlling for traffic incidents, special events, rain, ramp metering, and excess demand, ramp metering reduced travel delay 33% during peak periods. Like research on toll ways, most of the literature on ramp metering has focused on unit level analysis. Few studies, outside of the Cambridge Systematics experiment, have attempted to study the system wide effect of ramp metering on traffic congestion.

- **Increase residential densities**

The central theory behind increasing residential densities as a strategy for reducing traffic congestion is that higher residential densities are better served by transit systems and are typically closer to services and amenities, allowing for alternate modes of travel (e.g., walking or biking). Some research indicates that higher residential densities lead to higher rates of transit use (Ewing et al., 2002). However, there is no consensus in the literature relating to effect of higher residential densities on traffic congestion, with research findings decidedly mixed. For instance, (Ewing et al., 2002) found that, a 25-unit increase in residential density resulted in a 5.4% decrease in VMT per capita, but had no effect on travel delay per capita. In contrast, (Sarzynski et al., 2006) found residential density and annual delay per capita to have a positive relationship (an increase in one leads to an increase in the other), with a one unit increase in residential density, equivalent to one standard deviation from the mean, increasing annual delay per capita by 2.38 hours. These findings by (Ewing et al., 2002) and (Sarzynski et al., 2006) suggest, that if people do not use their vehicles less frequently, increasing residential densities may actually worsen traffic congestion.

2.8 Peak hour's traffic congestion

Traffic volumes for an interval of time shorter than a day more appropriately reflect the operating conditions that should be used for design. The brief, but frequently repeated, rush-hour periods are significant in this regard. In nearly all cases, a practical and adequate time period is one hour. The traffic pattern on any highway shows considerable variation in traffic volumes during the various hours of the day and in hourly volumes throughout the year. A key design decision involves determining which of these hourly traffic volumes should be used as the basis for design. While it would be wasteful to predicate the design on the maximum peak-hour traffic that occurs during the year, the use of the average hourly traffic would result in an inadequate design. The hourly traffic volume used in design should be a value that will not be exceeded very often or by very much. On the other hand, it should not be a value so high that traffic would rarely be sufficient to make full use of the resulting facility. One guide in determining the hourly traffic volume that is best suited for use in design is a curve showing variation in hourly traffic volumes during the year (Lambert and Wolshon, 2010).

2.9 Peak Hours Traffic Congestion Mitigation Measure

2.9.1 The concept of reversible lane

A tidal flow lane is a reversible lane in which traffic may travel in either direction depending on the time of day or traffic condition. It is designed to improve traffic flow during peak periods by making an extra lane available for vehicle travel along the busier side of the road. The benefit of tidal flow (reversible lanes) operation is that the available capacity in each direction of traffic can be varied in response to highly directional inbound or out bound traffic flows. If there is no a median on the road, an odd number of lanes, usually three to seven lanes are required for effective tidal flow lane operation. The middle lane operates as a contra flow buffer zone to serve traffic in different directions which considered as an interchangeable lane. A drawback, however, is the cost to efficiently control reversible lanes and the confusion to drivers and safety (Konstantinos et al., 2018)

Reversible lanes are used to mitigate congestion caused by unbalanced directional traffic flow, especially during peak-hour. The outcome of a reversible lane is an improvement in directional flow volume. On a reversible lane, traffic can move in either direction, depending on time of day. Overhead signs are used to inform the direction of traffic flow for motorist. Recently, a new concept known as movable barrier system is being used to reorganize the alignment of roads according to the prevailing traffic demand. As the name suggests, the barriers are realigned by using a moving machine installed on to the truck that moves the heavy barriers from one side to other side. Major drawback of this process is, it takes a considerable amount of time for realignment of lanes. Reversible lanes take advantage of underutilized lanes by reorienting the direction of traffic flow at certain times of day. It is an interesting concept because reversible lanes can increase the capacity of a roadway significantly without major investments in roadway or control infrastructure (Lambert and Wolshon, 2010).

2.9.2 Operational Condition of Reversible lane

According to (Lambert and Wolshon 2010) the basic principle of a reversible lane is simple; however, its implementation needs clear planning for safe and efficient operation. Safety is a major hurdle in the implementation of reversible lanes. Reports suggest an increase of vehicle collisions in areas where reversible lanes are implemented. The primary cause of collisions is the driver's limitations of understanding and failure to follow the traffic rules as directed. Signs and pavement markings have to convey appropriate information to driver and must not lead to confusion that may result in wrong way driving, as is the case in most reversible lanes. Reversible lanes with enhanced safety features will be very helpful in optimizing directional traffic demand.

2.10 Practical Outcome of Reversible Lane

The American Association of State Highway and Transportation Officials (AASHTO, 2011) suggest that, 65 percentages or more traffic moving in a particular direction during peak hours justifies the application of reversible lanes. There are many computational studies done on reversible lanes, which reinforce the claim of adjusting the number of lanes in each direction depending upon traffic demand on hourly basis. However, the problem with the implementation of reversible lanes is the risk of safety of the commuters as there are chances of drivers getting confused leading to a dangerous traffic scenario. The modern advancement of reversible lanes leads to Dynamic Lane Reversal (Hausknecht et al., 2011). It is a concept by which the lane directionality is updated quickly and automatically in response to the instantaneous traffic conditions recorded by the traffic sensors. Matthew Hausknecht and his team studied the effectiveness of dynamic lane reversal by comparing the programming formulation of a standard approach and contra flow approach. Using integer linear programming formulation and bi-level programming formulation, they computed an optimum lane reversal configuration that increased the efficiency of the network by 72%. The major drawback in implementation of lane reversal is the method of communication, which informs the drivers about the present traffic scenario. According to a study by (Lambert and Wolshon, 2010) drivers tend to use normal-flow lane until it becomes more crowded, and then begin to move into the adjacent and less utilized reverse-flow lane. This shows the confidence levels of drivers pertaining to reversible lanes and its usage. It also suggests most of the drivers are comfortable in tailgating a car, which is already there instead of going alone. These drawbacks have to be overcome in order to pave a way for wider implementation of reversible lanes.

(Bede and Peter, 2011) perform a mathematical modeling of reversible lane system in Budapest, Hungary. The method defines a dynamic contact structure consisting of n parts inner sections and m part exterior sections. First the examinations hold on the morning and the afternoon peaks. In the second case they did the examinations with an already operating reversible lane. The analysis results are received on a 20 minute time interval. The results show, that the capacity growths by 20 percent in the morning peak and 30 percent in the afternoon peak for the full model's case. The result shows 26 percent growth for the whole day. In the morning peak the vehicle density decreases with activated reversible lane (left side). It is noticeable, that the traffic density on these sections reduced with 25, 33 and 87 percent, though the speed of the traffic has grown with 50, 48 and 12 percent on the same sections.

2.11 Directional Distribution

It is an indication of a tidal flow during the day peak periods. According to (Sharma and Reedy, 1992), the directional distribution is simply the distribution or split of the total traffic volume in two opposite directions during a particular time period. It is commonly expressed in terms of percentage of total traffic in the heavier direction of travel; therefore, the possible values of directional split vary from 50 percent to 100 percent. Directional distribution, when multiplied by design hour volume (DHV), results in directional design-hour volume (DDHV). Projections of the annual average daily traffic are multiplied by the design hour factor (i.e., K factor) and D factor, which correspond to a particular facility type, to obtain a future estimate of the major direction design hourly volume (DDHV) (Satish et al., 1992).

A multilane highway with a high percentage of traffic in one direction during the peak hours may need more lanes than a highway having the same ADT but with a lesser percentage of directional traffic. During peak hours on most rural highways, from 55 to 70 percent of the traffic is traveling in the peak direction, with up to as much as 80 percent occasionally. Directional distributions of traffic vary enough between sites that two multilane highways carrying equal traffic may have peak direction volumes that differ by as much as 60 percent. For example, consider a rural road with a design volume of 4,000 vph for both directions of travel combined. If during the design hour, the directional distribution is equally split, or

2,000 vph is one direction, two lanes in each direction may be adequate. If 80 percent of the DHV is in one direction, at least three lanes in each direction would be needed for the 3,200 vph; and if a 1,000-vehicles-per-lane criterion is applied, four lanes in each direction would be needed. The peak-hour traffic distribution by direction of travel is generally consistent from day to day and from year to year on a given rural road, except on some highways serving recreational areas. Except for urban highways, the directional distribution of traffic measured for current conditions may generally be assumed to apply to the DHV for the future year for which the facility is designed (Lambert and Wolshon, 2010).

2.12 Performance Measures for Congestion

2.12.1 Volume to capacity ratio

Traffic congestion impacts can be measured based on roadway volume to capacity ratios (V/C). A V/C less than 0.85 is considered under-capacity, 0.85 to 0.95 is considered near capacity, 0.95 to 1.0 is considered at capacity, and over 1.0 is considered over-capacity. Congestion is a non-linear function, so as a road approaches its maximum capacity, small changes in traffic volumes can cause proportionately larger changes in congestion and delays (Fasika, 2015).

The v/c ratio is a measure of capacity sufficiency, that is, whether or not the physical geometry and signal design provide sufficient capacity for the subject movement or movements. Delay is a measure of quality of service to the road user. Both must be analyzed to fully understand the anticipated operational characteristics of route under consideration, and neither can be substituted for the other (Layton, 1996).

2.12.2 Volume

The total number of vehicles that pass over a given point or section of a lane or roadway during a given time interval is called volume. It is the actual number of vehicle observed or predicted to passing a point during a given interval. It can be calculated on hourly, daily, weekly and annually based. Quantifying the vehicle flow should have to consider the vehicle occupancy of the road way. The concept of passenger car equivalence and passenger car units are introduced to know those proportions on the route.

The passenger car equivalence & Passenger car unit

Different vehicle types occupy different spaces on the road, move at different speeds, and start at different accelerations. The vehicles volume was counted in category as "Passengers car" and "Goods vehicles". The Passengers cars category includes vehicle types namely; Cars and Taxi, 4WD, Minibus Taxi, Mid-Bus and Standard Bus, whereas the Goods Vehicle category includes vehicle types namely; Small truck, Medium truck and Heavy trucks.

Furthermore, the behavior of drivers of the different types of vehicles may also vary considerably. A uniform measure of vehicles is thus necessary to estimate traffic volume and capacity of roads under mixed traffic flow. This is rather difficult to achieve unless the different vehicle types are stated in terms of a common standard vehicle unit. For these reasons, the concept of Passenger Car Unit (PCU) or Passenger Car Equivalent (PCE) was developed and it became a common practice to convert the other vehicle types into PCE_S or PCUs. It is generally expressed as PCU per hour, PCU per lane per hour, or PCU per kilometer length of lane (Rana and Mohit, 2016). The stated passenger car equivalent factors are shown in table 2.1.

Table 2.1: Passenger Car Equivalent factors Vehicle

			Passenger vehicle			**Goods vehicles**		
Vehicles Type	**Car & Taxi**	**4WD**	**Small bus**	**Medium bus**	**Large bus**	**Small track**	**Medium truck**	**Large truck**
PCU	1	1	1.5	1.5	3	1.5	3	3

Source: HCM 2000 and 2010

The Peak hour Factor

The accepted unit of time for expressing flow rate is a one-hour period. It is customary to design highways with a sufficient number of lanes and with other features that will enable the highway to accommodate the forecasted DHV for the design year, which is frequently 20 years from the date of construction. Because flow is not uniform throughout an hour, there are certain periods within an hour during which congestion is worse than at other times. The HCM considers operating conditions prevailing during the most congested 15-minute period of the hour to establish the service level for the hour as a whole. Accordingly, the total hourly volume that can be served without exceeding a specified degree of congestion is equal to or less than four times the maximum 15-minute count. The factor used to convert the rate of flow during the highest 15-minute period to the total hourly volume is the peak hour factor (PHF). The PHF may be described as the ratio of the total hourly volume to the number of vehicles during the highest 15-minute period multiplied by 4. The PHF is never greater than 1.00 and is normally within the range of 0.75 to 0.95. Thus, for example, if the maximum flow rate that can be served by a certain freeway without excessive congestion is 4,200 vehicles per hour during the peak 15-minute period, and further, if the PHF is 0.80, the total hourly volume that can be accommodated at that service level is 3,360 vehicles, or 80 percent of the traffic flow rate, during the most congested 15-minute period (Lambert and Wolshon, 2010).

2.12.3 Capacity

The capacity of a facility is the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions. Vehicle capacity is the maximum number of vehicles that can pass a given point during a specified period under prevailing roadway, traffic, and control conditions. Person capacity is the maximum number of persons that can pass a given point during a specified period under prevailing conditions. Person capacity is commonly used to evaluate public transit services, high-occupancy vehicle lanes, and pedestrian facilities.

Capacity analysis examines segments or points (such as signalized intersections) of a facility under uniform traffic, roadway, and control conditions. These conditions determine capacity;

therefore, segments with different prevailing conditions will have different capacities. Reasonable expectancy is the basis for defining capacity. That is, the stated capacity for a given facility is a flow rate that can be achieved repeatedly for peak periods of sufficient demand. Persons per hour, passenger cars per hour, and vehicles per hour are measures that can define capacity, depending on the type of facility and type of analysis. The concept of person flow is important in making strategic decisions about transportation modes in heavily traveled corridors and in defining the role of transit and high-occupancy vehicle priority treatments. Person capacity and person flow weigh each type of vehicle in the traffic streams by the number of occupants it carries (Layton, 1996).

2.12.4 Capacity in Multilane Highways

Multilane facilities are roads which have two or more lanes available for use for each direction of travel. A multilane facility may vary from undivided rural highways without access control to freeways, which are divided access-controlled facilities. Except where traffic is controlled by signals, measures of congestion on other multilane highways are similar to those for freeways. Where the interference with traffic from marginal development is slight, the traffic densities that result in acceptable degrees of congestion on freeways may also be served by other multilane highways. This situation is notably true in rural areas. In urban areas, the traffic volumes that can be served on other multilane highways, at acceptable levels of congestion, are generally somewhat lower than those for freeways (AASHTO, 2001).

United States National Cooperative Highway Research Program (NCHRP Report 825, 2017) recommends using the HCM method. The HCM method is recommended for capacity and LOS calculations.

The capacity and LOS for multilane highways can be calculated by using the formula

$$Capacity = Base\ capacity \times fhv \times Lanes \text{ .... Eqn. 2.1}$$

Where:

$Base\ capacity = 1000 + 20\ \times FFS; FOR\ FFS \leq 60\ Mile/hr\ \left(for\ \frac{\frac{pc}{h}}{lane}\right), 2{,}200\ Otherwise$

$$fhv = \frac{1}{(1+PT\times(ET-1))} \text{.............................. Eqn. 2.2}$$

Where:

fhv- Adjustment factor for heavy vehicle

ET- Passenger car equivalence for truck and bus 1.5 for level terrain (HCM, 2000)

PT- Proportion of truck and bus

(US Department of transportation, for highway performance monitoring system, 2017)

3. MATERIALS AND METHODS

3.1 Introduction

This chapter is about the methods that were used for collecting information in the field. It mainly explains how the study was conducted, the applied methods and techniques in data collection and the reasons as to why they were used according to the research aims and main objectives of the study. It also involves discussion of the research process, the selection of the study area, sampling methods and justification and sources of data used in the study. Analytical techniques used in analyzing the data for the study are also discussed.

3.2 Description of the Study Area

Addis Ababa is the capital, political, commercial, and industrial city of Ethiopia. It is where the African Union and its predecessor the OAU were based. The city has a number of arterials which have a great congestion problem especially during peak hours of the day; the study will mainly focuses on the Eastern Parts of the city where the selected route (i.e. Megenagna to Ayat) found. The route is selected due to its representative nature with two ways and an eight lane geometric feature. It serves as an access for the commuter community towards the CBD of the capital. The selected road which serves as a boundary for the two sub cities (i.e. Bole & Yeka), is located in eastern parts of the capital and it longs 7.89 km. It mainly used by the commuter community from well-known residential areas of the city called; Ayat, CMC, Meri and different nearby neighborhoods to the CBD of the capital called Megenagna, Bole, Hayahulet and other parts of the Northern, Southern and Western areas. It is an 8 lane two way road which separated by the AALRT lines serves as median but only permitting exchanges around 4 locations (i.e. Century Mall, Sealite-Mihret Square, CMC Square and Ayat Square). The route exhibits noticeable congestion during the morning and afternoon periods. To overcome the problem the Addis Ababa Traffic Management Agency applied the reversible lane method which diverts the congested traffic to the opposite direction. It mainly applied during the morning periods and vice versa in the afternoon. The implemented remedial measure started around Century Mall and ended on Ayat square with crossing two intersections and roundabouts as shown in figure 3.3. One of the intersections which found around Saint Mikael is not operable because it increases the congested level of the route.

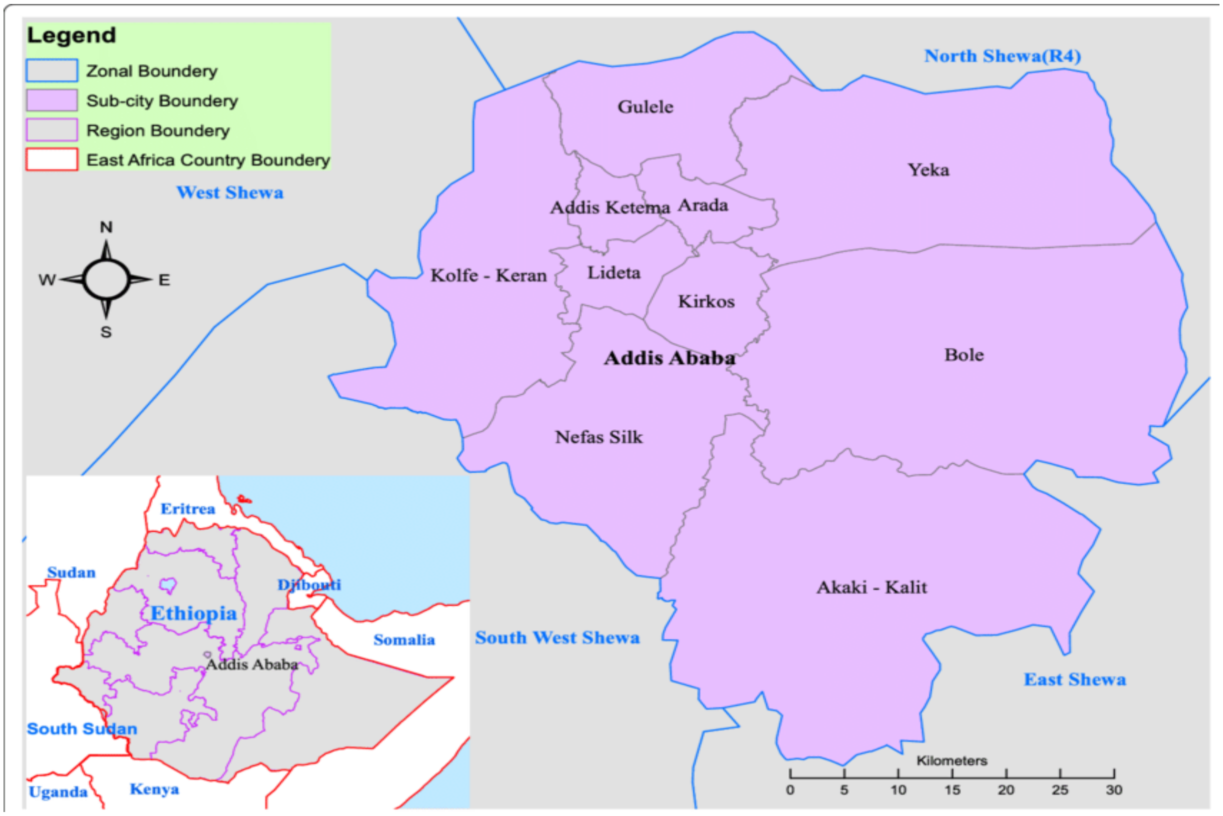

Figure 3.1: Map of Addis Ababa City (Source: Addis Ababa city Municipality, 2017)

3.2.1 Application of Reversible lane

On the way from Megenagna to Ayat, reversible lane is used as a remedy for expected traffic congestion on peak periods since the year 2010 EC during the morning and afternoon peaks. Their coordinated descriptions are latitude 9^{0}1'10''N and longitude 38^{0}48'08''E for Megenagna round about and latitude 9^{0}1'15''N and longitude 38^{0}51'06''E for Ayat round about. The reversible flow lane is functional on weekdays from Monday to Friday. The first operational segment started at Century Mall and end at Sealite-Mihret roundabout. The next reversible lane operates between the roundabouts of Sealite-Mihret and CMC. Ayat round about is the last operational destination. Posted marking that shown in figure 3.2 is used as a guiding tool to manage the operation condition.

Figure 3.2: Reversible lane signs in the selected route

3.2.2 Selected Road Segments

A road segment is the length of roadway between two points. Traffic volumes and physical characteristics generally remain the same over the length of a segment, although small variations may occur (e.g., changes in traffic volumes on a segment resulting from a low-volume driveway). Segments may or may not be directional. The HCM defines them as basic freeway segments, freeway weaving segments, freeway merge and diverge segments and urban street segments (HCM, 2010).

As stated in the objectives, the study mainly focuses on measuring the challenges and effectiveness of the implemented congestion remedial measure. Those parameters are tested by dividing the selected route on three segments. The road under study serves as a boundary for the two sub cities of the capital (i.e. Bole and Yeka). Traffic flows in multilane highways have two flow patterns of the interrupted and the uninterrupted one. Since it is not the objective of the study, Parts of the road where the reversible lane operations ceased are not covering on it. This helps to measure the road way capacity in relatively the less interrupted sections and to apply the multilane analysis concept by adapting the methods to the route under study (Ref. Fig. 3.3). Even though selected segments are operable section of reversible lane, effects of junctions and pedestrian crossing is also under consideration. The geometric features of the route, pedestrian crossing intervention points, the entrance and exit location of the reversible lane and also the neighborhoods land use pattern is discussed below.

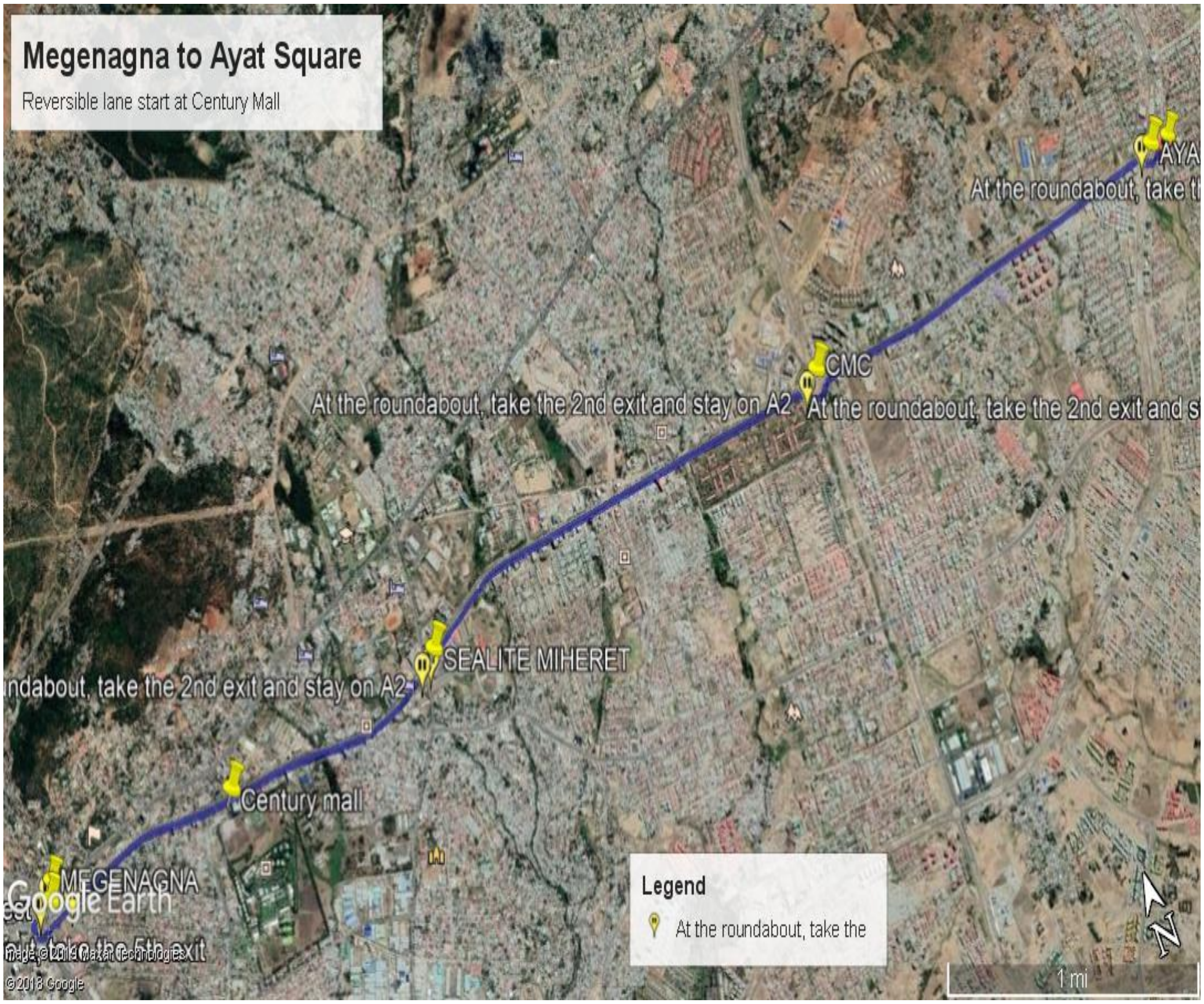

Figure 3.3: Study Area (Source: Google Earth Map, 2019)

3.2.2.1 Megenagna to Sealite-Mihret

The segments longs 2.5 km which started at Megenagna and lasts on Sealite-Mihret. It is a four lanes one way route with level geometric features. There is a junction at Gurd-shola where vehicle uses to access the reversible lane. Governmental institution like East African Deseret Locust Prevention Center, Ethiopian Athletics Federation, Ethiopian Construction

Corporation, Addis Ababa Environmental, Ethiopian Telecommunication Corporation and Forest Protection Authority, Commercial centers like Century Mall, governmental and private banks, market halls are found on the sides of the road. Schools also presents around the lane. The reversible lane operation starts at Century Mall and the first exit is at Sealite-Mihret round about and vice-versa as shown in figure 3.4.

Figure 3.4: Starting location of reversible lane at Century Mall

3.2.2.2 Sealite-Mihret to CMC-Mikael

The segments longs 2.8 km which started at Sealite-Mihret and lasts on CMC. The segment has similar geometric features with the previous one. In these segments residential and commercial areas highly used the road sides. Community institutions like Tsehay real estate Sealite-Mihret and CMC-Mikael Church, Civil Service University and Ethiopian Management Institute are also found on these segments. During the morning periods the commuting community from those residential areas are uses this route to reaches the center of the capital.

Since it leads to the congestion, the Saint Mikael intersection used as a U-turn now a day ceased its operation as shown in figure 3.5.

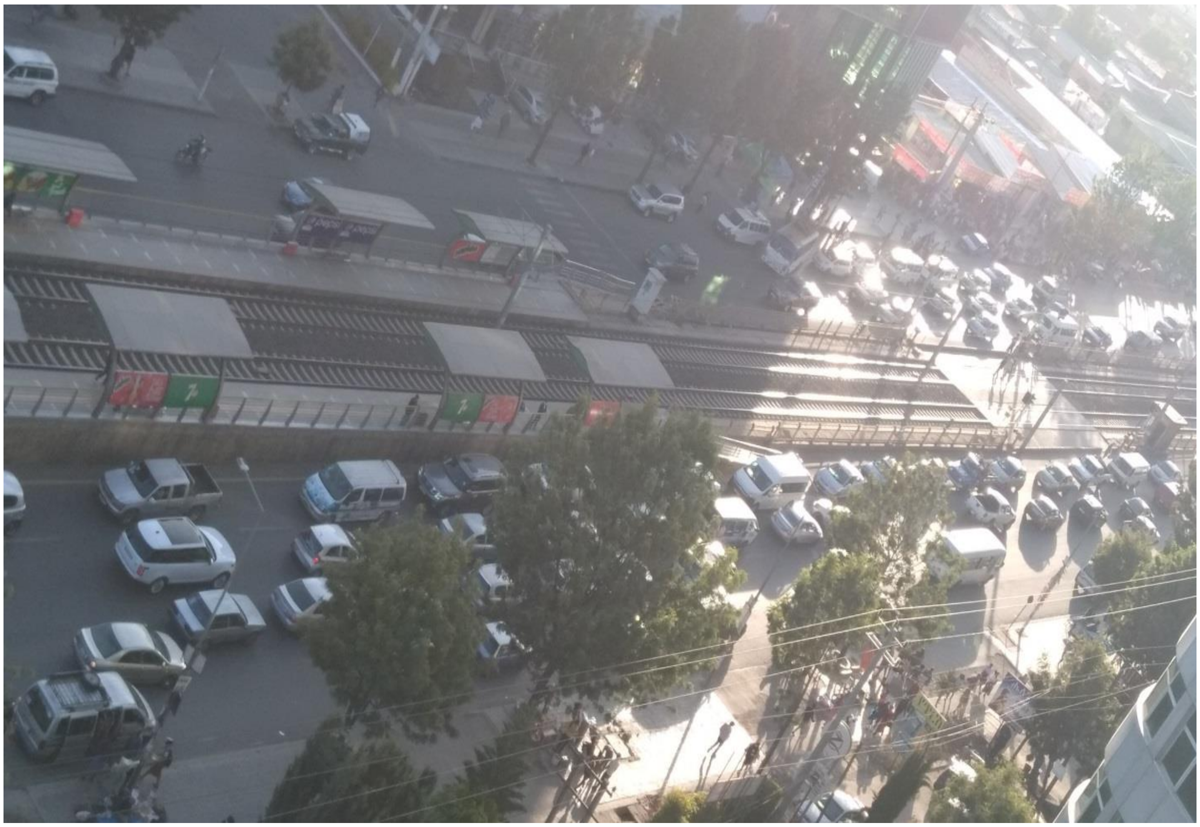

Figure 3.5: Traffic Congestion around St. Mikael (4:00-5:00 p.m.)

3.2.2.3 CMC to Ayat

The segments longs 2.59 km which started at CMC-Square and lasts on Ayat-Square. The segment has similar geometric features with the previous segments. It is the starting location for the first phase AALRT. In these segments residential areas highly used the road sides. In its local name Zone-2 the route passed under the constructed bridge for the train which decreases the road width at that specific location. The famous Ayat residential and commercial areas are found on the route (Ref. Fig. 3.6). Since a wide presence of the residential areas on the route, during the afternoon peak the community uses as an access to reach their home. There is a wider residential construction activity in the area which leads to the capacity of traffic movement in the near future.

Figure 3.6: The reversible lane marking around Ayat residential area

Name and the geometrical features of the road segments, the exit and entrance point of reversible lane are described in table 3.1.

Table 3.1: Geometrical description of selected road segments

Sl. No.	Selected road segments	Length (KM)	Road way side	No of lanes	Lane width (M)	Terrain Type	Remarks
1	Megenagna to Sealite-Mihret	2.5	Separated Two way	4	3.5	Level	Starting point of Reversible lane at Century Mall 1.1 Km from Megenagna.
2	Sealite-Mihret to CMC	2.8	Separated Two way	4	3.5	Level	Exit and entrance point of reversible lane
3	CMC to Ayat	2.59	Separated Two way	4	3.5	Level	End Point of Reversible lane

3.3 Study Approach

The study involves a quantitative data analysis approaches. Quantitative data's are used to determine existing level of service of road segment during peak hours, to measure capacity increment by the reversible lane, to quantify the directional distribution and to perform the congestion trend changes of the off peak periods. The study considered during the immediate 2 hours after stoppage of reversible lane operation in the morning and before reversible lane operation in the afternoon. Pedestrian crossing intervention and accident rate also include in the study. Observation, video recording, manual traffic count, direct field measurements and secondary data will be the main sources of quantitative data. Collecting relevant data and subsequent analysis of the data help to generate inductive conclusions on the level of congestion and its improvement by the remedial measure at the observed or considered road sections. Though it is impossible to assess the peak hours management practice at all stretches in the Addis Ababa, representative segments taken along the selected route to derive a generalized conclusion. Measuring the challenge mainly try to consider the safety condition of the route and pedestrian comfort during crossing and also their effect on operational capability of the route. In the study the methods followed were designed in such a way that the key questions of the research be answered properly.

3.4 Study Design

The study started from reconnaissance survey on the areas to select and view the geometry of the road segments, to identify location for camera recordings positions to record the vehicle volume and pedestrian movements. The performance of road facility during peak period, the LOS improvement by the addition of reversible lane, congestion trend analysis and the impact of pedestrian intervention and the directional distribution difference carry out by using video camera recordings. Manual traffic counts also included to perform the count at Gurd shola junction while recording the video at that main route. After evaluating the effect of the reversible lane on existing traffic congestion, challenges and drawbacks are also addressed by the study. The congestion trend change analysis is leads to whether there is a need for extension of time on the remedial measure or not. The result and discussion leads to a certain conclusion and the study proposed recommendation based on the stated findings. Figural description of the study design is shown in figure 3.7.

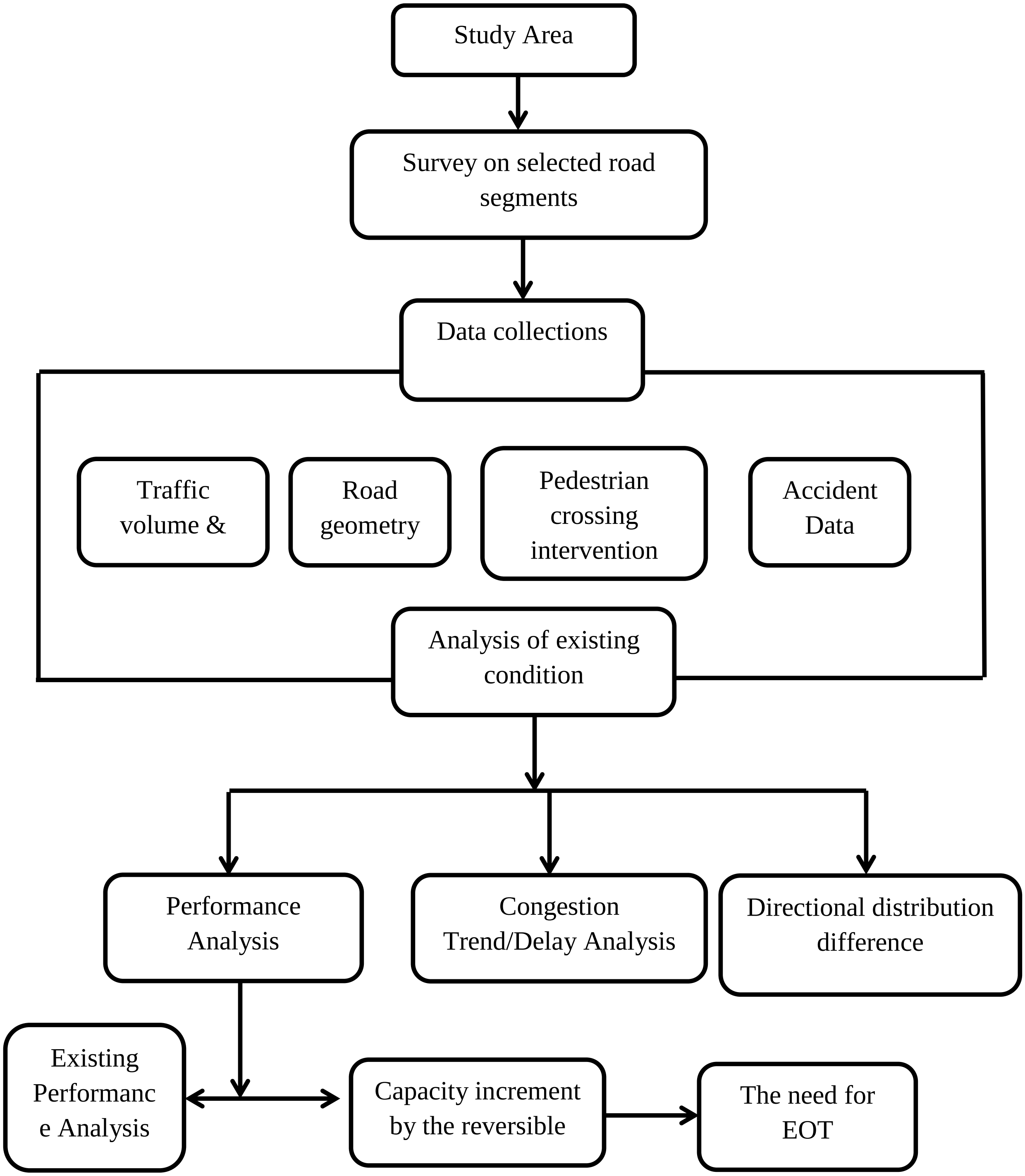

Figure 3.7: Study Design Procedure

3.5 Methods of Data Collection

3.5.1 Vehicle volume count by video recording

In its easy and cost effective nature of the method, vehicles volume data which uses for existing performance and further analysis were mainly collected by using video recording within 15 min interval. The camera arrangement location chooses based on their ability in viewing pedestrian movement while recording the vehicle flow in the route. The effects of pedestrian crossing intervention were being determined to know the effect on the overall performance of the roadway. In addition to the above traffic flow data collection techniques other field observations were done on the geometrical features of the segments for capacity analysis. These include, number of lanes, lane width, configurations of lanes etc. The survey was done for the segments capacity analysis and the existed volume in the route. According to travel time collection handbook; Video capturing techniques is preferred over the manual collection because it:

- ❖ Provides a permanent, easily-review record and show the traffic conditions at any time which helps to perform further analysis;
- ❖ Permits the reading of required parameters in a controlled environment in which plate characters can be closely examined;
- ❖ Provides additional information about traffic flow characteristics such as traffic volume and vehicle headway;
- ❖ Has better accuracy than manual methods; and
- ❖ Enables to capture a larger sample of the total number of vehicles.

Therefore, in order to exploit the above advantage and due to its convenience nature, video cameras arranged at convenient height where maximum possible view could be capture. The locations for video capturing were the roof & floors of high-rising buildings alongside the study sections. As stated on the above literatures, the main drawbacks of reversible lane concept are a safety issue and confusion on the drivers and pedestrian also obeying the operational rule by them. To measure the effect of pedestrian crossing intervention on traffic flow, video recording holds at two locations (i.e. around Gurd-shola & Saint Mikael) by taking a one hour data for each. To test the safety condition of the route by taking traffic accidents as a controlling factor before and during the application of the remedy, a five years traffic accident data were collected from Yeka sub city for the left side of the road and from Bole Sub city for the right side.

3.5.2 Manual traffic volume count

While recording the traffic volume by camera, manual traffic counts were conducted at two locations on Gurd-shola and Megenagna simultaneously. The reversible traffic volume diverted from Gurd-Shola commercial bank junction count manually to the interval of every 15 min. Vehicles volumes are also counted manually at Megenagna in order to assess the distribution difference at that location. Furthermore, quantifying the traffic data and vehicle equivalence study was conducted using manual count from the recorded video at the selected segments of the road. The data was manipulated and transformed to the required size for the analysis. Therefore, from this data collection the following quantitative data were generated. These include;

- Directional Traffic Volume/Flow per 15 Min of Interval for the Three Segments
- Vehicle Composition along the Segment

In addition to the primary data acquired in the above methods, some secondary data; mainly on traffic accident and operational background of the reversible lane operation. The sources of these secondary data are properly acknowledged at their respective locations.

3.6 Traffic Volume Data

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

The traffic count was directional and hence directional traffic flow characteristics can be easily summarized and studied. The analysis performs in separate manner for the reversible lane and main follow lanes of the road. The vehicles were counted by type “passengers Car” and “goods vehicles”. The passengers cars category includes vehicle types namely; cars and taxis, 4WD, minibus taxi, mid-bus and standard bus, whereas the goods vehicles category include vehicle types of pickups, light, medium and heavy commercial vehicles with trailers and without. It is also necessary that the vehicle volume count should be converted to passenger’s equivalent unit to conduct the analysis. The collected data’s organized to the passenger car and goods vehicle type to perform their equivalency on the route. The traffic volume in PCU is summarized and presented at appendix A.

3.6.1 Days and time period for data recording

As stated on the objective, testing the readiness of the selected route for any possible higher traffic is the main goals of the study. Contribution of the remedial measure in improving the roadway capacity is also assessed. For the proper analysis of the required data, the following points were taken under consideration: Monday and Friday have high traffic variation from the normal weekdays, Tuesday, Wednesday and Thursday represent the average value of traffic and weekends (Saturday and Sunday) have low traffic volume. So, due to time and budget limitation and also for representing the maximum expected traffic condition in the route data were collected on three different days of Monday. Specific days of data collections are December 21/2020 around Gurd-shola and Megenagna, December 28/2020 around St. Mikael and January 4/2021 around Ayat Zone-2.

Time period of recording is generally classified in four classes as shown below:

- Morning Peak Period: it includes time from 08:00 to 09:00 a.m.;
- Morning off-peak Period: it includes from 9:00 a.m. to 04:00 a.m.;
- Evening off-Peak Period: includes from 03:00 p.m. to 04:00 p.m.; and
- Evening peak Period: it includes from 04:00 p.m. to 05:00 p.m.;

3.7 Traffic Accident Data

Traffic accident rate in Ethiopia is one of the highest in the world. In determining the effects of road and traffic factors on road safety in Ethiopia (Girma, 2000) showed that, out of the total accident in the country about 62% of the total accident occurs in the capital city Addis Ababa. Data and documents show that the traffic accident in the city is alarmingly increasing and different researches were made in this regarded. Most of these researches showed the relationship between traffic flow and traffic accident. However, identifying the relationship between traffic accident and traffic management mitigation measures was rare. Hence, in this study, in order to see the relationship between traffic accident and traffic congestion especially during peak periods, accident data occurs in the selected route were collected from secondary source. The reversible lane contribution to the occurrence of accident also assessed on the study. Since the selected route found on the boundaries of the 2 sub cities, Accident data's for 5 years from 2008 EC to 2012 EC are collected from Bole and Yeka sub cities.

3.8 Methods of Data Analysis

A directional traffic volume analysis was conducted on a traffic volume data which count at 15 min interval and for two solid hours of a day starting from the early morning and another two hours data for the late afternoon. The traffic volume analysis is done for both direction and for three segments along the research corridor. The quantitative data analysis focuses on the existing level of service and its improvement by the implementation of the reversible flow lane.

3.8.1 Analysis on the existed traffic condition

3.8.1.1 Directional distribution and volume to capacity analysis

The volume to capacity ratio computed by the concept of capacity in multilane high ways by taking a base flow for the route. The V/C analysis holds for every stated hour of the peak and off peak periods to test the existed functional performance. The effect of pedestrian crossing intervention and other geometric features of the road on the efficiency of the reversible lane also considered on the analyses. The congestion trend change were analyses on the selected segment through one hour later during the morning peak and one hour before the uses of the tidal lane in the afternoon peak also include in the analysis to determine the need for extra time for the reversible lane. During the stated two hours the directional distribution factor (D factor) difference between the two ways will be analyzed to test congestion difference and the possibility of extension of time for reversible lane operation.

3.8.1.2 Vehicle queue and delay analysis

When computing the vehicle volumes from recorded data's, vehicles traverses the selected routes can be beyond or below the maximum capacity of the route. In a case where the traversed volumes are below the route capacity, it is difficult to reach on conclusion by saying that the traffic condition is under capacity. Since the traffic congestion is at observed condition, there is a need for further study to identify the reason for congestion. As stated on literatures and also for considering the above scenario, V/C analysis is not expected to give the full perspective of the traffic condition in the roadway. For every result which exhibited a V/C < 1 on the analysis part, the vehicle queue and delay analysis held on the segments for that particular hour which helps to get a full perspective on the traffic condition. Since the analysis is a segmental based and the traffic condition is highly interrupted, the concept of queue and delay analysis for work zone facilities is used.

3.8.2 Measuring the challenges of peak hours traffic management

3.8.2.1 Delay Analysis from pedestrians walking time

The analysis method used is helps in quantifying the effects of pedestrian crossing on the vehicle flow rate. This helps to know the frequency and time where pedestrian crossing intervenes on the main route. After repetitive field surveys on the route location which highly used by pedestrians is selected. Pedestrian crossings at two locations (i.e. Gurd-shola and CMC-St. Mikael) during the morning and afternoon peaks are under consideration. Crossing of pedestrians from North to South and South to North analyzed for every 15 minutes. The waiting time of vehicles to traverse a point is the same as time taken by the pedestrian flow from North to South direction. Average waiting time was calculated from video survey data. The average waiting time was determined from vehicles waiting time to give access for the pedestrians cross from North to South direction for 1:00 hr. in the morning and afternoon peak. While computing the waiting time, volumes of pedestrians were analyzed by ped/min and then it changes to cumulative hourly frequency of ped/hr. This helps to know the flow number of pedestrians and their effect on the traffic movement.

3.8.2.2 Delay Analysis from queue formed by vehicles

Once the flow rate of arrival vehicles exceeded the traversing frequency of the point, for a given time period the number of vehicles arriving would be larger than the number of departing at that point. The difference between the number of vehicles arrived and the number of vehicles departed is the vehicle queue formed at the specific location. For every random interruption of pedestrian on the traffic there is a formation of queue and delay. The concept of work zone delay analysis is used to quantify the time where it required in clearing the formed queue at that location. Comparison was made between the above two results from the work zone analysis and waiting time analysis.

3.8.2.3 The safety aspects of reversible lane operation

As stated on the above literatures, the main drawback of reversible lane operation is a safety issues. Both pedestrians and drivers fall under confusion while in crossing and driving at those routes. The study tries to measure the correlation between the traffic accident and the remedy. Generally, the Addis Ababa police commission has been adopted a unique format to register the road traffic accident. The format comprises various indictors to represent a specific accident such as day of month, time of day, severity, type of crash, location, road condition, age of driver, type of vehicle …etc. although, this section tries to see the occurrence rate of traffic accident on the selected route by comparing earlier recorded data's before the reversible lane operation and with the reversible operation years. Traffic accidents indicator parameters such as day of the month, time of day, type of crash and specific location are used as a defining factor. Accident data's are analyzed along the route for the two ways. Accordingly, the five years' traffic accident data were compiled and sorted for preparing the respective histogram to narrate about the situation based on subjective and scientific manner.

3.8.3 Measuring the effectiveness of peak hours traffic management

Besides identifying the challenges of the peak hour's management practice applied on the route, the study tries to answer the question; whether there is an improvement that comes in applying the remedy or not? The traffic distribution and level of service improvements were measured by taking the reversible operation periods as a controlling factor. The derived conclusions and recommendations are highly considered those challenges and effectiveness that observed on the selected route. Since non recurrent traffic congestion has temporal nature, in considering that, the study used the vehicle queue and delay measure that based on working zone concept.

3.8.3.1 Vehicle Queues and Delay during Congested Traffic

In determining the vehicle queues and delay on working zone areas (Yi Jiang, 2001) stated that, traffic congestion occurs when the traffic flow rate exceeds the work zone capacity. Under congested traffic conditions, the average speeds are lower than under uncongested traffic conditions and the average flow rates are below the capacity values. Apparently, these average values of speeds and flow rates should be used in estimating work zone traffic delays under congested traffic conditions. Once the flow rate of arrival vehicles exceeded the work zone capacity, for a given time period the number of vehicles arriving would be larger than the number of departing at the work zone. The difference between the number of vehicles arrived and the number of vehicles departed is the vehicle queue formed at the work zone. This can be written as

$$\mathrm{Q} = (\mathrm{Fa} - \mathrm{Fd})\mathrm{t} \text{………………………………….. Eqn. 2.3}$$

Where: t = time;

Q = vehicle queue formed during time t;

Fa = traffic flow rate of arrival vehicles;

Fd = vehicle queue-discharge rate (traffic flow rate of departure vehicles during congestion). If there was an original queue (Q_0) at the beginning of the time (t=0), then the total queue length at time t is

$$\mathrm{Qt} = \mathrm{Q}_0 + (\mathrm{Fa} - \mathrm{Fd})\mathrm{t} \text{ ……………………… Eqn. 2.4}$$

If vehicles arrive at a constant rate and depart the work zone at the vehicle queue-discharge rate within a given hour, then the total vehicle queue at the end of hour i can be calculated as follows:

$$Q_{i=Qi-1+Fai-Fd} \quad \text{.........................} \text{ Eqn. 2.5}$$

Where:

Qi = total vehicle queue at the end of hour i;

Fai = hourly volume of arrival vehicles at hour i;

Fd = vehicle queue-discharge rate.

This equation is equivalent to $Q_m = Qo + \sum_{i=1}^{m}(Fa - Fd)$ .... Eqn. 2.6

It should be pointed out that, in Equation 2.5 or 2.6, Fai and Fd are hourly traffic volumes under congested traffic conditions and time t is not explicitly expressed because it equals 1.0 hour. If time t is less than 1.0, i.e., t is somewhere between hour i-1 and hour i, the equation should be written as

$$Qi(t) = Qi - 1 + (Fai - Fd)t \quad \text{.............................} \text{ Eqn. 2.7}$$

Qi (t) represents the vehicle queue length at time t within hour i, where t is measured starting at the beginning of hour i. In Equation 2.7, only if Fai > Fd, the queue length increases during hour i, or Qi > Qi-1. On the other hand, if Fai < Fd, the queue length decreases during hour i, or Qi < Qi -1. If the calculated Qi from equation 3 is less than 0, it implies that Fai is less than Fd and that the vehicle queue has dissipated at some point in time within hour i. If Qi=0 from Equation 15, then the queue dissipated exactly at the end of hour i. If Qi < 0, then the queue was cleared at a time t before the end of an hour i (Yi Jiang, 2001).

In addition to traffic delay estimations, also derived are the equations of other characteristics of vehicle queues caused by traffic congestion. These equations can be utilized to calculate such values as maximum and average queue lengths, time needed to clear a given vehicle queue, and waiting time of vehicles in queue. According to Equation 2.7, Qi increase as long as Fai is greater than Fd. Therefore, the maximum queue length occurs just before Fai drops below Fd. For example, if Fai > Fd during hour 0 through hour I-1 and Fai < Fd at hour I, then the maximum of the vehicle queue up to hour I is max (*Q*) = *Qi-1*. Since the queue-discharge rate is Fd and the number of vehicles in the queue at time t is $Q\ (t)\ _{i}$, the time needed to clear all $Q\ (t)\ _{i}$ vehicles from the queue is

$$\mathrm{Wt} = \frac{\mathrm{Qi(t)}}{\mathrm{Fd}} = \frac{\mathrm{Qi-1+(Fa-Fd)t}}{\mathrm{Fd}} \quad \text{………………………… Eqn. 2.8}$$

Wt is also the waiting time for the Q (t) ith vehicle to be cleared from the queue (Yi Jiang, 2001).

4. RESULTS AND DISCUSSIONS

This chapter presents the analysis and discussion of the findings of the study. The presentation is organized according to the research specific objectives and research questions. The analysis of this paper was done on the selected road segments using quantitative and qualitative data to look in to the trend of the traffic flow were done on the day's peak period and peak hour volumes. The collected data following the proper and best methodology and the results are presented in the following sections.

4.1 Existing Traffic Congestion

4.1.1 Directional traffic volume during reversible lane operation

A directional traffic volume analysis was conducted by counting the existed traffic condition for both direction of flow. A traffic volume data which is counted at 15 min interval for four solid hours of a day two hours from the early morning peaks and two hours from the late afternoon peaks. The volume analysis performs during reversible lane operation hours helps to quantify the directional distribution difference between the two ways. The collected data's with the passenger car unit values are shown in appendix table A of 4.1, 4.2, 4.3 and 4.4. Reversible side volume is counted separately and they are found on appendix table A of 4.5 and 4.6. The road segments or the mid blocks considered are from: Megenagna to Sealite-Mihret, Sealite-Mihret to CMC-Michael and CMC to Ayat. Directional distribution differences of the routes are shown in figures 4.1 and 4.2.

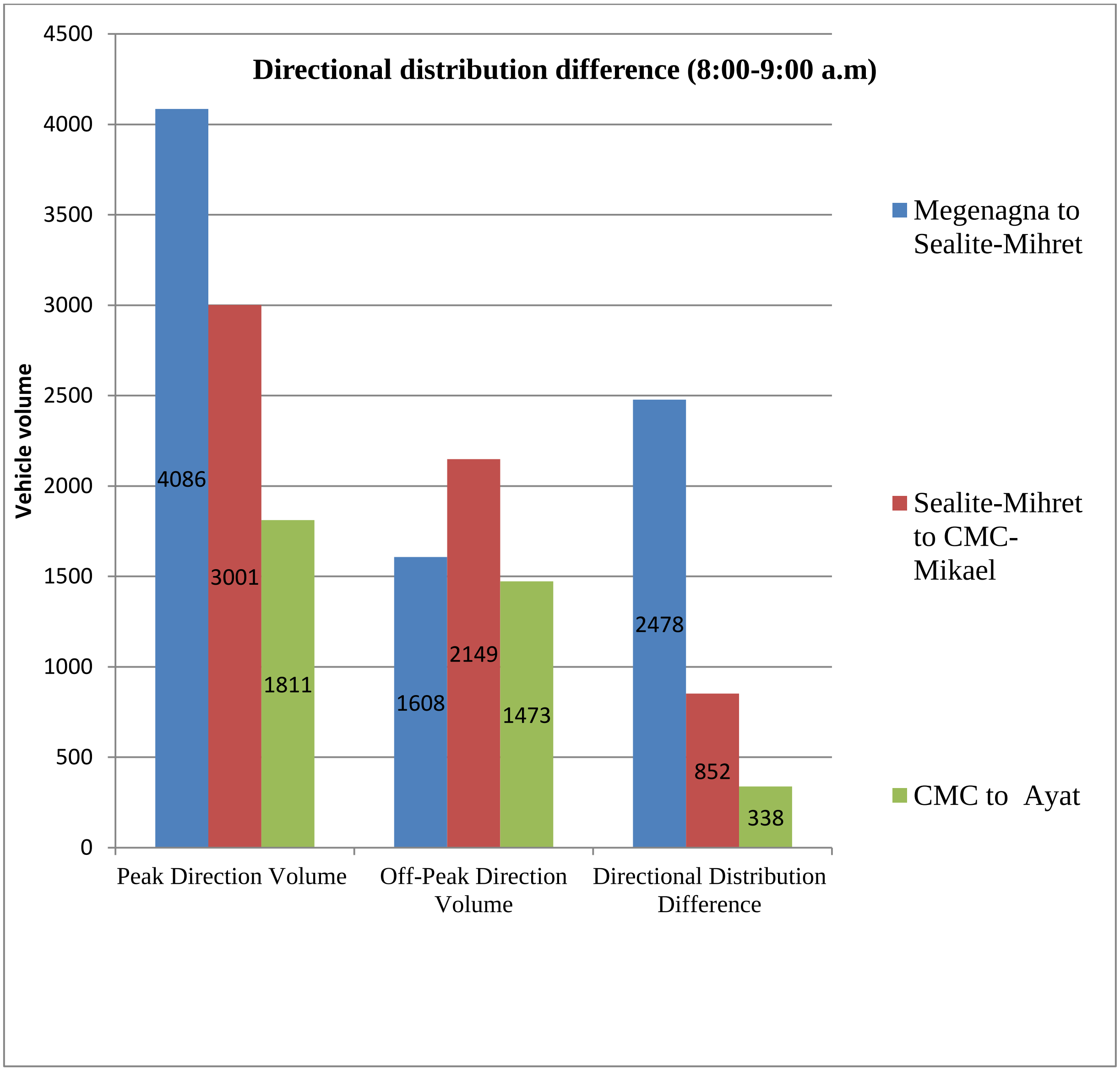

Figure 4.1: DD differences of the routes during reversible lane operation (8:00-9:00 a.m.)

The distribution differences between the two directions during the morning reversible lane operation are; 2478, 852 and 338 passenger cars; and the percentile differences are 254%, 140% and 123% for Megenagna to Sealite-Mihret, Sealite-Mihret to CMC-Mikael and CMC to Ayat respectively. The result shown that, the Peak direction has greater distribution amount on three segments.

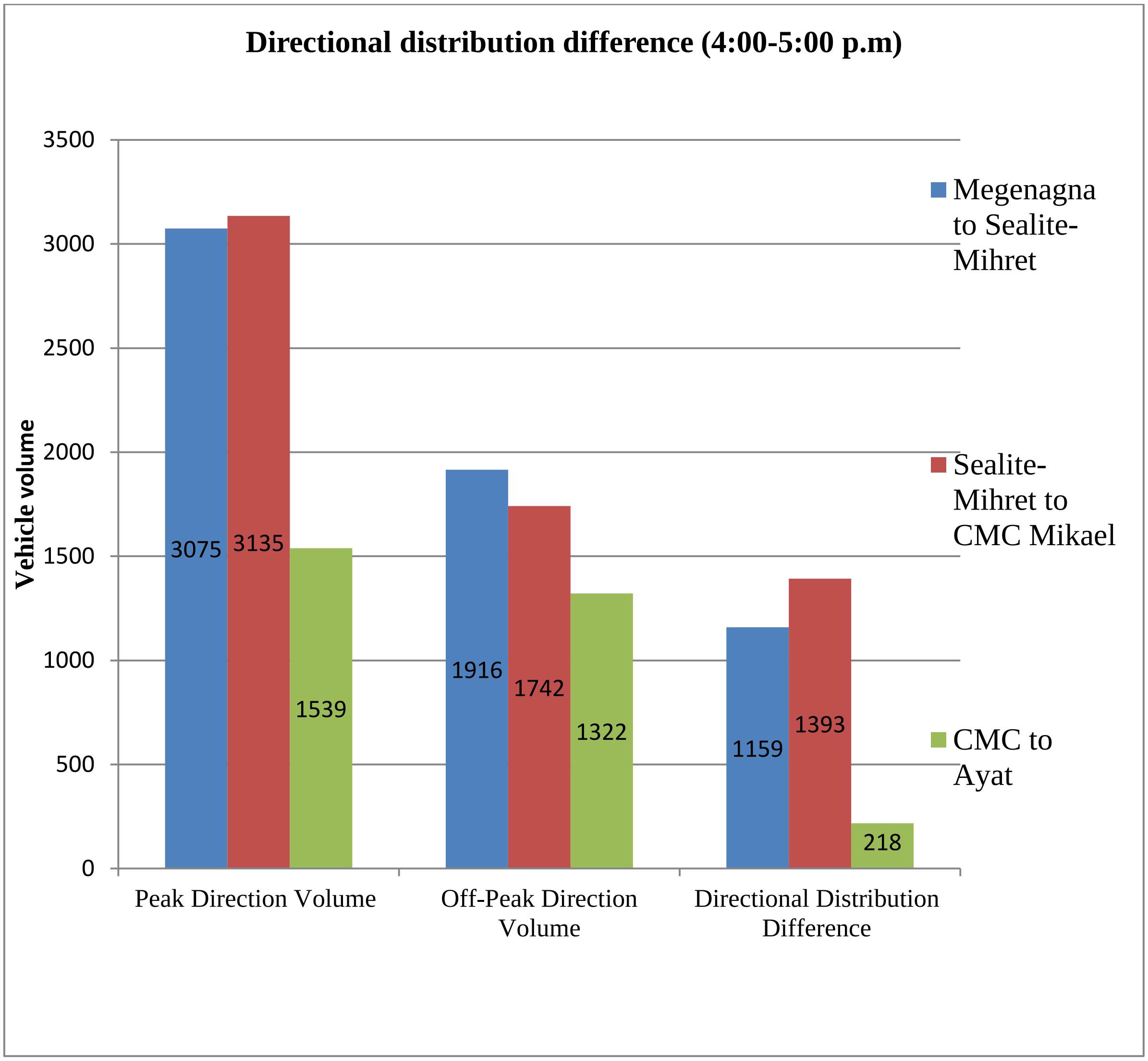

Figure 4.2: DD differences of the routes before reversible lane operation (4:00-5:00 p.m.)

The distribution differences between the two directions during the evening reversible lane operation are; 1159, 1393 and 218 passenger cars; and their percentile differences are; 161%, 180% and 116% for Megenagna to Sealite-Mihret, Sealite-Mihret to CMC-Mikael and CMC to Ayat respectively. The result shown that, the Peak direction has greater distribution amount on three segments.

4.1.2 Congestion trend analysis without reversible lane operation

Measuring the distribution difference during off periods of the reversible lane operation helps in quantifying the flow pattern change with and without it. The question whether or not there is a need for extension of time of the remedial measure also answered by the analysis. Directional distribution differences of the routes are shown in figures 4.3 and 4.4.

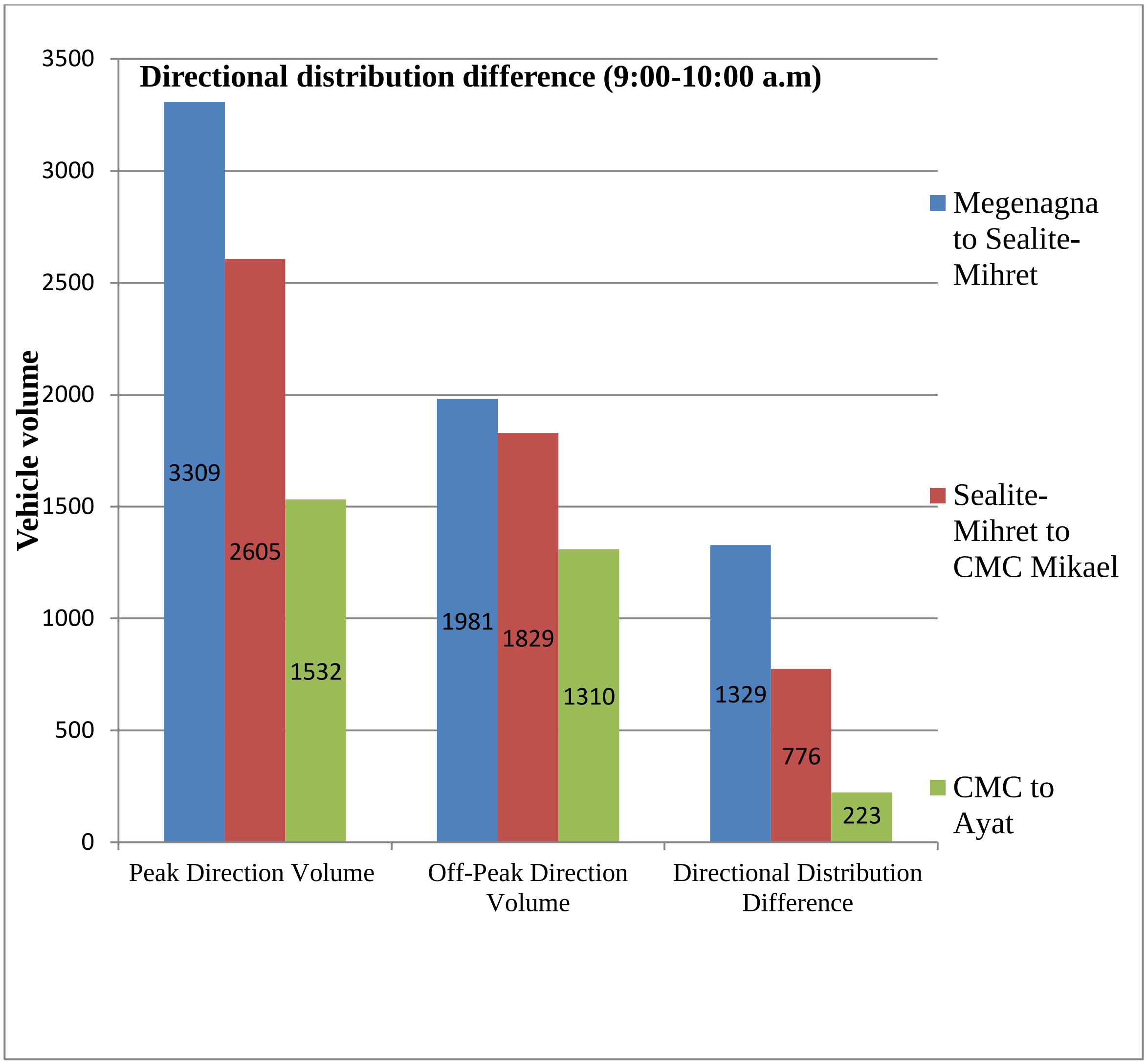

Figure 4.3: DD differences of the routes after reversible lane operation (9:00-10:00 a.m.)

The distribution differences between the two directions after the morning peak reversible lane operation are; 1329, 776 and 223 passenger cars; and their percentile differences are; 167%, 142% and 117% for Megenagna to Sealite-Mihret, Sealite-Mihret to CMC-Mikael and CMC to Ayat respectively. The result shown that, the Peak direction has greater distribution amount on three segments.

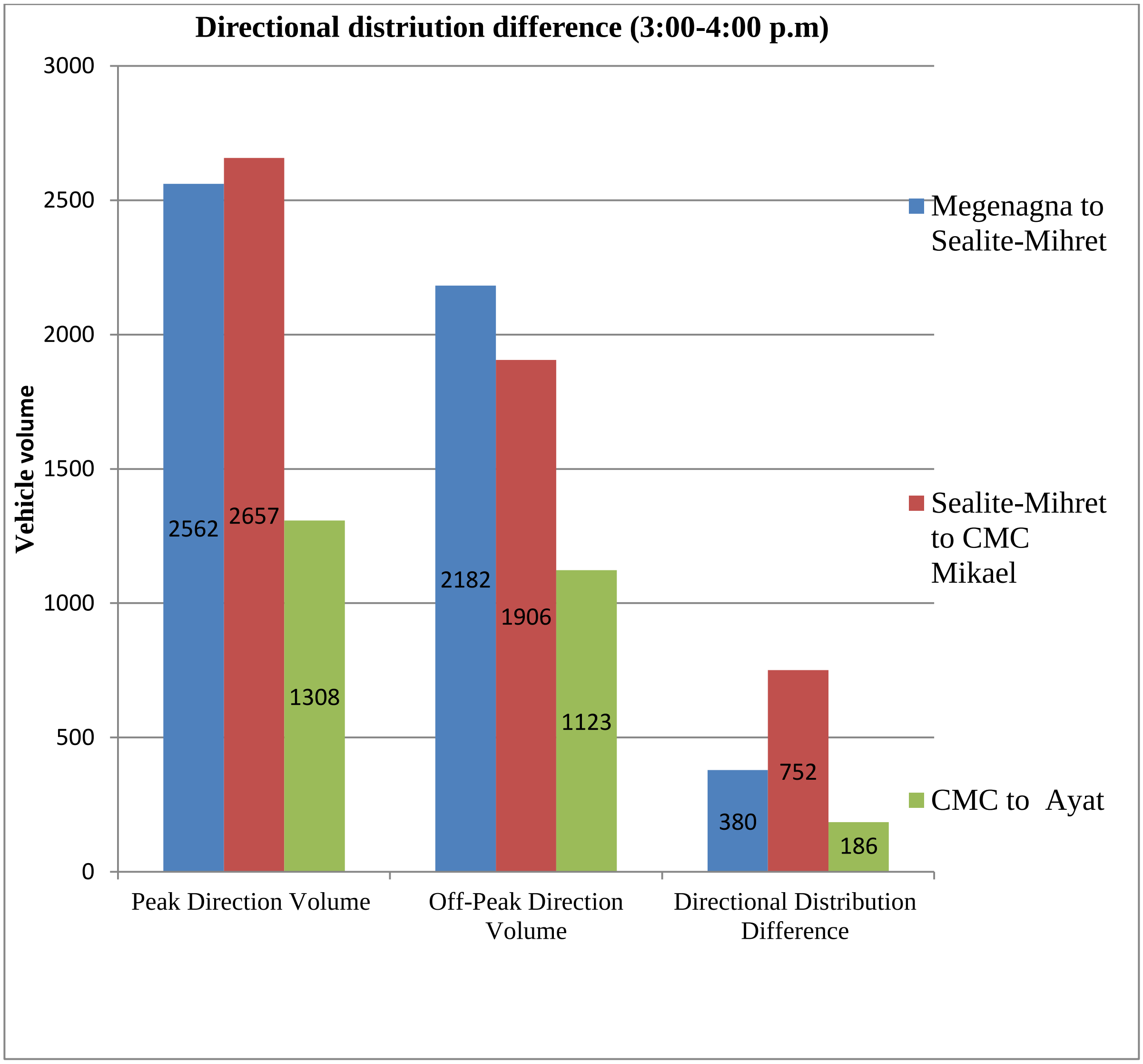

Figure 4.4: DD differences of the routes before reversible lane operation (3:00-4:00 p.m.)

The distribution differences between the two directions before the evening peak reversible lane operation are; 380, 752 and 186 passenger cars: and their percentile differences are 117%, 139% and 116% for Megenagna to Sealite-Mihret, Sealite-Mihret to CMC-Mikael and CMC to Ayat respectively. The result shown that, the Peak direction has greater distribution amount on three segments. The above results are shown that, the traffic flow has similar pattern during and off periods of the reversible operation which indicates that there is need for extension of time at least for the immediate hour of before and after the reversible lane operation.

4.1.3 Segmental capacity analysis as a LOS indicator

The study starts by trying to answer a question whether the existed facility can able to serve the maximum expected traffic on the route or not. As stated on the above literatures, the volume to capacity ratio helps to test the sufficiency of the route for maximum expected traffic during peak periods. Due to less availability of initial traffic flow data and also time and budget constraints the analysis was made for the three segments specifically where travel volume data's was collected. Capacity measurement method for multilane highways is used to quantify the V/C ratio. The following assumption is considered in adapting the derived formula by US Department of transportation for the route under consideration. The derived formula uses a free flow speed less or equals to 60 Mile/hr. by considering there is less flow interruption for the multilane facilities. Since the reality of driving in Addis Ababa roads not much with this assumption, posted speed limit in the location is used for capacity measurement. The speed limits varied from 30 to 40Km/hr. for considering any inconvenience of flow, the study uses the minimum free flow speed in the route which is 30 Km/hr.

4.1.3.1 Volume to capacity analysis during reversible lane operation

According to the observed flow pattern in directional distribution analysis above, maximum passenger vehicle volumes are exhibited on the last hour of the morning peak periods (i.e. 8:00-9:00 a.m.) during reversible lane operation and the first hour of the evening peak periods (i.e. 4:00-5:00 p.m.) on Megenagna to Sealite-Mihret segment. In performing the volume to capacity ratio, testing the roadway capacity for the maximum expected traffic on the route can give a representing value. Details of those periods and their respective results are discussed with tabulated and computational form. Their figurative descriptions are shown in figure 4.5 and 4.6.

Table 4.1: V/C Ratio during the reversible lane operation (8:00-9:00 a.m.)

Road Way Segments	Peak Direction Volume (PCU)	Bus & Truck On peak direction (PCU)	Bus & Truck Proportion Rate	fhv taking ET=1.5 for Level terrain	Base Capacity (Pc/hr/lane)	Capacity (Pc/hr/lane)	Volume to Capacity
Megenagna to Sealite-Mihret	4086	595	0.15	0.93	1375	5127	0.80
Sealite-Mihret to CMC Mikael	3373	612	0.18	0.92	1375	5042	0.67
CMC to Ayat	2069	413	0.20	0.91	1375	5001	0.41

- The bus and truck proportion can be found out as the summation of bus and truck is divided by the total number of vehicle present on the segment. For Megenagna to Sealite-Mihret segment the proportion can be found as $595/4086 = 0.15$ It has been tabulated in column 3 of table 4.1
- Heavy vehicle factor for that segment can be calculated as $1/((1 + (0.15 * (1.5 - 1))$ which become 0.93. It has been tabulated in column 4 of table 4.1
- Base capacity for the specified segment can be found by a formula $Base\ capacity = 1000 + 20 * FFS$ taking the free flow speed on segments 30 Km/hr. which converted to 18.75 Mile/hr. the base capacity become 1375 for the entire route. It has been tabulated in column 5 of table 4.1

- Capacity of the segments is found by a formula$Capacity = Base\ capacity * fhv * lanes$. For Megenagna to Sealite-Mihret the calculated capacity $1375 * 0.15 * 4$ which become 5127. It has been tabulated in column 6 of table 4.1
- The volume to capacity ratio for the segment is calculated by dividing$4086/5127 = 0.8$. It has been tabulated in column 7 of table 4.1

Results in remaining parts of the table are calculated with similar manner

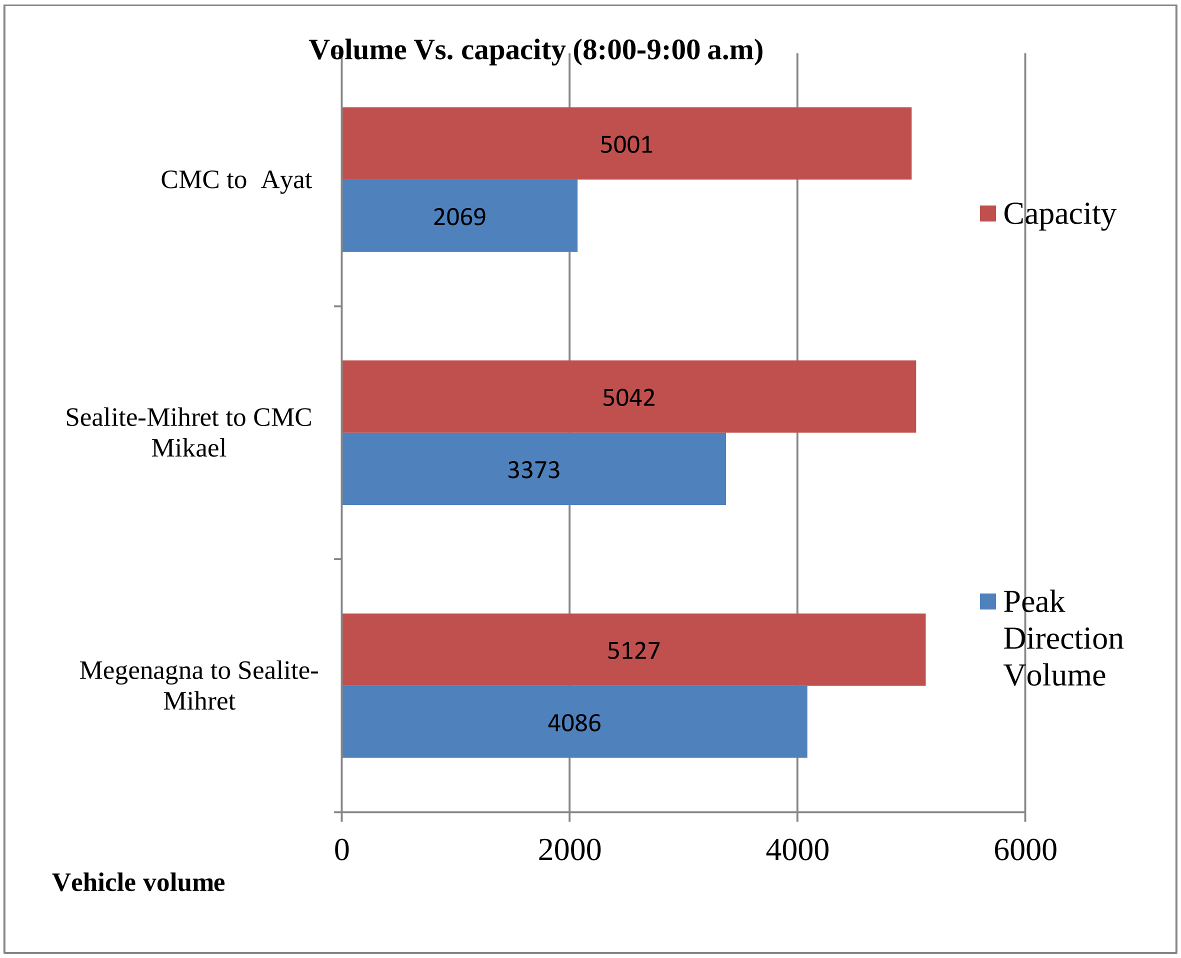

Figure 4.5: V/C Ratio during the reversible lane operation (8:00-9:00 AM)

The value of volume to capacity ratios occurred are 80%, 67% and 41% of the route capacity at Megenagna to Sealite-Mihret, Sealite-Mihret to CMC-Mikael and CMC to Ayat respectively which indicates under the capacity of the route.

Table 4.2: V/C Ratio during the reversible lane operation (4:00-5:00 p.m.)

Road Way Segments	Peak Direction Volume in (PCU)	Bus & Truck On peak direction in (PCU)	Bus & Truck Proportion Rate	fhv taking ET=1.5 for Level terrain	Base Capacity (Pc/hr/lane)	Capacity (Pc/hr/lane)	Volume to Capacity
Megenagna to Sealite-Mihret	3075	454	0.15	0.93	1375	5122	0.60
Sealite-Mihret to CMC Mikael	3135	550	0.18	0.92	1375	5056	0.62
CMC to Ayat	1539	246	0.16	0.93	1375	5093	0.30

The value of volume to capacity ratios occurred are 60%, 62% and 28% of the route capacity at Megenagna to Sealite-Mihret, Sealite-Mihret to CMC-St. Mikael and CMC to Ayat respectively which indicates under the capacity of the route. Result pictorial description is shown in figure 4.6.

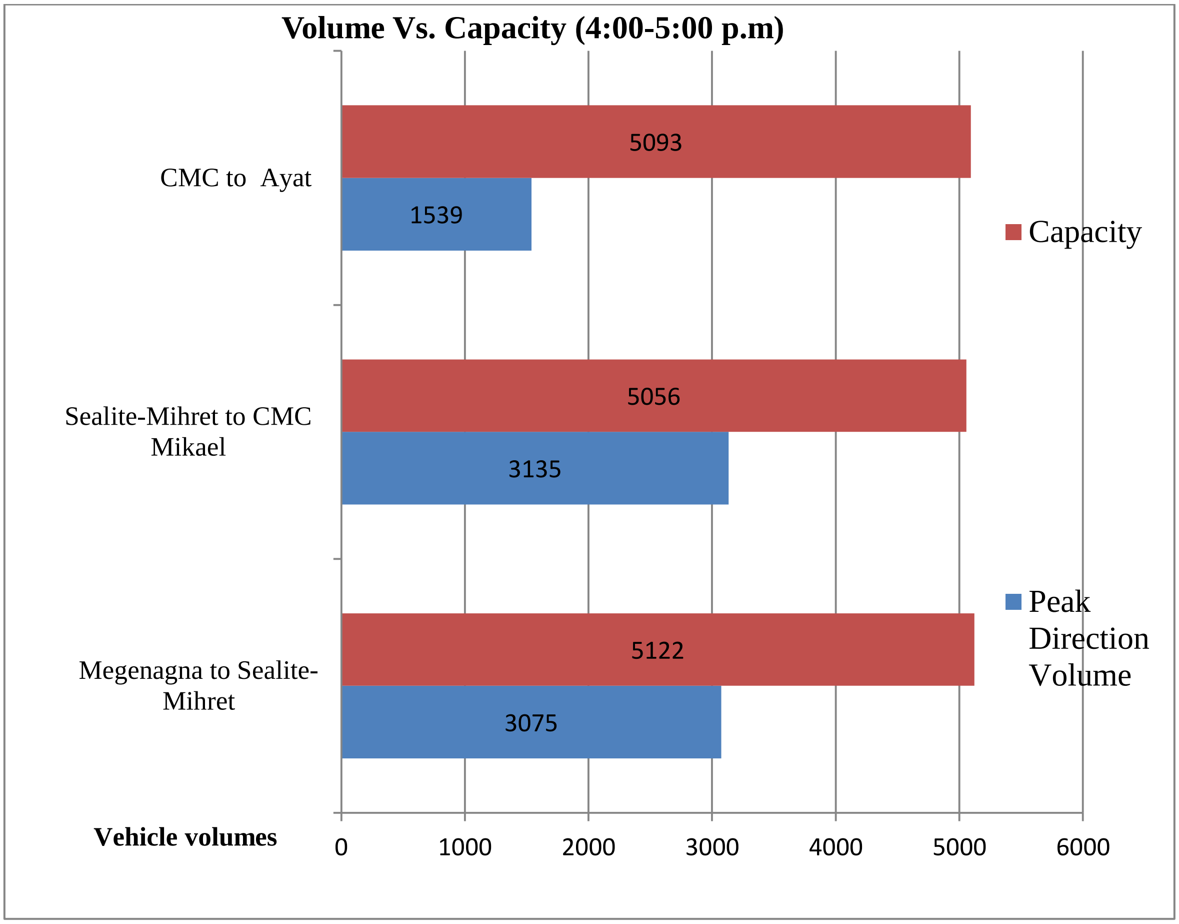

Figure 4.6: V/C Ratio during the reversible lane operation (4:00-5:00 p.m.)

Considering the above results, the road facilities are able to serve the traffic flow on the route. The maximum flow exhibited on the morning and afternoon peaks are only 80% and 62% of the road segments capacity respectively. Those results leads to a question that; why the route is still congested while the segments are able to serve? It is known that the outcome of volume to capacity ratio is highly depends on the maximum vehicle numbers which able to traverse a certain points or road segments. According to the analysis performed above, it is real that there is a distribution difference between the two ways but finding an answer for the raised question is beyond it. Identifying the cause and proposing a solution to the observed congestion is the main focuses of the study.

The above results indicate that, congestion is a concept beyond capacity of roadway facilities. A road way facility can be sufficient but it cannot give assurance for the level of service on them. The analysis which holds below is aimed at answering the above crucial question by tracing parts of the road where the congestion created. Repeated field surveys are used to identify those points and their quantified results are discussed below.

4.2 Challenges of Peak hour Traffic Management

4.2.1 Pedestrian and traffic volumes

Counting of pedestrian and traffic were conducted around Gurd-shola and CMC-St. Mikael church. Count survey was conducted on working days for 2 hours of morning and evening peak. Pedestrians crossing pattern on the morning time from 9:00 – 10:00 a.m. at Gurd-shola and on evening from 4:00 – 5:00 p.m. at St. Mikael has shown similar pattern. Pedestrian crossing trend and waiting time of vehicle to traverse the point is discussed and their pictorial description is shown in fig. 4.7 and 4.8

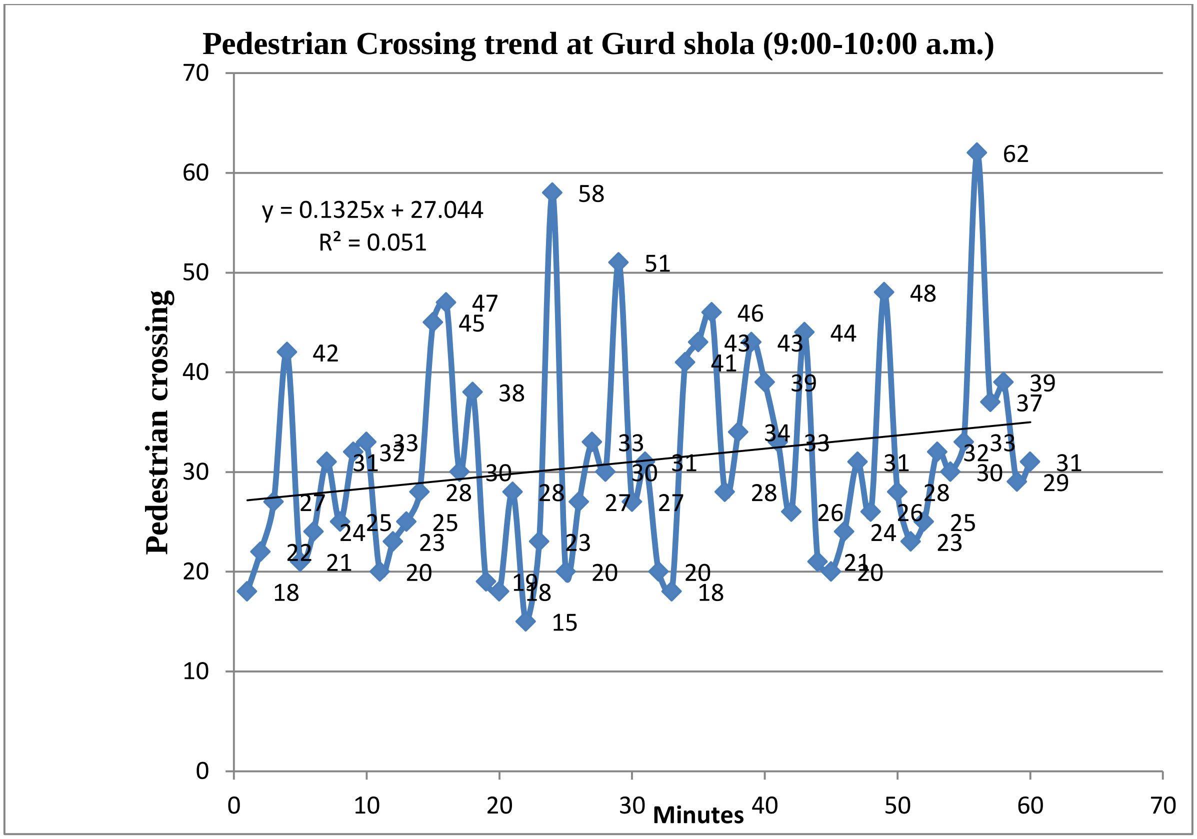

Figure 4.7: Pedestrian Crossing from North to South and Vice-Versa at Gurd-Shola

The result shows an R^2 value nears to zero. It indicates that, there is no a linear relation between the pedestrian flow and the time under study. If there is no any means used to regulate random movements of pedestrian under consideration, one cannot able to estimate the crossing pattern of the pedestrians for any increment of minute. The values are highly affected by the presence of light rail train on the area. Values are also shows increment when trains with trailers were presence on the segments.

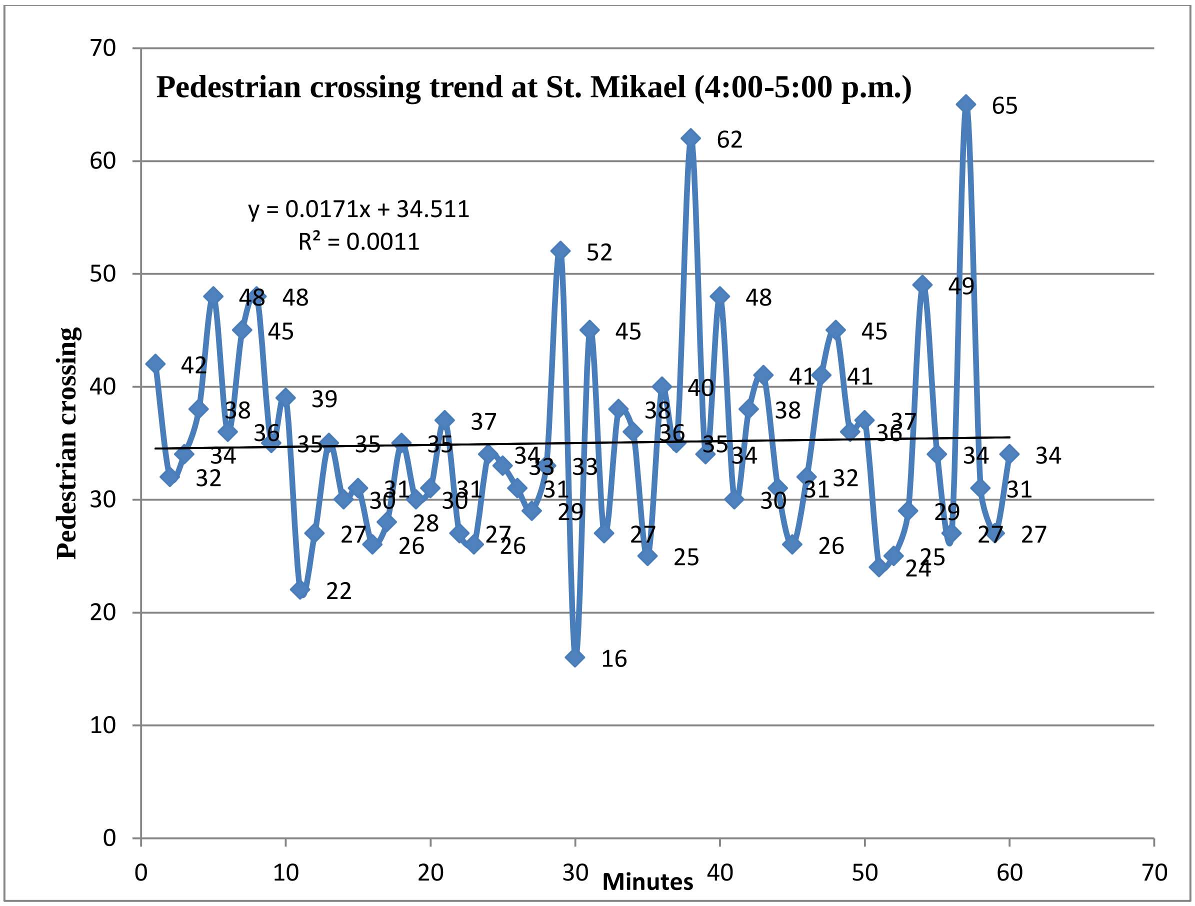

Figure 4.8: Pedestrian Crossing from North to South and Vice-Versa at St. Mikael

Table 4.3 Shows the waiting time of vehicles when pedestrians cross the roadway from North to South and vice versa. Each individual seconds while the crossing are counted from the recorded video. The total delayed seconds of every 15 counting minutes are converted hourly wasted time of vehicles at that location. 12.82 Minutes and 13.70 Minutes are delayed by the pedestrians at Gurd-Sola and St.-Mikael respectively.

Direct measuring of the waiting time has subjective drawbacks. In analyzing the recorded videos different individuals may come with different result. To overcome these drawbacks, the waiting time from working area concept is used as a comparison.

Table 4.3: Pedestrian and Vehicle volumes at the morning peak from 8:00 – 9:00 a.m. and Evening Peak 4:00- 5:00 p.m.

Around Gurd-Shola			**Around St. Mikael**		
Time (a.m. Peak)	**Pedestrian Crossing From North to South and Vice-Versa**	**Vehicles Waiting time (Sec)**	**Time (p.m. Peak)**	**Pedestrian Crossing From North to South and Vice-Versa**	**Vehicles Waiting time (Sec)**
8:00-8:15	416	180	4:00-4:15	542	206
8:15-8:30	464	195	4:15-4:30	468	199
8:30-8:45	487	198	4:30-4:45	556	208
8:45-9:00	498	196	4:45-5:00	536	209
Sum	1865	769	**Sum**	2102	822
Vehicle waiting time (Min)		**12.82**	**Vehicle waiting time (Min)**		**13.70**

4.2.2 Segmental queue and delay analysis

It is real that according to the methodology described above, it is necessary to justify that the segments and the road sections to be analyzed are in congested state based on accepted standards. Besides quantifying the delay time by a direct measurement, vehicle queue and delay analysis is used to create a full perception of the traffic operation. Contribution of the reversible lane in improving the level of service of the route is discussed separately.

Techniques used to trace the flow pattern

The collected vehicles volume during the two peak periods were an hourly based. But, computing the vehicle queue by considering the flow pattern for every infinitesimal time change (t, t+Δt) is become difficult. To overcome those difficulties, repetitive plays of the recorded videos at the selected segments uses as a techniques to understand the flow pattern for every minute under study. Three flow patterns are observed and they are discussed below:

- ❖ The first observed flow pattern; there is one full flow cycle for the stated (t+Δt) before the interruption occurred;
- ❖ The second flow may falls between two consecutive minutes then the obstruction occurred;
- ❖ The last flow pattern observed were, at the end of the previous and the start of the following minutes

Dispersing the vehicle volumes for each minute were in considering the above three scenarios. To make a fairly comparison throughout the route, times which has nearest vehicle traverse value selected. Those are (3:00 to 4:00 p.m. at Gurd-Shola with 2561 passenger cars, 4:00 to 5:00 p.m. at St. Mikael with 2422 passenger cars and Sealite-Mihret 2716 passenger cars). Vehicles traverse at the Sealite-Mihret segment disrupted by both pedestrians and vehicles. Delays are computed with the form by including and excluding the reversible volume. Details of vehicle queue computation for the three segments are attached in appendix B of tables 4.7, 4.8 and 4.9.

For the segment around Gurd-Shola

- ❖ The vehicle queue is calculated for each minute under consideration. On the segment around Gurd-Shola for the first time interval of 5 minutes, vehicle queue can be found as $Qi(t) = Qi - 1 + (Pa - Pd)t$; for the first minute $Qi(t) = 0 + (19 - 16) * 0.0167 = 0.1$
- ❖ The computation continued for the first 5 minutes is shown in table 4.4 below.

Table 4.4: Vehicles queue before reversible operation (3:00–4:00 p.m.) Around Gurd-Shola

Vehicle arrival and departure; excluding reversible volume (Where Qi=0)			
Minutes	**0.0167**		**Vehicle Queue (Veh-hr.)**
	Pa (Veh)	**Pd (Veh)**	
0:00-1:00	19	16	0.1
1:00-2:00	20	16	0.2
2:00-3:00	26	15	0.7
3:00-4:00	26	19	1.2
4:00-5:00	23	17	1.7

- The total vehicle queue at the end of an hour for the segment around Gurd-shola is Q (t) = 185.3 Veh-hr. and the summations of departed vehicles are Pd = 1071 vehicles.
- To compute the time it takes to clear the queued vehicles is calculated by a formula $(Q(t))/Pd$. For segment on Gurd-shola the results become $\frac{185.3}{1071} = 0.1729hr$.
- The minute required to clear the queued vehicle is $= 0.1729 * 60 = 10.38\ Minutes$

Therefore; the time required to clear the queued vehicle is 10.38 Minutes for the given time before reversible operation (i.e. 3:00 to 4:00 p.m.).

For the segment around CMC-Saint Mikael

- The vehicle queue is calculated for each minute under consideration. On the segment around Gurd-Shola for the first time interval of 5 minutes, vehicle queue can be found as $Qi(t) = Qi - 1 + (Pa - Pd)t$; for the first minute $Qi(t) = 0 + (24 - 18) * 0.0167 = 0.1$
- The computation continued for the first 5 minutes is shown in table 4.5 below.

Table 4.5: Vehicles queue during reversible operation (4:00–5:00 p.m.) Around St. Mikael

Vehicle arrival and departure; excluding reversible volume (Where Qi=0)			
Minutes	**0.0167**		**Vehicle Queue (Veh-hr.)**
	Pa (Veh)	**Pd (Veh)**	
0:00-1:00	24	18	0.1
1:00-2:00	23	17	0.3
2:00-3:00	23	17	0.6
3:00-4:00	24	18	1.0
4:00-5:00	26	18	1.7

- The total vehicle queue at the end of an hour for the segment around Saint-Mikael is Q (t) = 188.2 Veh-hr. and the summations of departed vehicles are Pd = 1014 vehicles.
- To compute the time it takes to clear the queued vehicles is calculated by a formula $(Q(t))/Pd$. For segment on Saint Mikael the results become $\frac{188.2}{1014} = 0.1855hr$.
- The minutes required to clear the queued vehicle is $= 0.1855 * 60 = 11.13\ Minutes$

Therefore; the time required to clear the queued vehicle is 11.13 Minutes for the given time during reversible operation of the p.m. hour (i.e. 4:00 to 5:00 p.m.).

4.2.3 Composite intervention from pedestrian & diverted vehicles from round about

For the segment around Sealite-Mihret

- The total vehicle queue at the end of an hour for the segment around Sealite-Mihret is Q (t) = 254.7 Veh-hr. and the summations of departed vehicles are Pd = 1108 vehicles.

- To compute the time it takes to clear the queued vehicles is calculated by a formula $(Q(t))/Pd$. For segment on Sealite-Mihret the results become $\frac{254.7}{1108} = 0.2291hr$.
- The minute required to clear the queued vehicle is $= 0.2291 * 60 = 13.74\ Minutes$

Therefore; the time required to clear the queued vehicle is 13.74 Minutes for the given time during reversible operation of the p.m. hour (i.e. 4:00 to 5:00 p.m.).

4.2.4 Bottleneck effect nears to Megenagna round about

After traversing a congested section at Gurd-Shola, the peak side volume faced other spot at Megenagna which has a bottleneck effects. The diverted traffic from the reversible lane has merged with the peak side traffic at Century Mall towards to the CBD of the capital. The geometric feature of the first segment is changes from four to two lanes when the vehicles approach the roundabout at Megenagna. The two lanes forms an underpass below Megenagna round about and the rest two has grade separated pattern and forms a merging traffic with it. Traffic volume proportions are shown in table 4.6 and 4.7 below.

Table 4.6: Traffic volume proportion at Megenagna (8:00-9:00 A.M.)

Manual Count at Megenagna		
Vehicle Types	**Vehicles via Round about**	**Vehicles via underpass**
Car	1519	639
4WD	611	272
Small Bus	286	140
Medium Bus	45	19
Large Bus	39	15
Small Truck	22	9
Medium Truck	15	4
Heavy Truck With Trailer	5	0
Total Hourly Volume	2542	1098
Total (PCU) Hourly	2837	1220

Table 4.7: Traffic volume proportion difference at Megenagna (8:00-9:00 AM)

Road Way Segments	Vehicles via Round about in (PCU)	Vehicles via underpass in (PCU)	Proportion Difference in (PCU)	DD Rate
Megenagna to Gurd Shola	2837	1220	1617	43.01

As shown in the table, more 1617 vehicles are in need to use the roundabout than the underpass that creates a bottleneck effect on the traffic and there forms delay back to the route.

4.2.5 The safety aspects of reversible lane operation

4.2.5.1 Traffic accident trends and reversible lane

As stated on earlier parts of the study, the selected road is serves as a boundary for the two sub cities of the capital (i.e. Bole & Yeka). Accident data's are recorded and administered by them separately. On the ways from Megenagna to Ayat, the right side of the road is administered by Bole sub city police commission and the left one is administered by Yeka sub city police commission. While it gives an opportunity to study accident occurrence on the two ways separately, but the recorded data's from Bole sub city has short comings. From the collected five years data, three months data for the year 2010 EC is not available, six months data on the same year not have recorded accident occurrence time. For the year 2012 EC, eight months data from November to June is not available. In considering those short comings, further analysis is performed only on left side of the road by the accident data's collected from Yeka sub city. Data's from Yeka sub city has better completeness in comparing with Bole sub city. On the year 2010 EC accident occurrence locations are not available for the month of July. To make reasonable analysis between the observed years, accident occurred on the month of July on the following years are not included. Detail description of traffic accident data's for the stated five years (2008 EC to 2009 EC) is shown on table 4.8 and 4.9 below.

Table 4.8: Accident occurred on the route left side (on ways from Megenagna to Ayat)

Accident Recording Years E.C.	Total Accidents Megenagna to Ayat	Accident type		
		Car with Car	Car with road sides	On pedestrian
2008	176	140	18	18
2009	281	245	22	14
2010	308	270	26	12
2011	430	387	20	23
2012	399	362	20	17
Sum	1594	1404	106	84

Table 4.9: Accident rate at the selected Road left side (on ways from Megenagna to Ayat)

Accident Recording Years E.C.	Total Accidents Megenagna to Ayat	Occurrence date			Occurrence time		Percent Increase/Decrease Accident During Reversible Operations Times
		Week days	Week end	Weekdays occurrence %	During reversible lane operation	% reversible lane operation	
2008	176	143	33	81.25	33	18.75	
2009	281	203	78	72.24	39	13.88	
2010	308	236	72	76.62	103	33.44	14.69
2011	430	323	107	75.12	137	31.86	13.11
2012	399	307	92	76.94	126	31.58	12.83
Sum	1594	1212	382				

The reversible lane operation on the route was started on the year 2010 EC. Results on the table shows, accidents occurrence on the time where the reversible lane operated is increased from 18.75% to 33.44% between the years 2008 EC to 2010 EC. It is difficult to conclude that all the increment is comes from the application of the reversible lane. The study suggested that, if the future accident data recording format includes such special operations on the city arterials, one can drive a better conclusion about the road safety on the capital.

4.3 Effectiveness of Peak hour Traffic Management

Results and discussion below try to show the improvement of operational capacity due to the implementation of the reversible lane on the route. Since higher values of traffic volumes are recorded on the location, the morning and afternoon peak traffic condition of Megenagna to Sealite-Mihret segment is selected for further analysis.

4.3.1 On diverting the unbalanced traffic

The directional distribution results show that, there is a high distribution between the peak and off peak sides of the route. Implementing the reversible lane concept on the selected route helps in diverting up to 14.58 % of the peak traffic to the opposite direction on the morning peak. Detail descriptions of the results for Megenagna to Sealite-Mihret Segments are shown in Figure 4.8.

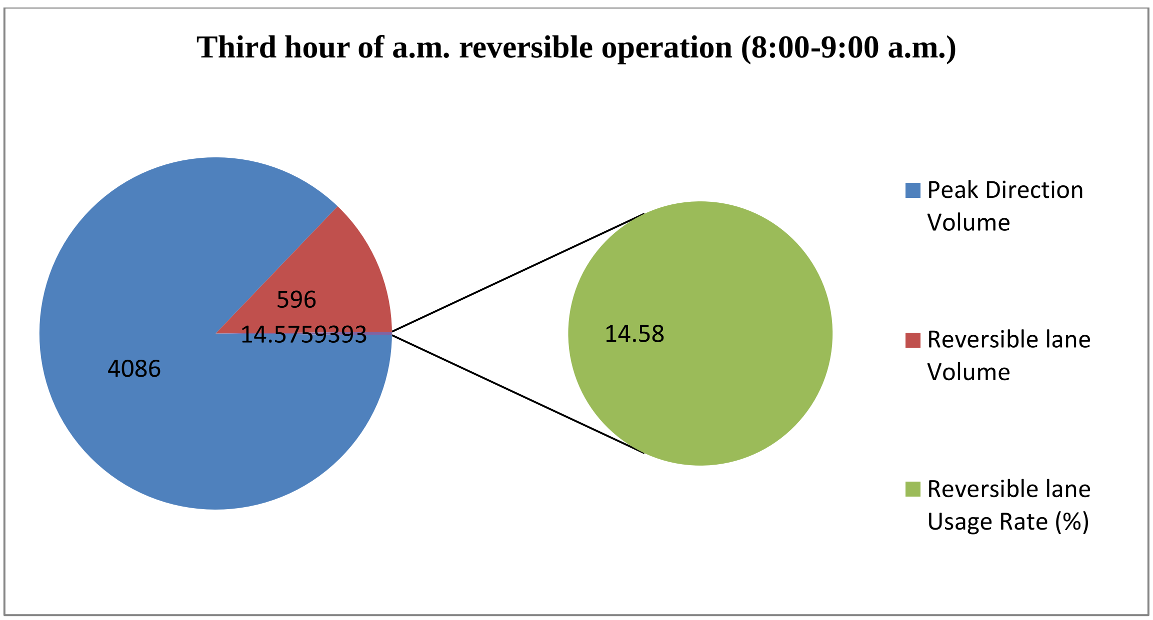

Figure 4.8: Reversible lane usage rate at the third hour of reversible lane operations (8:00-9:00 a.m.)

At similar location on the route, the value extended up to 21.22% on the afternoon peak period as shown in figure 4.9.

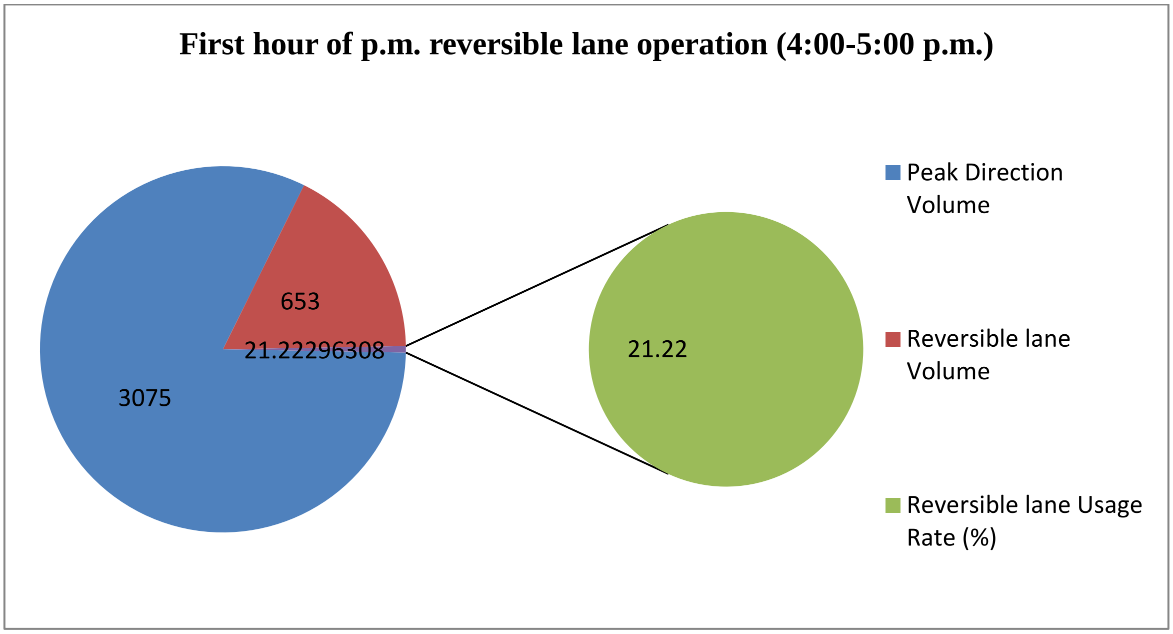

Figure 4.9: Reversible lane usage rate at the first hour of reversible lane operations (4:00-5:00 p.m.)

Details of reversible lane usage rate for the remaining segments are listed in table 4.10 and 4.11 for the morning and afternoon peak respectively.

Table 4.10: Reversible lane usage rate at the third hour of reversible lane operations (8:00-9:00 a.m.)

Road Way Segments	Peak Direction Volume in (PCU)	Reversible lane Volume in (PCU)	Reversible lane Usage Rate (%)
Megenagna to Sealite-Mihret	4086	596	14.58
Sealite-Mihret to CMC-Mikael	3001	372	12.38
CMC to Ayat	1811	258	14.22

Table 4.11: Reversible lane usage rate at the first hour of reversible lane operations (4:00-5:00 p.m.)

Road Way Segments	Peak Direction Volume in (PCU)	Reversible lane Volume in (PCU)	Reversible lane Usage Rate (%)
Megenagna to Sealite-Mihret	3075	653	21.22
Sealite-Mihret to CMC-Mikael	3135	419	13.35
CMC to Ayat	1539	205	13.32

4.3.2 On decreasing vehicle queue and delay

Segmental and queue analysis performed on section 4.1.2 is not included the effects of reversible lane in decreasing the vehicle queue and delay on the segments. To quantify those improvements on the route, there is a need to analyses the diverted volumes together with the peak side volumes. When traffic volumes from the reversible lanes are merged with the peak side volumes, their arrival and departure rates become similar.

For segment around Saint-Mikael

At this location there is only a disruption on the traffic movement from the pedestrian crossing. Wider availability of commercial and recreational buildings at that location highly increased the movement of pedestrians from both directions of the road way. It also serves as a terminal point for the city midi and mini buses.

- ❖ 418 Passenger cars use the reversible side. This traffic volume should have to be correlated with the previous arrival and departure rates of that similar segment on section 4.1.2 The total traffic volume were 2405 passenger cars, arrived and departed passenger vehicles were 1391 and 1014 respectively. Therefore; the vehicles arrival rates calculated as $1391/2405 = 0.578$

the vehicle departure rates calculated as $1014/2405 = 0.422$ By using these the number of arrived and departed passenger vehicles from the reversible lane becomes $0.578 * 418 = 241\ passenger\ vehicles$ and $0.422 * 418 = 176\ Passenger\ vehicles$ respectively. Detail results of the first 5 minutes for the spot on Sainte-Mikael are listed in table 4.12

Table 4.12: Vehicles queue during afternoon peak hour (4:00–5:00 p.m.) Around St. Mikael

Vehicle arrival and departure of peak direction with reversible lane volumes (Where Qi=0)			
Minutes	**0.0167**		**Vehicle Queue (Veh-hr.)**
	Pa (Veh)	**Pd (Veh)**	
0:00-1:00	28	21	0.1
1:00-2:00	29	18	0.5
2:00-3:00	29	18	1.0
3:00-4:00	28	21	1.5
4:00-5:00	30	21	2.3

- The total vehicle queue at the end of an hour for spot on Saint-Mikael is Q (t) = 249.1 Veh-hr. which previously has a value of 188.2 Veh-hr. The reversible lane helps to decrease a vehicle queue of 61 Veh-hr. and the summations of departed vehicles are Pd=1167 vehicles.
- To compute the time it takes to clear the queued vehicles is calculated by a formula$(Q(t))/Pd$. For segment around St. Mikael the result become $\frac{249.1}{1167} = 0.2134hr$.
- The minute required to clear the queued vehicle is $= 0.2134 * 60 = 12.47\ Minutes$

Previous calculated result to clear the queued vehicle at similar spot was 11.13 Minutes with excluding the reversible volume. Therefore, 1.67 Minutes of delay is saved by the operation of reversible lane at that specific location.

For Segment around Sealite-Mihret

At this location there is a disruption on the traffic both from movement from the pedestrian crossing and diverted traffic from the roundabout.

- ❖ 652 Passenger cars use the reversible side. This traffic volume should have to be correlated with the previous arrival and departure rates of that similar spot on section 4.1.3 The total traffic volume were 2716 passenger cars, arrived and departed passenger vehicles were 1608 and 1108 respectively. Therefore; the vehicles arrival rates calculated as $1608/2716 = 0.592$ the vehicle departure rates calculated as $1108/2716 = 0.408$ By using these the number of arrived and departed passenger vehicles from the reversible lane becomes $0.592 * 652 = 386\ passenger\ vehicles$ and $0.408 * 652 = 265\ Passenger\ vehicles$ respectively. Detail results of the first 5 minutes for the spot on Sealite-Mihret are listed in table 4.13

Table 4.13: Vehicles queue during morning peak hour (4:00–5:00 p.m.) Around Sealite-Mihret

Vehicle arrival and departure of peak direction with reversible lane volumes (Where Qi=0)			
Minutes	0.0167		Vehicle Queue (Veh-hr.)
	Pa (Veh)	Pd (Veh)	
0:00-1:00	34	20	0.2
1:00-2:00	34	20	0.7
2:00-3:00	32	24	1.1
3:00-4:00	32	22	1.8
4:00-5:00	34	21	2.9

- ❖ The total vehicle queue at the end of an hour for spot on Sealite-Mihret is Q (t) = 368 Veh-hr. which previously has a value of 254 Veh-hr. The reversible lane helps to decrease a vehicle queue of 114 Veh-hr. and the summations of departed vehicles are Pd = 1348 vehicles.

- To compute the time it takes to clear the queued vehicles is calculated by a formula$(Q(t))/Pd$. For spot on Sealite-Mihret the results become $\frac{368}{1348} = 0.257hr$.
- The minute required to clear the queued vehicle is $= 0.257 * 60 = 15.41\ Minutes$

Previous calculated times required to clear the queued vehicle at similar spot was 13.75 Minutes. Therefore, 1.66 Minutes of delay is saved by the operation of reversible lane at that specific location. If the reversible lane is not applied on the route, the vehicle queue could be raised from 182veh-hr. to 249veh-hr and from 255veh-hr to 368veh-hr. for St. Mikael and Sealite-Mihret segments respectively. Details of vehicle queue computation for both stated spots are attached in appendix C of tables 4.10 and 4.11.

5. CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

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

- While in evaluating the existed traffic congestion results indicated that, congestion is a concept beyond the serving capacity of roadway facilities. The maximum traffic flow exhibited on the morning and afternoon peaks are only 80% and 62% of the road segments capacity respectively. It shows a road way facility can be sufficient to the expected traffic, but it cannot give assurance for the level of service on them.

  The traffic flow trend in directional distribution analysis shows that, the vehicle distribution during off periods of the reversible lane operation shows; 167%, 142%, and 117% percentile difference after the morning peak reversible lane operation (i.e. 9:00-10:00 a.m.) and 117%, 139% and 116% percentile difference before the evening peak reversible lane operation (i.e. 3:00-4:00 p.m.) for Megenagna to Sealite-Mihret, Sealite-Mihret to CMC-Mikael and CMC to Ayat respectively. Even though the reversible lane operation ceased, result shows the Peak direction traffic still has greater distribution difference.

- Interruption from pedestrians and diverted vehicles, bottleneck geometrical features and safety conditions are the main identified challenges of the traffic management practice. For the first segment around Gurd-shola, the total vehicle queue Q(t) at the end of an hour is equals to 185.3 Veh-hr. and the time required to clear the queued vehicle is 10.38 minutes before the first hour of the morning reversible lane operation (i.e. 3:00 to 4:00 p.m.) in only considering the peak side volume. Delays for the other two segments during the first hour of p.m. reversible lane operation (i.e. 4:00-5:00 p.m.) are 11.13 Minutes and 13.74 Minutes for CMC-Saint Mikael and Sealite-Mihret segments respectively. There is 43.01% or 1617 passenger cars proportion difference between the underpass and adjacent lanes to the roundabout at Megenagna.

- ❖ Implementing the reversible lane as a remedial measure for the peak hour’s traffic helps in diverting the unbalanced traffic up to 14.92% and 21.22% of the peak traffic to the opposite direction on the morning and afternoon peak respectively. If the reversible lane is not applied on the route, the vehicle queue could be raised from 182veh-hr. to 249veh-hr and from 255veh-hr to 368veh-hr. for St. Mikael and Sealite-Mihret segments respectively. The time required to clear the congested traffic is decreased up to 1.67mintues.

5.2 Recommendations

The following recommendation forwarded for possible use by pertinent policy makers

- ❖ Results from the analysis of existed traffic congestion shown that, even in times where the reversible operation ceased, the Peak direction traffic still has greater distribution difference. The study recommends at least a one hour extension of time after the last morning reversible operation hour (i.e. 9:00-10:00 a.m.) and another one hour before the first evening reversible operation (i.e. 3:00-4:00 p.m.) at Sealite-Mihret and St. Mikael segments.

  Since there is a composite intervention both from vehicles and pedestrians, the maximum vehicles waiting time is exhibited on segment at Sealite-Mihret at the evening peak period. The study proposes giving a priority for this segment by using a traffic light with the existed roundabout as a remedial. Since the other adjacent approaching legs only have two lanes the proposing idea will have a significant functional improvement.
- ❖ Pedestrian crossing identified as one of the challenges on the existed traffic congestion. The result shows that, random crossing intervention becomes a cause for vehicle queue formation and delay. The study proposes the following two mechanisms to regulate the crossing patterns of pedestrians. The first mechanism could be regulating the pedestrian intervention by traffic light. The second mechanism can be complete separation of pedestrian movement by providing a crossing bridge. The first regulating mechanism has a better advantage in its cost effective and easiness to implement.

  There is a diverted traffic at Gurd-shola commercial bank junction which entered to the reversible lane by interrupting both the off peak and reversible traffic direction. Any vehicle which wants to access the reversible lane should have to use the roundabout at Sealite-Mihret. To overcome the bottleneck effects at Megenagna, the study proposes to increase cycle time of the traffic light for that leg which improves the traverse rate of vehicles and decrease vehicle queue at that segment.
- ❖ The peak period traffic management helps in diverting the unbalanced traffic up to 22% of the peak side volume. But there is a possibility to increase this percent by improving the safety issue on the reversible lane. It can be achieved by providing protective facilities which temporarily separates the opposite traffic to create the convenient driving environment. Creating awareness for the road users, maintaining the wear and tear reversible lane operation

guiding marks are also helpful. Their presence helps the new drivers by notifying the operation rules, and also serves as an alerting signs for any intend of violation from the off peak direction traffic. On street parking reduces road way efficiency in serving the traffic. Especially it narrows the width of the road and becomes the reason for congestion. Even though on street parking is prohibited on the route during the two peak periods, vehicles violate that rule and accessed the fourth route as a parking facilities. Intense follow up is needed to check the functionality of the rule. To get a better understanding on the safety issues of the reversible lane, accident data recording format should have to consider the reversible lane separately.

- Finally, the study recommends the following issues for future studies. The effects of light rail train presence on the traffic flow and drivers and pedestrian's perception about the applied mitigation measures can be a determining issue to assess.

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7. APPENDIX

Appendix A

Table 4.1: Directional Hourly Traffic Volume During reversible lane Operation within the Segments (8:00-9:00 AM)

	Count at Gurd-Shola		Count at CMC Mikael		Count at Ayat Zone-2	
Vehicle Types	**Peak Direction Volume**	**Off-Peak Direction Volume**	**Peak Direction Volume**	**Off-Peak Direction Volume**	**Peak Direction Volume**	**Off-Peak Direction Volume**
Car	1921	580	1548	1129	874	681
4WD	750	299	472	288	286	174
Small Bus	304	261	405	302	271	248
Medium Bus	63	29	46	40	20	26
Large Bus	54	66	72	65	35	31
Small Truck	23	34	23	8	29	26
Medium Truck	19	10	15	1	17	24
Heavy Truck With Trailer	5	5	3	3	5	1
Total Hourly Volume	3139	1284	2584	1836	1537	1211
Total (PCU) Hourly	3490	1608	3001	2149	1811	1473

Table 4.2: Directional Hourly Traffic Volume After reversible lane Operation within the Segments (9:00-10:00 AM)

	Count at Gurd-Shola		Count at CMC Mikael		Count at Ayat Zone-2	
Vehicle Types	**Peak Direction Volume**	**Off-Peak Direction Volume**	**Peak Direction Volume**	**Off-Peak Direction Volume**	**Peak Direction Volume**	**Off-Peak Direction Volume**
Car	1743	806	1466	1023	707	705
4WD	585	315	359	233	237	198
Small Bus	403	384	345	241	287	200
Medium Bus	37	16	33	31	11	16
Large Bus	49	35	50	47	18	13
Small Truck	44	63	16	8	36	13
Medium Truck	35	18	10	1	9	7
Heavy Truck With Trailer	1	2	3	3	2	1
Total Hourly Volume	2897	1639	2282	1587	1307	1153
Total (PCU) Hourly	3309	1980.5	2605	1829	1532	1309.5

Table 4.3: Directional Hourly Traffic Volume Before reversible lane Operation within the Segments (3:00-4:00 PM)

	Count at Gurd-Shola		Count at CMC Mikael		Count at Ayat Zone-2	
Vehicle Types	**Peak Direction Volume**	**Off-Peak Direction Volume**	**Peak Direction Volume**	**Off-Peak Direction Volume**	**Peak Direction Volume**	**Off-Peak Direction Volume**
Car	1396	1133	1440	984	667	652
4WD	375	380	389	227	194	163
Small Bus	368	312	359	318	224	165
Medium Bus	6	16	19	12	11	11
Large Bus	37	38	32	31	13	6
Small Truck	27	26	72	35	15	7
Medium Truck	22	7	16	16	9	5
Heavy Truck With Trailer	4	1	3	2	2	0
Total Hourly Volume	2235	1913	2330	1625	1135	1009
Total (PCU) Hourly	2561.5	2182	2657	1905.5	1308	1122.5

Table 4.4: Directional Hourly Traffic Volume During reversible lane Operation within the Segments (4:00-5:00 PM)

	Count at Gurd-Shola		**Count at CMC Mikael**		**Count at Ayat Zone-2**	
Vehicle Types	**Peak Direction Volume**	**Off-Peak Direction Volume**	**Peak Direction Volume**	**Off-Peak Direction Volume**	**Peak Direction Volume**	**Off-Peak Direction Volume**
Car	1514	1046	1437	849	735	659
4WD	326	241	421	222	245	262
Small Bus	253	269	371	335	190	186
Medium Bus	25	25	25	11	12	11
Large Bus	45	54	54	34	8	13
Small Truck	10	11	20	15	8	22
Medium Truck	3	0	15	8	5	9
Heavy Truck With Trailer	2	3	9	1	0	2
Total Hourly Volume	2178	1649	2352	1475	1203	1164
Total (PCU) Hourly	2422	1915.5	2716	1741.5	1334	1321.5

Table 4.5: Directional Hourly Traffic Volume within the Three Segments Third Hour of a.m. reversible lane operations (8:00-9:00 A.M.)

	Count at Gurd Shola	Count at CMC Mikael	Count at Ayat Zone-2
Vehicle Types	**Reversible lane Side Volume**		
Car	275	208	161
4WD	130	84	41
Small Bus	114	28	26
Medium Bus	5	3	2
Large Bus	0	4	1
Small Truck	8	12	7
Medium Truck	0	1	0
Heavy Truck With Trailer	0	0	0
Total Hourly Volume	532	340	238
Total (PCU) Hourly	596	372	258

Table 4.6: Directional Hourly Traffic Volume within the Three Segments First Hour of p.m. reversible lane operations (4:00-5:00 P.M.)

	Count at Gurd Shola	Count at CMC Mikael	Count at Ayat Zone-2
Vehicle Types	**Reversible lane Side Volume**		
Car	353	231	140
4WD	118	93	29
Small Bus	93	32	15
Medium Bus	5	5	0
Large Bus	2	5	1
Small Truck	13	12	7
Medium Truck	3	2	0
Heavy Truck With Trailer	0	0	0
Total Hourly Volume	587	380	192
Total (PCU) Hourly	653	419	205

Appendix B

Table 4.7 Vehicles queue during peak hour (3:00 – 4:00 p.m.) around Gurd-Shola

Vehicle arrival and departure; excluding reversible volume (Where Qi=0)			
Minutes	**0.0167**		**Vehicle Queue (Veh-hr.)**
	Pa (Veh)	**Pd (Veh)**	
0:00-1:00	19	16	0.1
1:00-2:00	20	16	0.2
2:00-3:00	26	15	0.7
3:00-4:00	26	19	1.2
4:00-5:00	23	17	1.7
5:00-6:00	28	17	2.8
6:00-7:00	24	19	3.4
7:00-8:00	25	16	4.6
8:00-9:00	23	18	5.3
9:00-10:00	24	21	5.8
10:00-11:00	18	19	5.7
11:00-12:00	22	17	6.7
12:00-13:00	20	17	7.3
13:00-14:00	25	19	8.7
14:00-15:00	26	18	10.7
15:00-16:00	28	21	12.6
16:00-17:00	21	19	13.1
17:00-18:00	24	16	15.5
18:00-19:00	21	18	16.5
19:00-20:00	19	18	16.8
20:00-21:00	21	19	17.5
21:00-22:00	20	18	18.3
22:00-23:00	22	19	19.4
23:00-24:00	29	19	23.4
24:00-25:00	19	18	23.8
25:00-26:00	22	19	25.1
26:00-27:00	25	17	28.7

27:00-28:00	24	17	32.0
28:00-29:00	27	19	35.9
29:00-30:00	22	19	37.4
30:00-31:00	24	21	38.9
31:00-32:00	17	16	39.4
32:00-33:00	25	16	44.4
33:00-34:00	24	18	47.8
34:00-35:00	25	18	51.9
35:00-36:00	24	19	54.9
36:00-37:00	21	18	56.7
37:00-38:00	26	17	62.4
38:00-39:00	25	18	67.0
39;00-40:00	24	16	72.3
40:00-41:00	25	19	76.4
41:00-42:00	22	20	77.8
42:00-43:00	27	21	82.1
43:00-44:00	26	18	88.0
44:00-45:00	24	17	93.2
45:00-46:00	21	19	94.8
46:00-47:00	24	18	99.5
47:00-48:00	20	15	103.5
48:00-49:00	27	17	111.6
49:00-50:00	21	19	113.3
50:00-51:00	25	18	119.2
51:00-52:00	23	16	125.3
52:00-53:00	26	18	132.4
53:00-54:00	24	16	139.6
54:00-55:00	28	16	150.6
55:00-56:00	28	19	159.0
56:00-57:00	24	16	166.6
57:00-58:00	25	19	172.4
58:00-59:00	21	14	179.3
59:00-60:00	25	19	185.3
Sum	**1414**	**1071**	

Table 4.8 Vehicles queue during peak hour (4:00 – 5:00 p.m.) Around CMC-Saint Mikael

Vehicle arrival and departure; excluding reversible volume (Where Qi=0)			
Minutes	0.0167		Vehicle Queue (Veh-hr.)
	Pa (Veh)	Pd (Veh)	
0:00-1:00	24	18	0.1
1:00-2:00	23	17	0.3
2:00-3:00	23	17	0.6
3:00-4:00	24	18	1.0
4:00-5:00	26	18	1.7
5:00-6:00	23	17	2.3
6:00-7:00	26	18	3.2
7:00-8:00	26	18	4.3
8:00-9:00	23	17	5.2
9:00-10:00	23	17	6.2
10:00-11:00	19	15	6.9
11:00-12:00	21	16	7.9
12:00-13:00	23	17	9.2
13:00-14:00	20	16	10.1
14:00-15:00	23	17	11.6
15:00-16:00	21	15	13.2
16:00-17:00	23	16	15.2
17:00-18:00	23	16	17.3
18:00-19:00	24	17	19.5
19:00-20:00	26	17	22.5
20:00-21:00	23	16	25.0
21:00-22:00	26	17	28.3
22:00-23:00	26	17	31.7
23:00-24:00	23	16	34.5
24:00-25:00	23	16	37.5
25:00-26:00	19	14	39.6
26:00-27:00	21	15	42.3
27:00-28:00	23	16	45.6

28:00-29:00	20	15	48.0
29:00-30:00	23	16	51.5
30:00-31:00	27	18	56.2
31:00-32:00	21	16	58.8
32:00-33:00	23	17	62.1
33:00-34:00	23	17	65.5
34:00-35:00	21	16	68.4
35:00-36:00	24	18	72.0
36:00-37:00	23	17	75.7
37:00-38:00	29	22	80.2
38:00-39:00	23	17	84.1
39;00-40:00	26	18	89.4
40:00-41:00	20	16	92.1
41:00-42:00	24	18	96.3
42:00-43:00	24	18	100.6
43:00-44:00	23	17	105.0
44:00-45:00	21	16	108.8
45:00-46:00	23	17	113.4
46:00-47:00	24	18	118.1
47:00-48:00	26	18	124.5
48:00-49:00	23	17	129.4
49:00-50:00	23	17	134.4
50:00-51:00	19	15	137.8
51:00-52:00	21	16	142.1
52:00-53:00	23	17	147.4
53:00-54:00	26	18	154.6
54:00-55:00	23	17	160.1
55:00-56:00	21	16	164.8
56:00-57:00	29	22	171.4
57:00-58:00	23	17	177.2
58:00-59:00	21	16	182.2
59:00-60:00	23	17	188.2
Sum	**1391**	**1014**	

Table 4.9 Vehicles queue during peak hour (4:00 – 5:00 p.m.) around Sealite-Mihret

Vehicle arrival and departure; excluding reversible volume (Where Qi=0)			
Minutes	**0.0167**		**Vehicle Queue (Veh-hr)**
	Pa (Veh)	**Pd (Veh)**	
0:00-1:00	27	16	0.2
1:00-2:00	27	16	0.6
2:00-3:00	25	20	0.8
3:00-4:00	25	18	1.3
4:00-5:00	27	17	2.1
5:00-6:00	28	17	3.2
6:00-7:00	21	19	3.4
7:00-8:00	28	18	4.8
8:00-9:00	27	18	6.1
9:00-10:00	28	21	7.3
10:00-11:00	26	19	8.6
11:00-12:00	27	17	10.6
12:00-13:00	25	17	12.3
13:00-14:00	28	19	14.4
14:00-15:00	27	18	16.7
15:00-16:00	29	21	18.8
16:00-17:00	27	19	21.1
17:00-18:00	26	16	24.1
18:00-19:00	28	24	25.3
19:00-20:00	26	18	28.0
20:00-21:00	27	19	30.8
21:00-22:00	25	18	33.4
22:00-23:00	25	17	36.4
23:00-24:00	29	19	40.4
24:00-25:00	28	18	44.6
25:00-26:00	25	19	47.2
26:00-27:00	28	17	52.1
27:00-28:00	27	19	55.9
28:00-29:00	28	19	60.2
29:00-30:00	25	19	63.2

30:00-31:00	27	21	66.3
31:00-32:00	26	16	71.7
32:00-33:00	27	16	77.7
33:00-34:00	28	22	81.1
34:00-35:00	27	18	86.4
35:00-36:00	26	19	90.6
36:00-37:00	25	18	94.9
37:00-38:00	27	22	98.0
38:00-39:00	28	18	104.5
39;00-40:00	28	16	112.5
40:00-41:00	29	19	119.4
41:00-42:00	27	20	124.3
42:00-43:00	29	21	130.0
43:00-44:00	28	18	137.3
44:00-45:00	27	17	144.8
45:00-46:00	28	19	151.7
46:00-47:00	27	18	158.8
47:00-48:00	26	15	167.6
48:00-49:00	28	17	176.6
49:00-50:00	27	19	183.2
50:00-51:00	29	18	192.6
51:00-52:00	27	16	202.1
52:00-53:00	28	20	209.2
53:00-54:00	26	19	215.5
54:00-55:00	27	20	221.9
55:00-56:00	28	23	226.6
56:00-57:00	28	16	238.0
57:00-58:00	24	19	242.8
58:00-59:00	23	17	248.7
59:00-60:00	25	19	254.7
Sum	**1609**	**1108**	

Appendix c

Table 4.10 Vehicles queue during peak hour (4:00 – 5:00 p.m.) around St-Mikael

Vehicle arrival and departure of peak direction with reversible lane volumes (Where Qi=0)			
Minutes	**0.0167**		**Vehicle Queue (Veh-hr.)**
	Pa (Veh)	**Pd (Veh)**	
0:00-1:00	28	21	0.1
1:00-2:00	29	18	0.5
2:00-3:00	29	18	1.0
3:00-4:00	28	21	1.5
4:00-5:00	30	21	2.3
5:00-6:00	27	20	3.0
6:00-7:00	33	19	4.6
7:00-8:00	33	19	6.5
8:00-9:00	27	20	7.5
9:00-10:00	27	20	8.7
10:00-11:00	23	18	9.6
11:00-12:00	25	19	10.8
12:00-13:00	27	20	12.3
13:00-14:00	24	19	13.5
14:00-15:00	29	18	16.2
15:00-16:00	25	18	18.1
16:00-17:00	27	19	20.4
17:00-18:00	27	19	22.8
18:00-19:00	28	20	25.3
19:00-20:00	30	20	28.6
20:00-21:00	27	19	31.4
21:00-22:00	30	20	35.1
22:00-23:00	30	20	38.9
23:00-24:00	27	19	42.1
24:00-25:00	27	19	45.5
25:00-26:00	23	17	48.1
26:00-27:00	25	18	51.2
27:00-28:00	27	19	54.9

28:00-29:00	24	18	57.8
29:00-30:00	27	19	61.8
30:00-31:00	31	21	67.0
31:00-32:00	29	15	74.5
32:00-33:00	27	20	78.3
33:00-34:00	27	20	82.3
34:00-35:00	25	19	85.8
35:00-36:00	28	21	90.0
36:00-37:00	27	20	94.3
37:00-38:00	33	25	99.4
38:00-39:00	27	20	103.9
39;00-40:00	30	21	109.9
40:00-41:00	27	16	117.4
41:00-42:00	28	21	122.3
42:00-43:00	28	21	127.4
43:00-44:00	27	20	132.5
44:00-45:00	25	19	137.0
45:00-46:00	27	20	142.4
46:00-47:00	28	21	147.8
47:00-48:00	30	21	155.0
48:00-49:00	29	18	164.0
49:00-50:00	29	18	173.2
50:00-51:00	23	18	177.4
51:00-52:00	25	19	182.6
52:00-53:00	27	20	188.8
53:00-54:00	30	21	196.9
54:00-55:00	27	20	203.3
55:00-56:00	25	19	208.9
56:00-57:00	33	25	216.5
57:00-58:00	27	20	223.3
58:00-59:00	28	16	235.1
59:00-60:00	31	17	249.1
Sum	**1661**	**1167**	

Table 4.11 Vehicles queue during peak hour (4:00 – 5:00 p.m.) around Sealite-Mihret

Vehicle arrival and departure of peak direction with reversible lane volumes (Where Qi=0)			
Minutes	**0.0167**		**Vehicle Queue (Veh-hr.)**
	Pa (Veh)	**Pd (Veh)**	
0:00-1:00	34	20	0.2
1:00-2:00	34	20	0.7
2:00-3:00	32	24	1.1
3:00-4:00	32	22	1.8
4:00-5:00	34	21	2.9
5:00-6:00	35	21	4.3
6:00-7:00	28	23	4.8
7:00-8:00	35	22	6.6
8:00-9:00	34	22	8.4
9:00-10:00	35	25	10.0
10:00-11:00	33	23	11.9
11:00-12:00	34	21	14.5
12:00-13:00	32	21	16.9
13:00-14:00	35	23	19.7
14:00-15:00	34	22	22.7
15:00-16:00	36	25	25.6
16:00-17:00	34	23	28.7
17:00-18:00	33	20	32.6
18:00-19:00	35	28	34.8
19:00-20:00	33	22	38.5
20:00-21:00	34	23	42.3
21:00-22:00	32	22	46.0
22:00-23:00	32	21	50.2
23:00-24:00	36	23	55.4
24:00-25:00	35	22	60.8
25:00-26:00	32	23	64.7
26:00-27:00	35	21	71.0
27:00-28:00	34	23	76.2
28:00-29:00	35	23	82.0

29:00-30:00	32	23	86.5
30:00-31:00	34	25	91.1
31:00-32:00	33	20	98.1
32:00-33:00	34	20	105.8
33:00-34:00	35	26	110.9
34:00-35:00	34	22	117.9
35:00-36:00	33	23	123.9
36:00-37:00	32	22	130.0
37:00-38:00	34	26	135.1
38:00-39:00	35	22	143.5
39;00-40:00	35	20	153.5
40:00-41:00	36	23	162.4
41:00-42:00	34	24	169.4
42:00-43:00	36	25	177.3
43:00-44:00	35	22	186.8
44:00-45:00	34	21	196.6
45:00-46:00	35	23	205.8
46:00-47:00	34	22	215.2
47:00-48:00	33	19	226.4
48:00-49:00	35	21	237.8
49:00-50:00	34	23	247.0
50:00-51:00	36	22	258.9
51:00-52:00	34	20	271.0
52:00-53:00	35	24	280.7
53:00-54:00	33	23	289.7
54:00-55:00	34	24	298.9
55:00-56:00	35	27	306.4
56:00-57:00	35	20	320.6
57:00-58:00	31	23	328.4
58:00-59:00	30	21	337.2
59:00-60:00	32	23	346.2
Sum	**2029**	**1348**	

APPENDIX D

Traffic Count Format

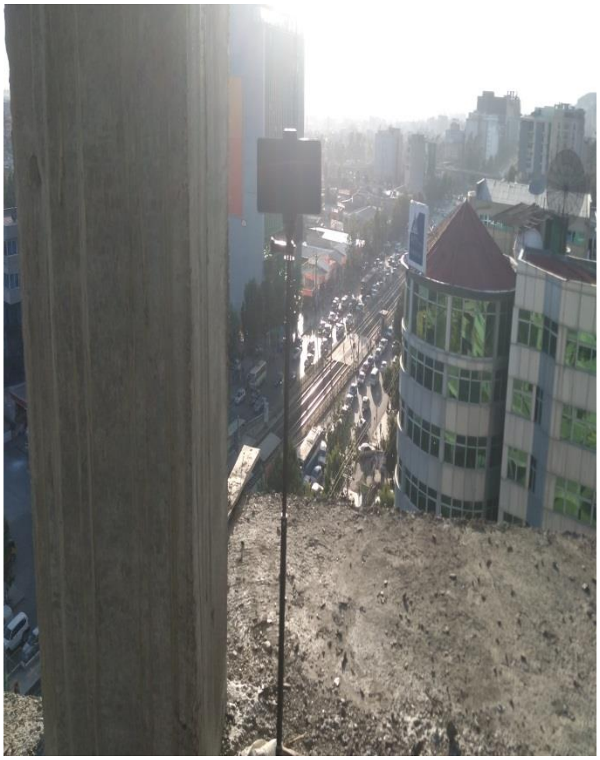
Location____________________ Direction__________________ Date______/______/______

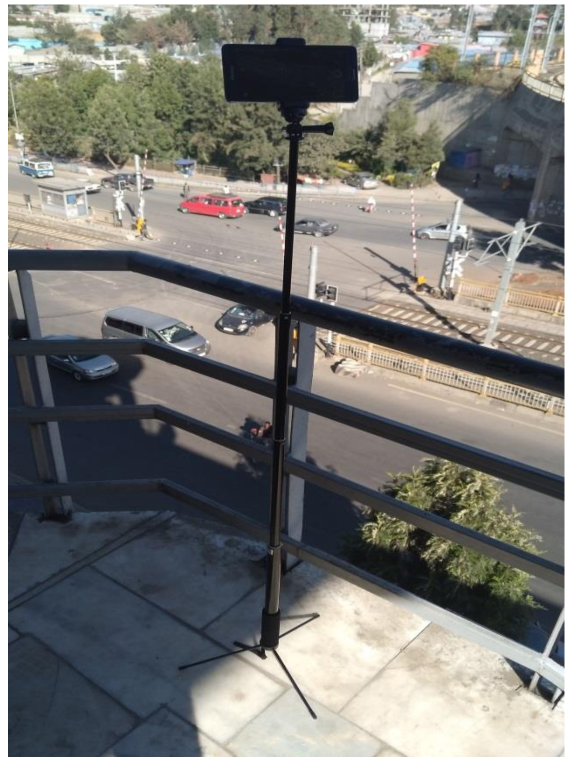
Enumerator: _________________ Weather Condition: _______________________

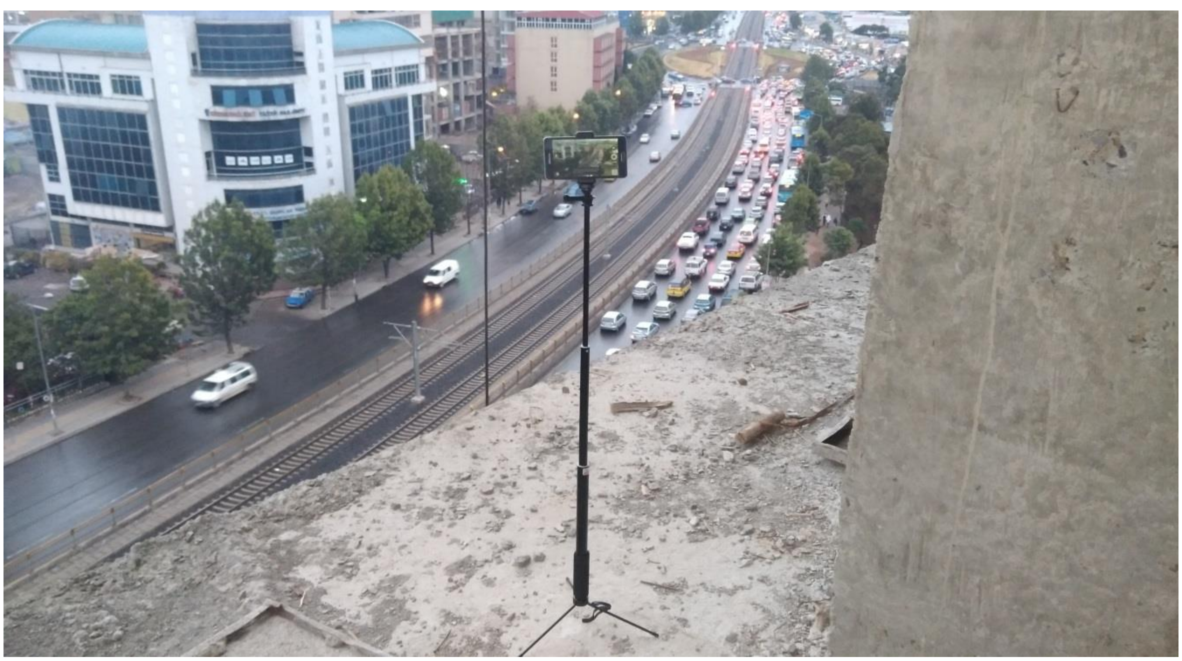
Time (Minutes)	Vehicle Type								
	Cars	Land rover	Small bus < 27 Seats	Medium Bus 27-45 Seats	Large Bus □ 45 Seats	Small Truck 3.5 Tones	Medium Truck 7.5 Tones	H/Truck with Trailer 7.5-12 Tones	Remark
1 to 15									
15 to 30									
30 to 45									
45 to 60									

APPENDIX E

Camera locations for data recording at St. Mikael, Ayat & Gurd-Shola respectively







Violation of reversible lane usage by opposite traffic

Pedestrian crossing intervention around St. Mikael

Wear and Tear of reversible markings around Gurd-shola