EVALUATING THE TRAFFIC OPERATIONAL PERFORMANCE IN ADDIS ABABA:
A CASE OF MEGENAGNA TO AYAT ROAD CORRIDOR

M.Sc. THESIS

BETHLEHEM TILAHUN GEBRE

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

JANUARY, 2021

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THESIS SUBMITTED TO

HAWASSA UNIVERSITY, DEPARTMENT OFCIVILENGINEERING,

INSTITUTE OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES,

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF

MASTER OF SCIENCE IN CIVIL ENGINEERING

SPECIALIZATION: (ROAD AND TRANSPORT ENGINEERING)

JANUARY, 2021

SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

ADVISORS' APPROVAL SHEET

This is to certify that the thesis entitled: "**EVALUATING THE TRAFFIC OPERATIONAL PERFORMANCE IN ADDIS ABABA: A CASE OF MEGENAGNA TO AYAT ROAD CORRIDOR"** submitted in partial fulfillment of the requirements for the degree of **Master of Science** with specialization in **Road and Transport Engineering**, the Graduate program of the **Department of Civil Engineering** and has been carried out by **BETHLEHEM TILAHUN,** Id number **PGRoTrR/004/11** under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department office.

Prof. Emer T.Quezon,P.E., Dr.(hc) ________________ ________________

Name of Major Advisor Signature Date

Mr Aschalew Mersha (MSc) ______________ ________________

Name of Co-advisor Signature Date

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We, the undersigned, members of the Board of Examiners of the final open defense by **BETHLEHEM TILAHUN,** have read and evaluated her thesis entitled "**EVALUATING THE TRAFFIC OPERATIONAL PERFORMANCE IN ADDIS ABABA: A CASE OF MEGENAGNA TO AYAT ROAD CORRIDOR**" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the Degree.

Tigest Asefa (MSC) Name of the Chairperson	________________ Signature	____________________ Date
Temesgen Ayenabeba (Msc) Name of Internal Examiner	_________________ Signature	____________________ Date
Dr. Robeam Solomon Name of External examiner	___________________ Signature	___________________ Date
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ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my advisors prof. Emer T. Quezon and Mr Aschalew Mersha for their excellent guidance, critical comments and kind encouragement throughout this study. It is a wonderful experience working with them and I am grateful for their advice. And I would like to thank ERA (Ethiopian Road Authority) for giving this full scholarship.

I would like to thank Addis Ababa city traffic management office especially Ato Henoke for their collaboration and positive reactions.

My deepest gratitude goes to Benyam Haile, Desalegne Mengesha, Samrawite Gebeyehu and Abeba Tilahun for their support during the data collections phase and typing the necessary documents.

And finally I am appreciative of the support and assistance of my families and friends.

DECLARATION

I hereby declare that this MSc thesis titled "**EVALUATING THE TRAFFIC OPERATIONAL PERFORMANCE IN ADDIS ABABA: A CASE OF MEGENAGNA TO AYAT ROAD CORRIDOR**" 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: **Bethlehem Tilahun Gebre**

Signature: ______________________

This MSc has been submitted for examination with my approval as Thesis advisor.

Name: **Prof. Emer T.Quezon,P.E., Dr.(hc)**

Signature: ____________________________________

Place and Date of Submission: ______________________________

ACRONYMS AND ABBRIVATIONS

ANOVA	Analysis Of Variance
Deg	Degree
DOS	Degree of Saturation
FHWA	Federal Highway Authority
HCM	High way Capacity Manual
Hr	Hour
LOS	Level of Service
LT	Left Turn
MOE	Measure of Effectiveness
Mov	Movement
NCHRP	National Cooperative Highway Research Program
PCU	Passenger Car Unit
RT	Right Turn
Sec	Second
SIDRA	Signalized & Un-signalized Intersection Design & Research Aid
SPSS	Statistical Package for Social Science
TH	Through movement
V/C	Volume to Capacity ratio
Veh	Vehicle
Veh/hr	Vehicle per hour

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ABSTRACT

Poor traffic performance is a major problem in many countries affecting urban traffic sustainable development at present. It has a significant effect on social, economic, and environmental. Due to economic development and urbanization, transport in Addis Ababa has faced traffic congestion problems. This paper presents a study on the evaluation of operational performance of traffic in Addis Ababa in the case of the Megenagna to Ayat road network by addressing the factors that cause traffic congestions. LOS, average delay, and degree of saturation were quantified for three roundabouts using SIDRA software to analyze the traffic conditions in the study area. And Levels of service for three road segments were quantified using HCM 2010. A multiple regression analysis using SPSS was applied to quantify the factors that cause congestion on the performance of the road network based on questionnaire and field data. From the analysis, average speed of Ayat to Yetebaberute, Yetebaberute to Sahilitmiheret, Sahilitmiheret to Megenagna road segments were 11.6km/hr, 6.3km/hr & 5.45km/hr respectively and it was 30.08%, 26.14% & 22.59% of the free flow speed respectively. The LOS of these three road segments was F, and the traveler perception score was greater than 5, indicating drivers perceived the worst service. And for the three roundabouts i.e., Sahilitmiheret, Yetebaberute, and Ayat roundabouts, the overall LOS was F, so the degree of saturation is greater than 1 with the overall average delay of 405.20sec, 211sec and 310.2sec, respectively. The results from SIDRA software indicated that the roundabouts are providing traffic service above their capacity during the peak hour. From the SPSS result of the mean-variance results are significant at 0.05(p-0.05), which means that the factors caused traffic congestion in the study area. The regression model developed with R^2 of 0.985, which is greater than 0.7, which shows the model was reliable. Based on the result of the study, the roundabouts were over congested; their operational characteristics were unsatisfactory, serving beyond their capacity & at a poor level of service. And the roundabouts contribute significant effect for the performance of the segments. The performance of the road network was poor and cause significant delay for the user. The factors that contribute for the poor traffic performance in the study area were significant to cause congestion.

Keywords: *Performance, Road segment, Roundabout, LOS, Delay, Degree of saturation*

1. INTRODUCTION

1.1 Background

Operational analyses is oriented toward current or near-term conditions aiming at providing information for decisions on whether there is a need for improvements to an existing point, segment, or facility (HCM, 2010). And performance refers to how successfully a task, system or operation functions (Matthew & Konstantinos, 2012). According to HCM 2010 a performance measure can be defined as a "quantitative or qualitative characterization of some aspect of the service provided to a specific road user group".

In transport sector the ultimate purpose of measuring performance is to improve transportation services for customers (Kane, 2005). The Highway Capacity Manual Level of Service and Volume/Capacity are the two commonly used MOE to qualify the facility performance (Traffic analysis handbook, 2014). And degree of saturation, delay, and queue length are typically used to measure the performance of intersections especially roundabouts (FHWA, 2000). Each measure provides a unique perspective on the quality of service at which a roundabout will perform under a given set of traffic and geometric conditions. And SIDRA is a very powerful analytical program for the analysis of the roundabouts that found in the study road network.

The operational efficiency of a road network largely depends on the prevailing road, traffic, driver and control conditions. The urban traffic congestion has been becoming a more and more serious issue and it posed significant problems worldwide. Currently, traffic congestion, delay, and unreliability are terms that are most associated with present-day travel, in which transport users spend their precious time on long traffic queues. The increment in the demand for private transportation will also hinder the traffic movement during peak hours (Yahia 2017; Yahia *et al*. 2017). Additionally, flows in the public transport system will result in longer waiting time (delay), and also very little headways between vehicles.

Developing countries have experienced high population growth. The increment of the population led to increase the demand for urban transport which make the transport system overloaded and cause serious road congestion (Mistro & Mfinanga, 2011). A good established transportation system is not only a key to national growth but also serves as catalyst for economic development of a country (Lu *et al*. 2009).

Presently, Ethiopia is one of the counties that are in rapid economic development. As Addis Ababa is the capital city of the country, urbanization and industrialization with high population number are the major features of the city, which influence the transportation system of the community. Currently Addis Ababa is showing low motorization rates as compared to global standards with the coverage of 9motor vehicle per 1000 people and ranked as 153th from 160 countries (JSTOR, 2019). From the total vehicle fleet in Ethiopia estimated as 831,265 which is 62 percent of the total fleet of the country found in Addis Ababa in 2018, which faces high challenges of providing provision of efficient, reliable, and safe transportation (Addis Ababa City Roads and Transport Bureau, 2018). Additionally, the quick economic progress at this time experienced in the city leads attracting business organizations, increase in private vehicle ownership which is also aggravating the challenges.

Evaluation of the operational performance of traffic on the road network is very necessary for future traffic planning, design, operation and maintenance. This study aimed to evaluate the performance of the road network in terms of measure of effectiveness parameters since a good established transportation system is a key to national growth and catalyst for economic development of a country, and this study determine the main factors that affect the traffic performance in order to improve the performance operation of the urban road network by proposing the proper alternatives to enhance the traffic capacity.

1.2 Statement of problem

Nowadays, traffic congestion, delay, and unreliability are terms that are most associated with present-day travel, in which transport users spend their precious time on long traffic queues (Seada & Emer, 2019). Due to economic and social development of cities in the world urban traffic congestion becomes severe which affect the transport system by increasing ownership of vehicles in turn which lead to traffic congestion.

As Addis Ababa is the capital city of Ethiopia, road traffic problem related with poor traffic operational performance is the major feature of the city. Despite the intensive road network expansion, the city has been facing traffic congestion problem which decrease the performance of the traffic movement (Temesgen, 2015). Additionally, there is lack of coordination between transport investments and urban developments.

The main problem of the poor traffic operation on the selected road network is associated with large vehicular queue which results high delay to work place & schools and poor accessibility & mobility for the road users especially in the morning and evening time which increase travel time. This makes the traveler to lose the most precious time in the road due to queuing, by waiting longer time for buses & taxies. Due to this, the productivity of the society is affected by decreasing the working hour. And indirectly it increases air & noise pollution.

There are different factors that aggravates the traffic congestion on the selected road segment like shortage of mass transport, the existence of high number of pedestrian at mid-block section and at entry & exit of the roundabouts, imbalance of vehicle & road capacity especially at the entry of intersection, parking of passenger cars, informal street trading, the land use condition and to some extent traffic accident.

Most researches related to traffic performance in Addis Ababa deals only about intersections especially signalized intersections rather to include roundabouts and road segments. Little attention has been paid to include the whole road network, segment and roundabouts. There are only little attempts made by Tewdros, 2007 and Temsgen, 2015 to assess the capacity of roundabout in their thesis researches. And on the study road network one research was done by Sileshi, 2019 to assess the Socio-economic impact of traffic congestion. In his research he fails to show the traffic performance of the road network & the roundabouts, and to model the factors that cause congestion. Without showing and following clear and detail methodology to show whether there is traffic congestion or not he simply deal with the impact.

This study fills the gap by evaluating the selected road corridor performance including road segments and the roundabouts which found in the study corridor. Furthermore this study modeled the factors that cause poor traffic performance related to the traffic parameter based on questionaries' and filed data.

In view of the above, it is found to conduct a research to evaluates the traffic operational performance of the road network in Addis Ababa and come up with some possible engineering solution to counter this problem.

1.3 Objectives

1.3.1 General Objective

The general objective of this study was to evaluate the performance of the traffic operation on selected routes in Addis Ababa.

1.3.2 Specific Objectives

- To evaluate the traffic performance of the roundabout on the selected road segment in terms of LOS, delay and degree of saturation using SIDRA intersection software.
- To analyze the traffic behavior of the road segment in terms of LOS using HCM 2010.
- To model the travel time considering factors affecting traffic flow using multiple linear regression model.

1.4 Research Questions

There are some questions occurred and need to answer. These are:-

1. What are the expected performances of the intersections?
2. What are the expected performances of the road segments?
3. At what level the traffic performances are affected by influencing factors?

1.5 Significant of the Study

The urban traffic congestion has been becoming a more & more serious issue, especially in the developing countries like Ethiopia. The good established transportation system is not only key to national growth but also serve as catalyst for economic development of a country. An effective transportation system is essential to economic activities & quality of life.

The research on evaluating the operational performance of traffic has a wide range of significance for both the researcher & for the study area.

It helps the researcher to have a better understanding regarding the measure of performance and helps to see the correct traffic condition in the study area. And also helps to predict what will happen in the near future. The findings are quite essential for the traffic planner in making judicious decisions regarding the roundabout performance.

It helps to take significant counter measures to improve the transportation system and to improve the traffic management system by identifies specific areas that need more improvements in order to improve the traffic operational performance.

Finally the study will help the researcher to fulfill the partial requirement for being awarded the degree of Master of Science in Road & Transport Engineering at Hawassa University.

2. LITERATURE REVIEW

2.1 Introduction

Traffic analysis is the process of evaluating the effect of traffic demand and supply on the performance of a transportation facility in relation to meeting goals and objectives of the facility. Demand is the amount of traffic load that intends to use the facility while supply is the capacity of the facility to handle the demand. (Transportation association of Canada, 2006)

There are different levels of traffic analysis which can be grouped as: Generalized (sketch-level) planning analysis, conceptual planning and preliminary engineering analysis, design analysis and operational analysis. (Transportation Association of Canada, 2006)

According to highway capacity manual, Operational analyses are generally oriented toward current or near-term conditions. They aim at providing information for decisions on whether there is a need for improvements to an existing point, segment, or facility. Occasionally, an analysis is made to determine whether a more extensive planning study is needed. Sometimes the focus is on a network, or part of one, that is approaching oversaturation or an undesirable LOS: When, in the near term, is the facility likely to fail (or fail to meet a desired LOS threshold)? To answer this question, an estimate of the service flow rate allowable under a specified LOS is required. (HCM, 2010)

2.1.1 Definition of Performance Evaluation

Performance evaluation is commonly encountered in a number of activities and processes relating to engineering, economics, health, and so on. Its definition is straightforward, in that performance essentially refers to how successfully a task, system or operation functions. From this perspective, performance measurement is a task required for assessing and improving characteristics and operations of a system, process, or infrastructure. (Matthew & Konstantinos, 2012)

A comprehensive definition of performance measurement as offered by the US Federal highway Administration stated, “Performance measurement is a process of assessing progress toward achieving predetermined goals, including information on the efficiency with which resources are transformed into goods and services (outputs), the quality of those outputs (how well they are delivered to clients and the extent to which clients are satisfied) and outcomes (the results of a program activity compared to its intended purpose), and the effectiveness of government operations in terms of their specific contributions to program objectives.” (Shaw, 2003)

The assessments of current & future conditions of road infrastructures and evaluation of road agencies efficiency with respect to provided services, productivity, and protection of the environment, cost-effectiveness & so on are some of reasons to measure the performance in the road sector. (Haas *et al*. 2009)

A performance measure can be defined as a “quantitative or qualitative characterization of some aspect of the service provided to a specific road user group”. (HCM, 2010)

2.1.2 Why Measure Performance

Performance indicators are an essential part of modern road asset management. The ultimate purpose of measuring performance in transport sectors is to improve transportation services for customers (Kane, 2005) and to quantify the achievement of a project's traffic operations objectives. Within that simple statement, two important emphases are contained: one regarding customers and the second regarding improving services.

The basic rationale for having measureable performance indicators is that limited availability of resources makes it necessary to allocate these resources as effectively as possible among competing alternatives; moreover, that considerations of safety, capacity, serviceability, functionality and durability are explicitly recognized. (Karlaftis & Kepaptsoglou, 2012).

2.2 Performance Measures

According to FHWA (traffic analysis tools volume VI, 2007), there are a numerous performance measures and grouped in to different categories. These are input performance measures, basic performance measures and derived performance measures.

Input performance measures, such as v/c ratio, are necessary for computing the basic travel time, speed, and delay performance measures. Travel time and speed are interchangeable. If one is known the other can be computed. Basic performance measures are those measures, which cannot be derived from other performance measures. Capacity, speed, and its inverse, travel time, number of stops and travel time reliability are some of the basic performance measures. The other performance measures can be computed from these measures. (FHWA traffic analysis tools volume VI, 2007)

Derived performance measures are those that could be computed from the basic performance measures and other inputs. Some of derived performance measures are Volume or throughput which can be computed from demand and capacity, and it also an input to several performance measures, delay which is the difference between ideal travel time and the actual travel time, density, queue length, travel Distance & volume to capacity ratio (V/C). Others like noise, fuel consumption, and pollutant emissions are measures that can be calculated from the other measures of volume, speed, delay and stops. (FHWA traffic analysis tools volume VI, 2007)

2.3 Developing Performance Measure

Development of appropriate performance measures (or indicators) is required for linking transportation and infrastructure data for road management. Performance indicators can be defined as a tool enabling for the effectiveness of an operation to be measured; or, to achieve result to be gauged or evaluated in relation to a set of objectives. (Karlaftis & Kepaptsoglou, 2012)

Objectives related to introducing performance indicators may be the following (Humplick & Paterson, 1994; Haas *et al.*, 2009):

1. Physical condition assessment, with respect to level of service offered, structural integrity and safety provision of infrastructures,
2. Support in management of the road network in terms of decision making for investments, expenditures and operations,
3. Diagnosis of critical network elements with respect to deterioration and remedial action related to decision making,
4. Tracking and monitoring of policies with respect to their effectiveness and compliance with associated objectives,
5. Information provision to road users and road service players,
6. Optimal allocation of resources through the quantification of the efficiency of road investments and other road administrative activities,
7. Cost (and relevant data) tracking with respect to construction and maintenance of road infrastructures and equipment.

Performance indicators can be exploited in a variety of manners, including in-house decision making and better communication between different road network stakeholders. (Transportation Association of Canada, 2006)

Performance indicators are expected to measure, among other issues like Compliance with operational and policy objectives, efficiency of transportation service providers, the relationship between policy makers and the road administrator. (Karlaftis and Kepaptsoglou, 2012)

The NCHRP Report 446 (Cambridge Systematics, 2000) raises particular issues with respect to selecting performance indicators for a road network. First, performance indicators should be suitable for forecasting purposes in order to assess future conditions and characteristics of alternative road management programs. Second, indicators must be straightforwardly understood by stakeholders. Third, indicators should be useful; such measures should aptly reflect objectives and capture cause-effect conditions between the actions of administrators and their results. An indicator's ability to diagnose problems should be considered as well; the indicator should reflect those actions that affect it.

Fourth is indicator selection process: temporal effects of the measure (is the measure comparable across time?), and compatibility to programming of actions (can the measure be used for developing a program of actions, budgeting and so on?). A summary of the most important properties of performance indicators are summarized in Table 2.1

Table 2.1 Major properties of performance indicators

Property	**Description**
Relevance	The indicator must be relevant to the purpose it was developed for
Clarity	The indicator must be clearly defined
Reliability	Measurements for obtaining the indicator should not be affected from the process or person performing them
Precision	As precise measures as possible should be anticipated
Availability	An indicator should be • Readily available as long as the cost of obtaining them does not exceed their usefulness. • still useful and up-to-date when available to the road administrator

Source: (Transportation Association of Canada, 2006)

Other issues that should be considered when selecting performance measures to evaluate a road network indicated in table 2.2

Table 2.2 Major properties of performance indicators

Forecast ability	Is it possible to compare future alternative projects or strategies using this measure?
Clarity	Is it likely to be understood by transportation professionals, policy makers and the public?
Usefulness	Does the measure reflect the issue or goal of concern? Is it an indicator of condition, which could be used as a trigger for action? Does it capture cause-and-effect between the agency's actions and condition?
Ability to diagnose problems	Is there a connection between the measure and the actions that affect it? Is the measure too aggregated to be helpful to agencies trying to improve performance?
Temporal Effects	Is the measure comparable across time?

Source: (TRB, 2000)

2.4 Performance Measures of Effectiveness (MOEs)

Numerical outputs from the traffic analysis are the MOEs which are metrics used to assess the performance of a system. MOEs are also used to compare and contrast the system performance under various design or improvement alternates. (Traffic analysis handbook, 2014)

The purpose of computing one or more traffic performance measures of effectiveness is to quantify the achievement of a project's traffic operations objectives. There are different parameters used to quantify the operational performance of traffic.

There are two commonly used MOE to qualify the facility performance. These are: Level of Service and Volume/Capacity (Traffic analysis handbook, 2014). In addition to these some of the required measures of effectiveness, which are the building blocks of most existing and potential future systems for evaluating the traffic operations performance of highway facilities, are: Travel time, speed, and delay are closely related measures of the amount of time that the general public must expend in order to complete their trips on the system. (FHWA traffic analysis tools volume VI, 2007)

2.4.1 Performance Measure for Road Segments

2.4.1.1 Level of Service

The level-of-service concept was introduced in the 1965 HCM as a convenient way to describe the general quality of operations on a facility with defined traffic, roadway, and control conditions. Using a letter scale from A to F, a terminology for operational quality was created that has become an important tool in communicating complex issues to decision-makers and the general public. (Bhuyan & Nayak, 2013)

Level of service (LOS) is 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". (HCM, 2010) It is readily recognizable indicator of traffic operations and has been widely used by different agencies when evaluating the traffic operations performance of facility. (FHWA traffic analysis tools volume VI, 2007)

Level of service (LOS) qualitatively measures both the operating conditions within a traffic system and how these conditions are perceived by drivers & passengers. It is related with the physical characteristics of the highway and the different operating characteristics that can occur when the highway carries different traffic volumes.

Two performance measures are used to characterize vehicular LOS for a given direction of travel along an urban street segment. One measure is travel speed for through vehicles. This speed reflects the factors that influence running time along the link and the delay incurred by through vehicles at the boundary intersection. The second measure is the volume-to-capacity ratio for the through movement at the downstream boundary intersection. These performance measures indicate the degree of mobility provided by the segment. (HCM, 2010)

Table 2.3 LOS thresholds for automobile mode on urban streets

Travel speed as a percentage of Base free flow speed (%)	LOS by volume-to-capacity ratio	
	$\leq$1.0	>1.0
>85	A	F
>67-85	B	F
>50-67	C	F

>40-50	D	F
>30-40	E	F
≤30	F	F

Volume-to-capacity ratio of through movement at downstream boundary intersection

Source: (HCM, 2010)

Poor letter grade levels of service (e.g., "F") and volume/capacity ratios greater than 1.00 are readily recognizable indicators of poor traffic operations. (Traffic analysis handbook, 2014)

2.4.1.2 Volume to Capacity Ratio

Volume to Capacity ratio is the ratio of the flow rate to capacity for a system element. It is a special-case for service measure. It cannot be directly measured in the field, nor is it a measure of traveler perceptions. Until capacity is reached (i.e., when flow breaks down on uninterrupted-flow facilities and when queues build on interrupted- or uninterrupted-flow facilities), the v/c ratio is not perceivable by travelers". V/C ratio is an MOE compatible with interrupted flow (i.e., arterial networks), but may also be useful for comparison purposes as a surrogate measure on uninterrupted flow facilities, such as freeways. (HCM, 2010)

Table 2.4 LOS analysis and volume/capacity ratio

LOS	Description	Volume/capacity
A	Represents a free flow. Individual users are virtually unaffected by others in the traffic stream. Freedom to select desired speeds and to maneuver within the traffic stream is extremely high.	0.00-0.60
B	Represents the range of stable flow but the presence of other users in the traffic stream begins to be noticeable. Freedom to select desired speeds is relatively unaffected but there is a slight decline in the freedom to maneuvers within the traffic stream from LOS A.	0.61-0.70
C	Stable operation with somewhat more restriction in making midblock lane changes than LOS B. motorist will experience appreciable tension while driving	0.71-0.80
D	Represents high-density but stable flow. Speed and freedom to maneuvers are severely restricted	0.81-0.90
E	Represents operating conditions at or near capacity level. All speeds are reduced to a low but relatively uniform value. Freedom to maneuver within the traffic stream is extremely difficult.	0.91-1.00

F	Represents forced or breakdown flow.	Greater than 1.0

Source: (Aftabuzzaman, 2007)

Based on Joshua and Iyiola (2009) the average capacity/volume ratio and intensity of congestion as depicted in table 2.5

Table 2.5 Average capacity/volume ratio and congestion

Average traffic V/Co ratio	Technical interpretation
Less than 0.6	No congestion
0.6 to 0.8	Slight congestion
0.8 to 1.0	Congestion
1.0 to 1.2	Sever congestion
Greater than 1.2	Extreme congestion

Source: (Joshua & Iyiola, 2009)

2.4.1.3 Speed

According to the HCM 2010, “speed reflects how fast motorists can traverse a roadway section, including the effects of traffic-control devices, delays due to turning vehicles at intersections and driveways, and traffic demands on the roadway”. Speed is an MOE compatible with either interrupted (arterial networks) or uninterrupted (freeway networks) flows.

2.4.1.4 Delay

Delay, as specified in the HCM 2010, is defined as “delay associated with vehicles slowing in advance of an intersection, the time spent stopped on an intersection approach, the time spent as vehicles move up in the queue, and the time needed for vehicles to accelerate to their desired speed”. Delay is an MOE compatible with interrupted flow (i.e., arterial networks). And measured in seconds per vehicle – sec/veh

2.4.1.5 Queue

Queues are indicators of operational problem spots within the system where capacity inefficiencies and/or safety problems may exist because of intersection blockages or turn bay overflows. Queue length is “how far the traffic backs up as a result of traffic control or a vehicle stopped in the travel lane while waiting to make a turn”. (HCM, 2010) The determination of queue length is complex. Queue length is an MOE compatible with interrupted flow (i.e., arterial networks).

2.4.1.6 Density

Density is used in the Highway Capacity Manual to compute level of service for uninterrupted flow facilities (facilities without stop signs or traffic signals). According to the highway capacity manual density is defined as “the number of vehicles occupying a given length of a lane or roadway at a particular instant”. Density is an MOE compatible with uninterrupted flow (i.e., freeway networks). And measured in passenger cars per lane per mile – pcplpm (HCM, 2010)

Table 2.6 and 2.7 summarize the MOE building blocks of performance measurement system and MOE performance indicator with their typical usage respectively.

Table 2.6 MOE Building Blocks of Performance Measurement Systems

MOE Building Blocks of Performance Measurement Systems	**Typical Usage**
Travel Time	• Used in long-range planning studies at regional or corridor level to evaluate traveler benefits of alternative improvements. • Used to evaluate traveler benefits of signal timing improvements for individual facility.
Speed	• Used to evaluate alternatives in long-range planning studies at regional or corridor level. • Used to evaluate benefits of signal timing improvements for individual facility. • Used to estimate fuel consumption and air quality impacts.
Delay	• Used to evaluate alternatives in long-range planning studies at regional or corridor level. • Used to evaluate benefits of signal timing improvements for individual intersection or facility. • Used to compare different degrees of congestion (Level of Service F). • Used to estimate fuel consumption and air quality impacts.
Queue	• Used to identify hot spots, operations problems at points of facility (left turn bays, blockages, safety).
Stops	• Used to evaluate fuel and air pollution savings of signal timing improvements for individual facility.
Density	• An input to the Highway Capacity Manual level of service for uninterrupted flow facilities.

Travel-Time Variance	Rarely used due to difficulty of computation. Potential use for evaluating benefits of traffic operations improvements that reduce variability but not mean travel time or delay.

Source: (FHWA, 2007)

Table 2.7 MOE Indicators of Performance

MOE Indicators of Performance	Typical Usage
HCM Level of Service	• Used to determine if facility design (for a given set of signal control parameters) will provide acceptable traffic operations as reported for the peak 15 minutes.
Volume/Capacity	• Used in planning studies to quickly determine if facility has sufficient number of lanes (sizing the facility) regardless of signal timing.

Source: (FHWA, 2007)

2.5 Intersection Analysis

A basic intersection analysis typically evaluates intersection operations with a minimum of two measures of effectiveness: delay (measured in seconds per vehicle) and queue length (measured in feet).

2.5.1 Methods for Estimating the Capacity of Roundabouts

Capacity is the main determinant of the performance measures such as delay, queue length and stop rate. The relationship between a given performance measure and capacity is often expressed in terms of degree of saturation (demand volume- capacity ratio).

Capacity is the maximum sustainable flow rate that can be achieved during a specific time period under prevailing road, traffic and control conditions. The prevailing condition is important since capacity is not a constant value, but varies as a function of traffic flow levels. Capacity represents the service rate (queue clearance rate) in the performance (delay, queue length, stop rate) functions, and therefore is relevant to both under saturated and over saturated conditions. Conceptually, this is different from the maximum volume that the intersection can handle which is the practical capacity (based on the target degree of saturation) under increased demand volumes, not the capacity under prevailing conditions (Akcelik, 2005).

There are two distinct theories or methodologies to assess the capacity of the roundabouts. These theories are:

(i) The empirical model; and

(ii) The analytical or gap acceptance based model.

i. Empirical (statistical) model

This model correlates geometric features and performance measures, such as capacity, average delay and queue length, through regression of field data. In this way, a relationship (generally linear or exponential) between the entering flow of an approach and the circulating flow in front of it (Rodegerdts L.*et al.*2004) is generated. This model is better than analytical ones but requires an oversaturated condition for calibration and may have poor transferability to other countries.

ii. Analytical (Gap-acceptance) model

This model can be developed from uncongested sites; the driver on the approach (entering flow) needs to select an acceptable gap in the circulating stream, to carry out the entering maneuver. The gap is the headway between two consecutive vehicles on the circulating flow; so, the “critical gap” (tc) is the minimum headway accepted by a driver in the entering stream. If the gap accepted is larger than minimum, then more than one driver can enter the roundabout; the headway between two consecutive vehicles in the entering flow, which utilizes the same gap, is defined as “follow-up time” (tf). So, the analytical model calculates the roundabout capacity as a function of the critical gap, the follow-up time and the circulating flow. However for capacity evaluation, the following are some assumptions due to the nature of geometry, turning movement, vehicle types and approach grade:

- Constant values for “tc” and “tf”;
- Exponential distribution for the gaps into the circulating flow;
- Constant traffic volumes for each traffic flow

These specific assumptions make the use of these models difficult in practice. Furthermore, there are other limitations, such as:

- The estimation of the critical gap is not easy;
- The geometric factors are not directly taken into account;
- The inconsistent gaps are not accounted for in theory (forced right of way when traffic is congested, circulating drivers give up right of way, different gap accepted by different vehicles, the rejection of large gap before accepting a smaller one, etc.)

2.5.2 Performance Analysis of Roundabout

Three performance measures are typically used to estimate the performance of a given roundabout design: degree of saturation, delay, and queue length. Each measure provides a unique perspective on the quality of service at which a roundabout will perform under a given set of traffic and geometric conditions. In all cases, a capacity estimate must be obtained for an entry to the roundabout before a specific performance measure can be computed. (FHWA, 2000)

2.5.2.1 Degree of Saturation

Degree of saturation is the ratio of the demand at the roundabout entry to the capacity of the entry. It provides a direct assessment of the sufficiency of a given design. While there are no absolute standards for degree of saturation, the Australian design procedure suggests that the degree of saturation for an entry lane should be less than 0.85 for satisfactory operation. When the degree of saturation exceeds this range, the operation of the roundabout will likely deteriorate rapidly, particularly over short periods of time. Queues may form and delay begins to increase exponentially.

2.5.2.2 Delay

Delay is a standard parameter used to measure the performance of an intersection.
The Highway Capacity Manual identifies delay as the primary measure of effectiveness for both signalized and un-signalized intersections, with level of service determined from the delay estimate. Currently, however, the Highway Capacity Manual only includes control delay, the delay attributable to the control device.
Control delay is the time that a driver spends queuing and then waiting for an acceptable gap in the circulating flow while at the front of the queue. The formula for computing this delay is given in Equation 2.1.

$$d = \frac{3600}{C_{m,x}} + 900T * [\frac{V_x}{C_{m,x}} - 1 + \sqrt{\left(\frac{V_x}{C_{m,x}} - 1\right)^2 + \frac{\left(\frac{3600}{C_{m,x}}\right)\left(\frac{V_x}{C_{m,x}}\right)}{450T}}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{equation 2.1}$$

Where: d = average control delay, sec/veh;

V_x = flow rate for movement x, veh/h;

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

T = analysis time period, h (T = 0.25 for a 15-minute period).

Note that as volumes approach capacity, control delay increases exponentially, with small changes in volume having large effects on delay. An accurate analysis of delay under conditions near or over saturation requires consideration of the following factors:

- **The effect of residual queues**. Roundabout entries operating near or over capacity can generate significant residual queues that must be accounted for between consecutive time periods. The factors are accounted for in the delay formulae developed by Kimber and Hollis; however, these formulae are difficult to use manually.
- **The metering effect of upstream oversaturated entries**. When an upstream entry is operating over capacity, the circulating volume in front of a downstream entry is less than the true demand. As a result, the capacity of the downstream entry is higher than what would be predicted from analyzing actual demand.

Geometric delay is the additional time that a single vehicle with no conflicting flows spends slowing down to the negotiation speed, proceeding through the intersection, and accelerating back to normal operating speed. Geometric delay be an important consideration in network planning (possibly affecting route travel times and choices) or when comparing operations of alternative intersection types.

While geometric delay is often negligible for through movements at a signalized or stop-controlled intersection, it can be more significant for turning movements such as those through a roundabout. Calculation of geometric delay requires an estimate of the proportion of vehicles that must stop at the yield line, as well as knowledge of the roundabout geometry as it affects vehicle speeds during entry, negotiation, and exit.

2.5.2.3 Queue Length

Queue length is important when assessing the adequacy of the geometric design of the roundabout approaches.

The average queue length (L vehicles) can be calculated by Little's rule, as shown in Equation 2.2

$$L = v \cdot d / 3600 \qquad \textit{equation 2.2}$$

Where: v = entry flow, veh/h

d = average delay, seconds/veh

Average queue length is equivalent to the vehicle-hours of delay per hour on an approach. It is useful for comparing roundabout performance with other intersection forms, and other planning procedures that use intersection delay as an input.

2.5.3 SIDRA Software

Signalized and Un signalized Intersection Design and Research Aid (SIDRA) is an intersection-based program developed by ARRB Transport Research, Ltd., in Australia as an aid for capacity, timing and performance analysis of isolated intersections . It is one of the three tools that are currently used in the U.S. for capacity analysis for roundabout intersections (the other two programs being ARCADY and Rodel, both British programs).

SIDRA is a very powerful analytical program for signalized intersections; roundabouts; and yield, two-way stop, or all-way stop-controlled intersections, with up to eight approaches. It can also be used for uninterrupted traffic flow conditions and merge analysis Besides optimizing phase sequences, splits, and cycle lengths, SIDRA has a wealth of graphic displays of intersection geometry, including the number of lanes, turning lanes, and channelization. . It can also be used for uninterrupted traffic flow conditions and merge analysis.

An option to implement the U.S. HCM method is included in SIDRA to help the analysis and investigation of the differences between the SIDRA and HCM methods.

SIDRA is perhaps the richest MOE-based intersection program. It offers MOEs such as total and average delay, v/c ratios, queues, stops, speeds, fuel consumption, emissions, and operating costs. It also allows modeling of separate Movement Classes with different vehicle characteristics.

For roundabout intersections, SIDRA can analyze intersections with up to eight approaches and also has provisions to assume either random or platooned arrivals (bunched vehicles) to analyze the effect of progression from nearby signalized intersections. (Transportation Research Circular E-C014: Traffic Analysis Software Tools, 2000)

Sidra Intersection allows analysis of single-lane and multi-lane roundabouts. It employs a combined (hybrid) geometry and gap-acceptance modeling approach in order to take into account the effect of roundabout geometry on driver behavior directly through gap-acceptance modeling. (Sisiopiku and Oh, 2001)

Special considerations should be given to the following parameters: HCM LOS, delay, degree of saturations, pedestrians.

Geometric delay is the delay caused by vehicles slowing down when entering, negotiating and exiting the roundabout. This delay is very important when comparing operations of different intersection alternatives. HCM roundabout LOS does not consider geometric delay; rather it calculates delay solely based on un-signalized intersection control delay.

Table 2.8 Delay LOS criteria

Level of service	Control delay per vehicles			Degree of saturation (v/c ratio)
	Signals	Roundabouts	Stop and Give way signs	
A	d≤10	d≤10	d≤10	0<X≤0.85
B	10<d≤20	10<d≤20	10<d≤15	0<X≤0.85
C	20<d≤35	20<d≤35	15<d≤25	0<X≤0.85
D	35<d≤55	35<d≤50	25<d≤35	0<X≤0.85
E	55<d≤80	50<d≤70	35<d≤50	0<X≤0.95
F	80<d	70<d	50<d	1<X

Source: (Akcelik, 2009)

Practical degree of saturation (DOS) is the maximum volume to capacity (v/c) ratio or degree of saturation that corresponds to an acceptable level of performance. It is one of the two MOEs of a roundabout analysis. The second MOE is the LOS based on delay. A DOS of 0.85 is desired for roundabouts without metered signals.

Pedestrians: in absence of existing count data taken within a 60-minute interval, default pedestrians count per hour of 400 and 50 should be used for projects located in the central business district (CBD) and other areas, respectively.

2.6 Causes of Traffic Congestion

There are predominantly two factors causing traffic congestion, that is micro-level factors, including the high number of people on the roads at the same time, and the overflow of vehicles on the limited road space; and macro-level factors, such as land use patterns, car ownership trends, and geographical economic development. Congestion is prompted at the micro-level, and steered at the macro-level (Tilak & Reddy, 2016). Some of the factors causing traffic congestion are listed in Table 2.10:

Table 2.10 Factors causing traffic congestion

Factors Causing Traffic Congestion	Relevant Studies
Excessive No. of Vehicles	As stated in the Report on Study of Road Traffic Congestion in Hong Kong (2014), the excessive number of vehicles on the roads is one of the primary reasons why traffic congestion arises.

Population Growth	Raheem et al. (2015) postulate that as the population of a country increases, the demand for road travel also grows. They however added that the growth in population has not been complemented by the construction of new roads, thus causing roads to be congested
Inefficient Public Transport Services	The ineffectiveness of public transport to offer services efficiently gives rise to traffic congestion, which in turn has critical repercussions on the socio-economic activities of a country (Harriet *et al*., 2013).
Inefficient Road Traffic Management	Road congestion can occur due to the narrow and poorly constructed roads and streets that are ineffective in handling various vehicle types. This results in the inability to effectively manage traffic, creating bottlenecks that last for extended periods (Jain *et al*., 2012).
Poor Roadway Condition	The uneven road network features, lack of lane discipline, and Unsuitable bus-stop locations prompt road congestion (Tilak & Reddy, 2016).
Economic Development / Urbanization	Road congestion in cities is mostly the result of prosperous economic development, and career, accommodation and societal programs that encourage individuals to work and live closer. The remarkable increase in the number of vehicles on the roads as a result of rapid urbanization has led to a rise in traffic volume, thus causing roads to be congested in every city in India (Tilak & Reddy, 2016).
Unforeseen Circumstances	According to the Report on Study of Road Traffic Congestion in Hong Kong (2014) Road networks are believed to be a major factor giving rise to traffic congestion. Incidents, such as road works, prompt the occurrence of bottlenecks and accidents, which in turn cause traffic congestion to take place (Schwietering & Feldges, 2016).
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. (Mahmud1 *et al*., 2012)

Traffic Influencing Events	External events have major impact on traffic flow. These included traffic incidents such as crashes and vehicles breakdown; work zones, bad weather such as heavy rainfall & etc. (Elisonguo, 2013).

2.7 Measures to mitigate traffic congestion

Traffic management is the best cost- effective measure of countering road traffic congestion. It has three distinct separate purposes: maximization of vehicle- carrying capacity; the maximization of people- carrying capacity; and the promotion of amenity and safety by assessing some roadway space predominantly or exclusively for pedestrian use. (Joshua & Iyiola, 2010)

FHWA, 2005 stated the key strategies to address congestions and categorized in 3 general categories.

1. Adding More Capacity for Highways and Providing More Transit and Freight Rail Service
2. Operating Existing Capacity More Efficiently
3. Encouraging the road users to Use the System in Less Congestion Producing Ways

Adding new physical capacity for highways, transit, and railroads is an important strategy for alleviating congestion. In many locations, the lack of physical capacity for the expansion contributes the most to congestion. In such locations, the addition of new capacity is critical. Further, the addition of new capacity presents an excellent opportunity to combine it with other types of strategies.

Transportation System Management and Operations aim is to mitigate the effects of roadway events and to manage short-term demand for existing roadway capacity. It includes the application of advanced technologies using real-time information about highway conditions to `implement control strategies i.e. Intelligent Transportation Systems (ITS), real-time control of highway operations through a transportation management center. ITS control strategies take many forms: metering flow onto freeways, dynamically retiming traffic signals, managing traffic incidents, and providing travelers with information about travel conditions, alternative routes, and other modes. Other approaches to the problem of congestion involve managing the demand for highway travel. These strategies include putting more people into fewer vehicles, shifting the time of travel, and eliminating the need for travel altogether (through telecommuting). (FHWA, 2005)

FHWA, 2014 also stated High-Occupancy Vehicle (HOV) Lanes are one of the most effective ways to minimize traffic congestions in urban areas. HOV lanes are exclusive roadways or lanes designated for high-occupancy vehicles, such as buses, vanpools, and carpools. The facilities may operate as HOV lanes full time or only during the peak periods. Keys to the success of lanes include location (areas of high congestion do better); enforcement; interagency coordination; synergy with parking policy, public and policy-maker support; and education and marketing. (FHWA, 2014)

Another measures to mitigate traffic congestion is Use of Regulations and Traffic Engineering to Control Traffic

Traffic regulations can be used to reduce congestion impacts on public transport. This means adding traffic restrictions that help public transport and removing traffic restrictions that hurt public transport. Examples of traffic regulations include:

- **Parking Restrictions** – one main cause of delays to transit vehicles is waiting while private vehicles maneuver in and out of parking spaces. Parking restrictions and controls can be implemented to reduce the impact of parking movements on transit vehicles and to provide space needed for exclusive transit lanes.
- **Turn Restrictions** – turning vehicles are another significant source of delay for transit vehicles. Implementing turn restrictions carefully can significantly reduce these delays.
- **Transit Exemption from Turning Requirements** – in some cases, restrictions to turning movements can lengthen and delay transit routes. In these cases, it can be beneficial to exempt transit from the turning movement restriction.
- **Loading Restrictions** – vehicle loading on public streets has been a problem in cities throughout history. Careful design of loading areas can improve transit priority by reducing interference with transit vehicles.

A research done by Haregewein (2007) reviews the key traffic congestion alleviation actions as follows: increase road capacity; increasing road network coverage; ensuring effective parking management ; sufficient parking areas; ensuring good traffic management; introducing effective land use management: applying flexible work schedule; different starting and ending work schedule; arranging residence; market and working place near to each other; discourage car ownership; ensuring technical fitness of vehicles every time; and managing an informal on-street trade.

2.8 Summary of Literature

Operational analyses are oriented towards current or near term conditions in order to provide information for decision whether there is a need for improvement or not. The ultimate purpose of measuring performance in transport sector is to improve transportation service for customers and to quantify the achievements of traffic operations.

The two commonly used measure of effectiveness to qualify the facility performance are HCM LOS and volume to capacity ratio. The other building blocks for evaluating the traffic operations performances are travel time, speed and delay. LOS is a quality measure describing operational conditions. LOS F & V/C greater than 1 are recognizable indicators of poor traffic operations which show there are extreme congestions.

Evaluation of roundabouts operations are commonly measured by LOS, degree of saturation, delay and queue. The LOS criteria for roundabouts were according to HCM 2010 and the others parameters are determined using the widely used SIDRA intersection software version 5.1. SIDRA software is developed using analytic method with geometric elements because the analytical method is more realistic than empirical method. Based on the delay parameters the LOS of the roundabout can be estimated if the delay is above 70 second the LOS become F and the practical degree of saturation is limited as 0.85.

There are different factors that cause poor traffic performance. From this some of them are excessive number of Vehicles, population growth, urbanization, inefficient public transport services, inefficient road traffic management, poor roadway condition, illegal Parking, traffic influencing events and so on.

The need of this research is to evaluate the current operational performance of the traffic on the selected road segments and roundabouts due to the fact that transportation is the main elements for development in order to show there is a need for improvements. After evaluating the current conditions, it will be easy to predict what will happen in the near future due the economic development and the dynamic increment of population numbers.

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location and Size

Addis Ababa, the capital city of Ethiopia, is one of the largest urban centers in sub-Sahara Africa located 8049'55.929" and 905'53.853" North Latitude and between 38038'16.555" and 38019.547" East Latitude with an altitudinal zone ranging from 2054 to 3023 meters above sea level. The city covers an area of about 519.5 km2 of land. (Addis Ababa City Administration Integrated Land Information, Atlas 2014.)

Due to large of the city, the study focused from Megenagna to Ayat roundabout road network. Because, the road network has more number of lanes than the others main road (this is not considering the Ring roads) with good pavement condition. This must one of the factors in order to improve the transportation service but in turn the road network found in the worst condition than other places with high traffic congestion especially in the morning & evening time. It has 4 lanes which were very narrow compared with the traffic volume and it is the only main road to reach the center of the city from east direction. The sprawling rate in the east direction was dynamically increased due to the existence of new residential buildings like condominium & apartments and the suitability of the area for living. The increment of the population increase the car ownership and movement of pedestrians which lead to congestion and makes the traffic nature very congested especially in peak hours. So, the road network represents Addis Ababa city roads with good road condition with high traffic movements and it need to be studied. The study area was located along west-east direction. The length of the selected section was approximately 8 km.

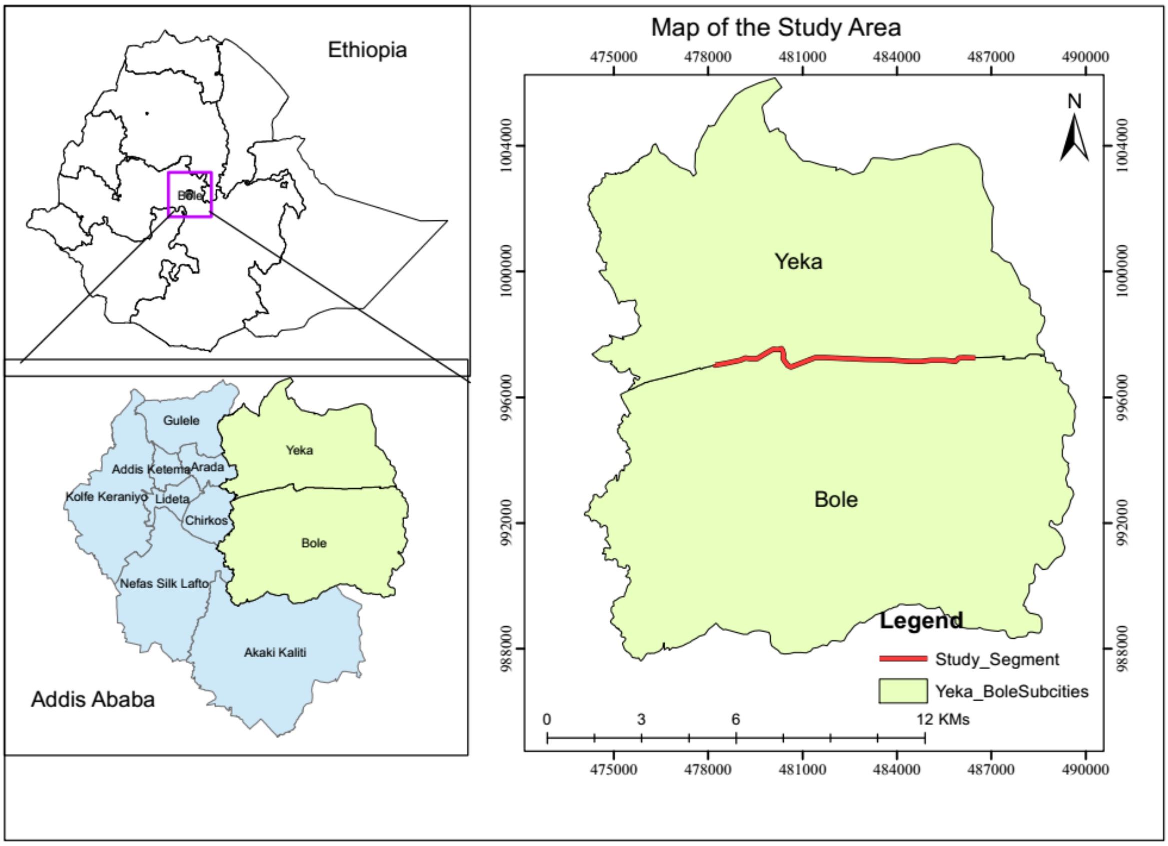

Fig 3.1 Location map of Study Area (source: DIVA-GIS, 2020)

3.1.2 Population Density

The recent population estimate for Addis Ababa was 3,384.569 million according to the 2007census. The population density was 5165 persons per square kilometer. The growth rate of the city was 3.8%. Currently, due to the economic and population growth in Ethiopia, especially in Addis Ababa, the transportation demand was growing greatly. As transportation increases traffic congestion becomes a problem because of inadequate infrastructure of road.

3.1.3 Traffic Nature

Due to the dramatic increment of residential settlement in the east direction, number of pedestrian, the number of private cars, school buses, passenger car increase which was beyond the capacity of the road at peak hour during in the morning & evening. In addition to the residential settlement in this area there are a lot of educational institutions, trading centers, construction sites, governmental & nongovernmental offices, which makes the traffic volume high. And around the school areas parking of parent’s cars, school services and buses for unloading purpose (even parking on more than one lane) makes the traffic movement lower. During weekday there were high traffic flows than weekend days.

3.2 Data Collection and Methods

3.2.1 Data Source

In this study, only primary data source was used to gather both qulitative and quantitative data for the study area. Quantitative data was used to determine the level of service and intensity of traffic congestion while qualitative data was used to gather information about people's perception about traffic performance in that area.

3.2.1.1 Primary Data

A primary data source was the original data source for this study in which the data's were collected by directly in the field. It was collected in the field for answering research questions through observation (field survey), questionnaires, geometric survey, video recording. This lead to have the correct & reliable data's for the analysis.

Table 3.1 Types and sources of data's

Data		**Size**	**Source**
Primary	Traffic volume	6hrs	Manual count, video survey
	Pedestrian volume	1hr	Manual count, video survey
	Geometric data		Geometric survey
	Questionnaire	385	Respondents in the study network
	Travel time	108	Direct field measurement

3.2.2 Data Collections Methods

The primary data of this research was collected using the following data collection methods.

i. Site observations:- was conducted to have a visusal inspection of the road. In the observation highly congested area, factors (causes) that contribute for poor performance, people reactions about their time value & the land use condition was observed and evaluated.
ii. Questionaries:- was conducted to have the right perceptions of the people about traffic performance in their view and its impact on their day to day activities. It was

distributed randomly for road users (public servants, private servants, drivers and students) along the road corridor.

Numbers of traffic offenders involved in traffic offences were calculated by sample size determination of Cochran's formula for the unknown population. (Scott & Smith, 2015)

$$\text{sample size (n)} = \left(\frac{z^2 * pq}{e^2}\right) \text{ .... } \textit{Equation 3.1}$$

$$= \left(\frac{1.96^2 \text{x} 0.5(1-0.5)}{0.05^2}\right) = 384.16 \text{ Taken as 385}$$

Where: n= Sample size required for the study

Z= Critical value (=1.96) for the 95 percent confidence level, the amount of uncertainty that one can tolerate. Most researchers recommend 95per cent confidence level.

P= Proportion of people expected to have the basic knowledge about the problem. (i.e. 0.5) because recommended value for 50 percent for the value of "P".

q= Proportion of people doesn't expect to have the basic knowledge about the problem. q=1-p

e = Margin of error that can be tolerated: it is the discrepancy between the sample size and the population. The recommended value is 5 percent (=0.05).

These 385 questionnaires paper were distributed randomly for the road users like drivers, students, pedestrians, public & private servants along the road corridor.

iii. Geometric survey:- the road geometric data was collected like number of lanes, lane width, and configuration of lanes, circulatory width by direct measurement.
iv. Video survey:- was used in order to count the traffic in the road. It was done from buildings top. From the recording, the necessary data like volume/flow per 15 minute interval, turning movements and composition of vehicles on selected routes was extracted manually.

v. Floating-Car Technique: The test car was driven along the segment so the test car "floats" with the traffic. The test vehicle was attempts to pass as many vehicles as those that pass the test vehicle. The time taken to traverse segment was recorded.

The minimum number of test runs is determined using values of the t distribution rather than the z values. The reason is that the sample size for this type of study is usually less than 30, which makes the t distribution more appropriate.

In this study the sample size for one segment was taken as 36 i.e. 4 samples in the morning, 4 samples in the mid-day and 4 sample in the night for three days.

3.2.3 Road Network Data

The selected road network starts from Megenagna and end up with Ayat roundabout. And it passes through these sections Megenagna–> Gurd Shola–> Sahilitmiheret roundabout–> Civil service–> CMC Michael–> Yetebaberute roundabout–> Meri–> Ayat roundabout.

In this road network, there were three roundabouts (Sahilitmiheret, Yetebaberute & Ayat) and three road segments (Megenagna to Sahilitmiheret, Sahilitmiheret to Yetebaberute and Yetebaberute to Ayat road segment). Addis Ababa light railway also passes in the midsection of the road which had 9 stations. From these nine stations the three stations (Gurd shola, Michael & Meri) were congested due to the pedestrian movement to cross the road. At Gurd shoal station near to Century Mall it allows U-turn movement which crosses the LRT which become one of the factor that cause poor traffic performance at peak hour in that area.

Fig 3.2 Selected road corridor (source: Google Satellite)

3.2.3.1 Road Segments in the study Road Corridor

Table 3.2 Road segment of the study road network

No	segment name	Length(Km)
1	Megenagna – Sahilitmiheret	2.65
2	Sahilitmiheret - Yetebaberute	2.92
3	Yetebaberute - Ayat	2.58

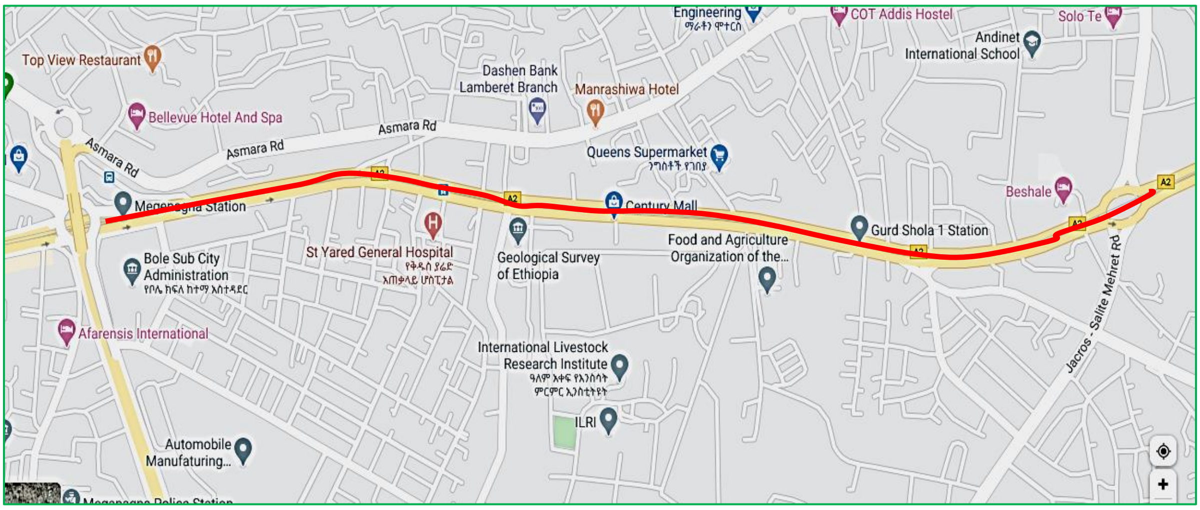

Fig3.3 Megenagna to Salite Meheret road segment (source: Google map)

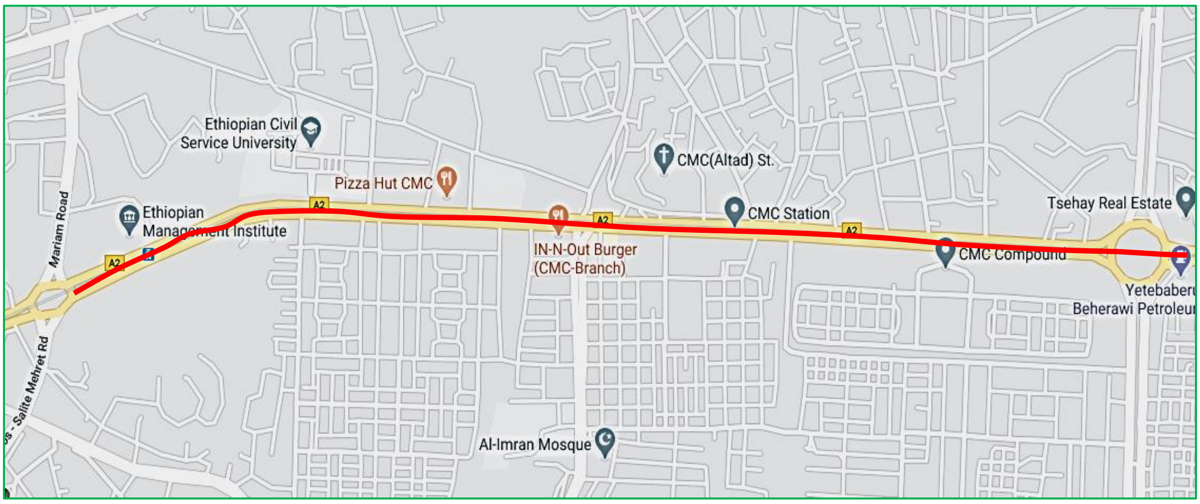

Fig 3.4 Sahilitmiheret to Yetebaberute road segment (source: Google map)

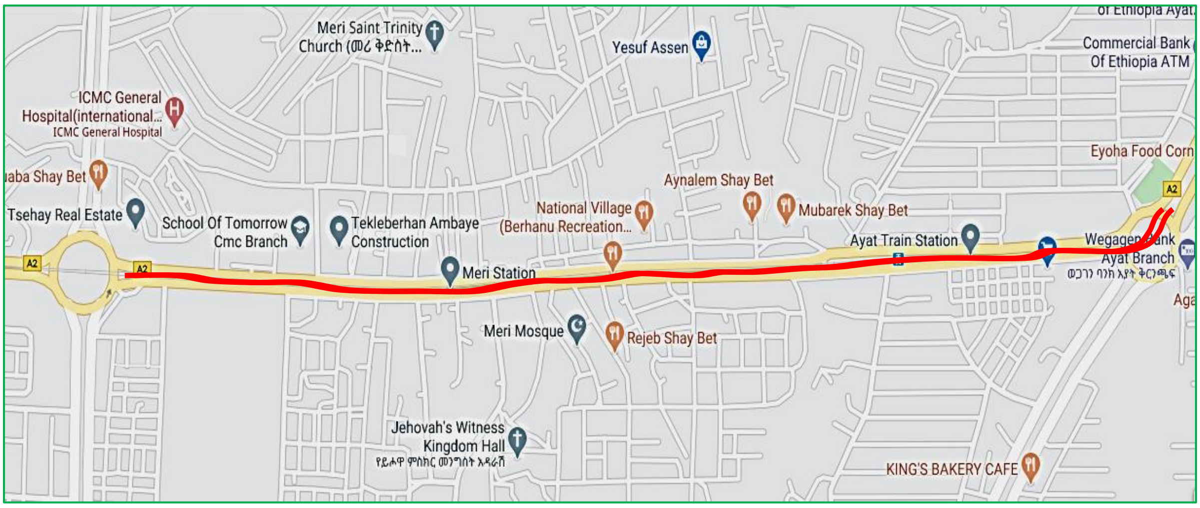

Fig 3.5 Yetebaberute to Ayat road segment (source: Google map)

3.2.3.2 Intersection in the Selected Road Corridor

Sahilitmiheret & Yetebaberute roundabouts were the two roundabouts which were crossed by light railway line in east-west direction.

Table 3.3 Intersections in the selected Road network

No	Roundabout name	Type of junction
1	Sahilitmiheret	4 leg roundabout
2	Yetebaberute	4 leg roundabout
3	Ayat	4 leg roundabout

Fig 3.6 Sahilitmiheret roundabout layout (source: Google map)

Fig 3.7 Yetebaberute roundabout layout (source: Google map)

3.2.3.2.2Ayat roundabout

Fig 3.8 Ayat roundabout layout (source: Google map)

3.2.4 Geometric data

Table 3.4 Geometric data for the roundabout

Roundabout name	*Orientation*	*Approach leg*	*Geometric data*				
			No of entry lane	*No of exit lane*	*Lane width (meter)*	*Median (meter)*	*Circulating island diameter (meter)*
Sahilitmiheret	East	Ayat	4	2	3.3	12	100
	South	Figa	2	2	3.3	12	
	West	Megenagna	4	4	3.3	12	
	North	Zero hulet	2	2	3.3	12	
Yetebaberute	East	Ayat	4	4	3.3	12	110
	South	Summit	2	2	3.3	56	
	West	Megenagna	4	4	3.3	12	
	North	Abem	2	2	3. 3	56	
Ayat	East	Ayat 49	4	4	3.3	2	120
	South	Summit	2	2	3.2	40	
	West	Megenagna	2	2	3.2	12	
	North	Tafo	2	2	3.2	40	

3.2.5 Traffic Volume Data

Traffic volume count was conducted to determine the numbers of vehicle, movements, classifications of roadway vehicles and pedestrian volume at a given location. These data was used to identify critical flow periods, to analyze the performance of roundabouts and road segment.

Due to time and budget limitation, the traffic volume data were collected for the average value of the whole weekday i.e. at Tuesday, Wednesday and Friday. And the time of recording for this paper was done from 07:00 AM- 09:00 AM in the morning, 12:00 AM-02:00 PM and 05:00 PM- 07:00 PM.

It is necessary to have a single unit to count the number of vehicles because different types of vehicles in a traffic stream have different effects. So, all vehicles on the corridor were converted to a common unit called passenger car unit. The PCU were taken from Highway Capacity Manual 2010 and present in table 3.5 as follow.

Table 3.5 Passenger car units for vehicles

	Small car	Standard Bus	Heavy vehicle
PCU factors	1	2	2

Source :(HCM, 2010)

The analysis of the level of service was based on peak 15-minute rate of flow occurring within the peak hour. The relationship between the peak 15-minute flow rate and the full hourly volume was given by the peak-hour factor (PHF) as shown in the following equation. (Roess, 2004).

$$\mathrm{PHF} = \mathrm{V}/(4 * V_{15}) \text{ ……………………………………} \textit{Equation 3.2}$$

Where: V =peak-hour volume (vph)

V_{15} = volume during the peak 15 minutes of flow (veh/15 minutes)

Table 3.6 Traffic volume data for the roundabouts

Roundabout name	**Approach leg**	**Total traffic volume(Count)**			**Pedestrian**
		LT	***TH***	***RT***	
Sahilitmiheret	Ayat	500	2899	255	430
	Figa	500	224	300	465
	Megenagna	102	380	238	320
	Zero hulet	86	221	354	342
Yetebaberute	Ayat	243	1774	200	220
	Summit	665	205	252	350
	Megenagna	253	425	154	421
	Abem	123	145	340	250
Ayat	Megenagna	378	302	60	342
	Summit	256	265	85	300
	Tafo	141	202	943	543
	Ayat 49	210	1123	125	645

3.3 Method of Data analysis

3.3.1 Analysis Using SIDRA Software

The SIDRA software was preferred for this analysis in this research due to the following reasons: It is easily available tool to offer full geometric and gap acceptance modeling capability within a single product, it employed a combined (hybrid) geometry and gap-acceptance modeling approach in order to take into account the effect of roundabout geometry on driver behavior directly through gap-acceptance modeling; and it can be calibrated for local conditions and it is highly flexible.

The LOS, degree of saturation and average delay of the three roundabouts through the study corridor were evaluated using Sidra intersection software (version 5.1). Traffic volume, geometric characteristics of road, and pedestrian volume data's were used. The traffic volume and pedestrian data was obtained by using video camera and manual traffic volume count method. The peak 15-minute rate of flow was used for each movement. Geometric data of the road like island diameter, circulatory width, number of circulatory lanes, entry and lane number, lane width, movement discipline, and peak hour factor and were obtained from direct field measurement. From the data peak hour for the morning and evening were determined. The default value of 1900 tcu/hr basic saturation flow was used.

3.3.2 Determination of LOS for Road Segment Using HCM 2010

To analyze the LOS of the road from Megenagna to Ayat, the road is divided in to three road segment as Ayat to Yetebaberute road segment, Yetebaberute to Sahilitmiheret road segment and Sahilitmiheret to Megenagna road segment.

The analysis of the LOS of the selected road corridor is based on HCM 2010, urban road segment. In the road corridor there are three roundabouts. The steps are based on considering the roundabouts and it is shown as follow.

Step 1: Determine Running Time

A procedure for determining segment running time includes the calculation of free-flow speed, a vehicle proximity adjustment factor, and the additional running time due to mid-segment delay sources. Each calculation was discussed as follow.

A. Determine Free-Flow Speed

Free-flow speed represents the average running speed of through automobiles traveling along a segment under low-volume conditions and not delayed by traffic control devices or other vehicles. The determination of free-flow speed was based on the base free flow speed.

Base Free-Flow Speed

The base free-flow speed is defined to be the free-flow speed on longer segments. It includes the influence of speed limit, access point density, median type, and curb presence. (HCM, 2010)

$$S_{fo} = S_o + f_{cs} + f_A \text{……………………………………………....} \textit{Equation 3.3}$$

Where S_{fo}= base free flow speed (km/h)

S_o=speed constant (km/h)

f_{cs}= adjustment for cross section (km/h)

f_A= adjustment for access point (km/h)

B. Adjustment for Vehicle Proximity

The proximity adjustment factor adjusts the free-flow running time to account for the effect of traffic density. The adjustment results in an increase in running time (and corresponding reduction in speed) with an increase in volume. (HCM, 2010)

The Equation used to compute the proximity adjustment factor is

$$f_v = \frac{2}{1+(1-\frac{V_m}{52.8 N_{th} S_f})^{0.21}} \text{……………………………………….. } \textit{Equation 3.4}$$

Where f_v= proximity adjustment factor

V_m= mid segment demand flow rate (veh/h)

N_{th}=number of through lanes on the segment in the subject direction of travel (ln)

S_f=free flow speed (km/h)

C. Estimate Delay due to Turning Vehicles

Vehicles turning from the subject street segment into an access point approach can cause a delay to the following through vehicles. For right-turn vehicles, the delay results when the following vehicles' speed is reduced to accommodate the turning vehicle. For left-turn vehicles, the delay results when the following vehicles must wait in queue while a vehicle ahead executes a left turn maneuver at the access point intersection. (HCM, 2010)

So for this paper, the U-turn movement near to century mall causes significant delay for the following vehicle. The delay was measured directly in the field and the minimum time of delay was taken for the analysis.

D. Estimate Delay due to Other Sources

Pedestrians at a mid- segments who crosses the road and maneuvers due to completing parallel parking are the other factors that cause a driver to reduce their speed. (HCM, 2010)

So for this paper, the delay due to pedestrians at mid-segment and maneuvers was measured together directly in the field and the minimum time of delay was taken for the analysis.

E. Estimate Segment Running Time

The estimation of segment running time was consider through movement control at the boundary intersection, free flow speed, vehicle proximity, and various mid segment delay sources.

$$t_R = \frac{6.0 - l_1}{0.0025L} f_x + \frac{3600L}{5280 S_f} f_v + \sum_{t=1}^{N_{ap}} d_{ap,i} + d_{other} \quad \text{.....................} \quad \textit{Equation 3.5}$$

With

$$f_x = \begin{cases} 1.00 \text{ (signalized or stops controlled through movement)} \\ 0.00 \text{ (Uncontrolled through movement)} \\ \text{Min } [{}^{V_{th}}/_{C_{th}}, 1] \text{ (Yield controlled through movement)} \end{cases}$$

Where t_R= segment running time (s)

l_1= start up lost time =2.5 for stop or yield control (s)

L= segment length (km)

V_{th}= through demand flow rate (veh/h)

C_{th}= through movement capacity (veh/h)

$d_{ap,i}$ = delay due to left and right turns from the street into access point intersection (s/veh)

N_{ap}= number of influential access point approaches along the segment

d_{other} = delay due to other sources along the segment (pedestrians, curb parking) (s/veh)

Step 2: Determine Through Delay

Through delay represents the sum of two delay sources. One is control delay which is the delay due to the traffic control at the boundary intersection and the other delay is due to the negotiation of intersection geometry, such as curvature which is called geometric delay.

The nature of the delay models used in HCM makes it difficult to separate the delay to through vehicles from the delay to non through vehicles. So the through delay was taken from SIDRA output for the downstream intersection.

Step 3: Determine Travel Speed

The Equation used to determine the travel speed for the subject direction of travel along the segment was

$$S_{T,seg} = \frac{3600L}{5280(t_R+d_t)} \quad \text{.. } \textit{Equation 3.6}$$

Where $S_{T,seg}$=travel speed of through vehicles for the segment (km/h)

L= segment length (km)

t_R= segment running time (s)

d_t= through delay (s/veh)

Step 4: Determine LOS

LOS is defined by two performance measures. One measure is the travel speed for through vehicles, expressed as a percentage of the base free-flow speed. The second measure is the volume-to-capacity ratio for the through movement at the downstream boundary intersection.

The LOS attributed to each direction of travel applies to the segment, which includes both the link and the downstream boundary intersection.

Step 5: Determine Through Stop Rate

Through stop rate describes the stop rate of vehicles that enter and exit the segment as through vehicles. The nature of the stop rate models is difficult to separate the stops to through vehicles from those incurred by non through vehicles.

The stop rate at a Yield-controlled approach will vary with conflicting demand. It can be estimated (in stops per vehicle) as equal to the volume-to-capacity ratio of the through movement at the boundary intersection. This approach recognizes that YIELD control does not require drivers to come to a complete stop when there is no conflicting traffic. The full stop rate was taken from SIDRA software output.

Step 6: Determine Spatial Stop Rate

The Equation used to compute the spatial stop rate for the subject direction of travel along the segment was

$$H_{seg} = 5280\frac{h+ h_{other}}{L} \quad \text{.. } \textit{Equation 3.7}$$

Where H_{seg}= stop rate for the segment (stops/m)

h= full stop rate (stops/veh)

h_{other}= full stop rate due to other sources (stops/veh)

L= segment length (km)

Step 7: Determine Automobile Traveler Perception Score

The automobile traveler perception score for urban street segments is provided as a useful performance measure. It indicates the traveler's perception of service quality. The score was computed by the following Equation

$$I_{a,seg} = 1 + P_{BCDEF} + P_{CDEF} + P_{DEF} + P_{EF} + P_F \quad \text{............................ Equation 3.8}$$

With $P_{BCDEF} = (1 + e^{-1.1614-0.253H_{seg}+0.3434P_{LTL,seg}})^{-1}$,

$P_{CDEF} = (1 + e^{0.6234-0.253H_{seg}+0.3434P_{LTL,seg}})^{-1}$

$P_{DEF} = (1 + e^{1.7389-0.253H_{seg}+0.3434P_{LTL,seg}})^{-1}$

$P_{EF} = (1 + e^{2.7047-0.253H_{seg}+0.3434P_{LTL,seg}})^{-1}$

$P_F = (1 + e^{3.8044-0.253H_{seg}+0.3434P_{LTL,seg}})^{-1}$

Where $I_{a,seg}$= automobile travel perception score for segment

P_{BCDEF}= the probability that an individual will respond with rating of B, C, D, E or F

P_{CDEF}= the probability that an individual will respond with rating of C, D, E or F

P_{DEF}= the probability that an individual will respond with rating of D, E or F

P_{EF}= the probability that an individual will respond with rating of E or F

P_F= the probability that an individual will respond with rating of F

$P_{LTL,seg}$= proportion of intersections with a left turn lane on the segment

A score of "1" was assigned to the rating of A (denoting "best"), "2" wa`s assigned to B, and so on. The score provides a useful indication of performance from the perspective of the traveler. Scores of 2.0 or less indicate the best perceived service, and values in excess of 5.0 indicate the worst perceived service.

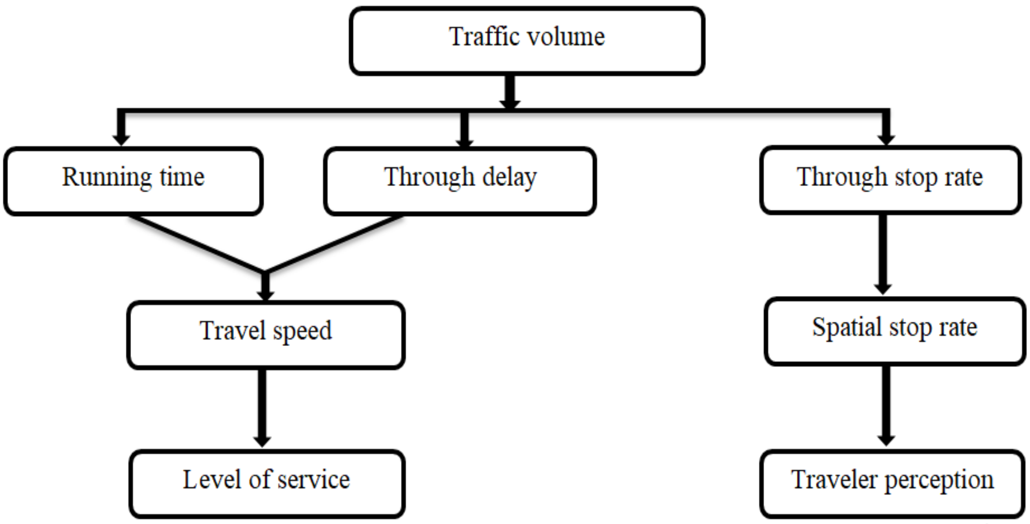

Fig 3.9 Flow chart for LOS determination

3.3.3 Regression Analysis

Base on field observation and questionnaire, areas that were highly congested and factors that contribute for congestions were identified. From the questionnaire, the respondents were asked to identify congested areas, their travel time by recognizing their origin & destination and to rank the factors that contribute for traffic crowding. The travel times that have the same origin and destination were taken as dependent variable. And the factors that have many respondents and which ranked up to four were taken as independent variable. The independent variables were pedestrian effects, parking effects, shortage of mass transport, imbalance of capacity & volume and speed.

3.3.3.1 Testing the Hypothesis

From the questionnaire, the hypothesis test was conducted by ANOVA test in order to check that there is significant difference between the factors or not. By testing the hypothesis, the corresponding p-value & F-value were determined in order to reject or accept the null hypothesis.

H_0: the factors that cause congestion has no difference between them

H_1: the factors that cause congestion has difference between them

3.3.3.2 Testing for Collinearity

In order to proceed to the regression analysis, the independent variables must be checked weather they are highly correlated each other or not. This mean their Pearson correlation must not be greater than 0.75 to get reliable result.

3.3.3.3 Developing Regression Model

After checking the significance of the factor, Regression model was generated using SPSS. The analysis method that was used in this study was to indicate the relation between the factors that contribute congestion and travel time. Regression analysis generates an equation to describe the statistical relationship between a set of independent variables and dependent variable. So multiple linear regressions was preferred for this study since the number of dependent variable was one and the independent variables were four.

The basic multiple regression equation is formulated in the following way (Kaya G & Güler N., 2013);

$Y=B_O+B_1X_1+B_2X_{2+......}e$………………………………………… *Equation 3.9*

Where: Y=is dependent Variable

X=are independent variable

e= is error term

Regression for questionnaire

- Dependent variable: travel time (sec)
- Independent variables: Pedestrian interface, shortage of mass transport, parking effect, imbalance of capacity & demand and speed

These independent variables were coded as a dummy variable as 0 and 1. Because they are a categorical variable and in the questionnaire they were rank up to 4.

Regression for field data

There were 108 travel time data samples taken from the three road segments which were used for multiple linear regression modeling. Floating car techniques was used to collect the travel time.

- Dependent variable: travel time(sec)
- Independent variables: number of pedestrians, speed(km/hr), length(m), volume, width and number of lane

3.4 Research Design Flow Chart

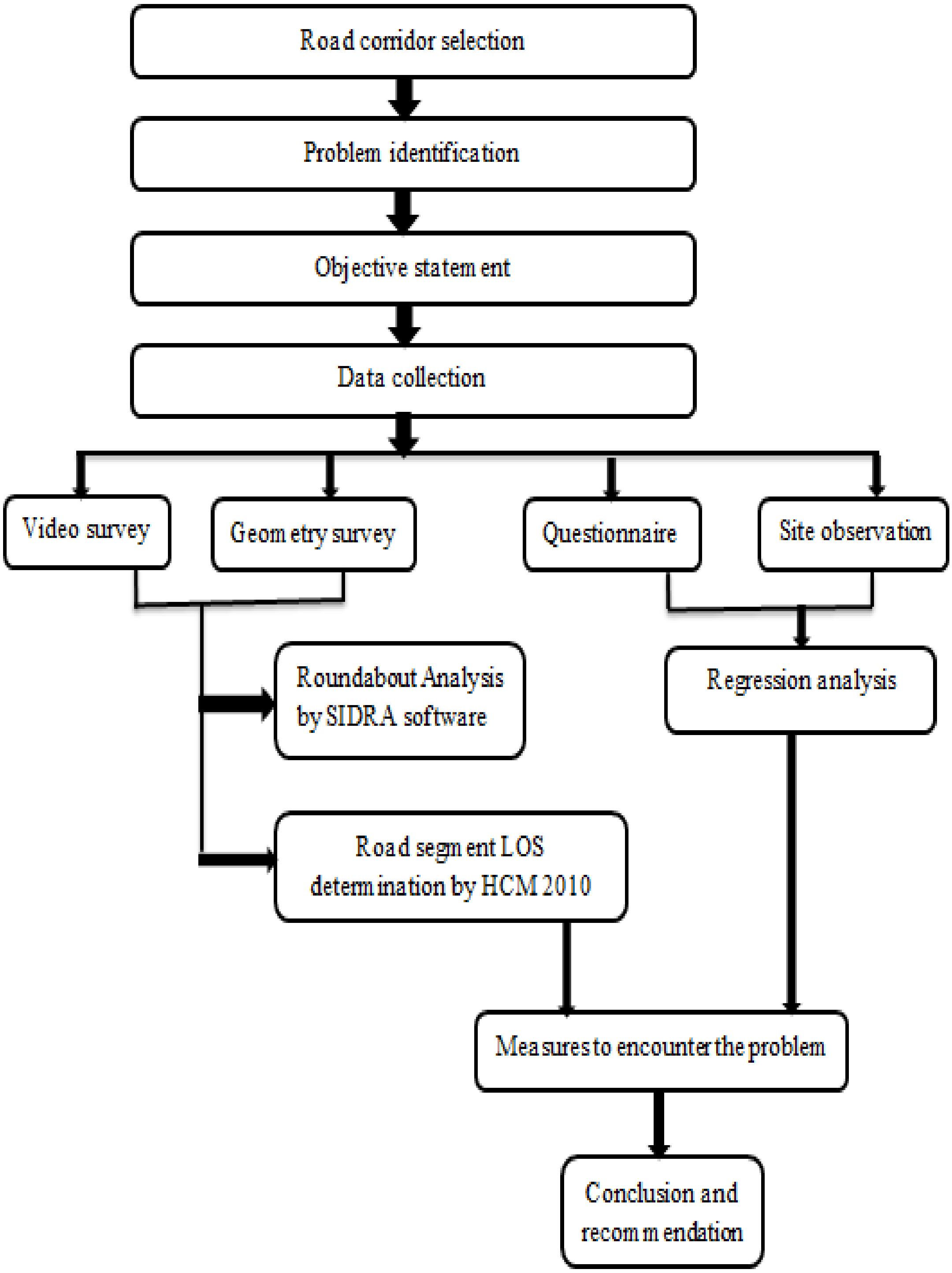

Fig 3.10 Research Design Flow chart

4. RESULTS AND DISCUSSIONS

This chapter presents the analysis result and its discussion based on the data gathered. The results were achieved by using the required input data and the procedure described in the methodology part.

4.1 SIDRA Software Analysis Result

Table 4.1 Summary of Sidra software analysis result of all roundabouts

Roundabouts	*Approaches*	*Approach LOS*	*Approach Delay (sec)*	*Approach V/C*	*Overall LOS*	*Overall Delay (sec)*	*Overall V/C*
Sahilitmiheret Roundabout	Figa entry	LOS F	488.3	2.219	LOS F	405.2	2.219
	Ayat entry	LOS F	479.4	2.124			
	02 entry	LOS F	508.7	2.022			
	Megenagna entry	LOS C	15.3	0.571			
Yetebaberute Roundabout	Summit entry	LOS F	243.4	1.643	LOS F	211.8	1.643
	Ayat entry	LOS F	264.1	1.585			
	Abem entry	LOS F	228.4	1.456			
	Megenagna entry	LOS B	10.9	0.369			
Ayat Roundabout	Summit entry	LOS C	21.2	0.584	LOS F	282	2.453
	Ayat 49 entry	LOS F	336.1	1.677			
	Tafo entry	LOS F	509.6	2.453			
	Megenagna entry	LOS C	18.6	0.8			

Based on the Australian design procedure and Akcelik suggestion the degree of saturation for an entry lane should be less than 0.85 for satisfactory operation. When the degree of saturation exceeds this range, the operation of the roundabout will likely deteriorate rapidly, particularly over short periods of time, queues may form and delay begins to increase exponentially. As the output of the analysis shows that the overall degree of saturation of all roundabouts was above 1 which is higher than the tolerable value and it indicated that the roundabouts were serving beyond its capacity and congested.

Delay is a standard parameter used to measure the performance of an intersection. Highway Capacity Manual also identifies delay as the primary measure of effectiveness for both signalized and un-signalized intersections, with level of service determined from the delay estimate. From the output of the analysis table 4.1 shows that the average delays per vehicle of all roundabouts were very far beyond the recommended value. According to Akcelik table 2.8 for roundabout for LOS F the delay is greater than 70 sec but in this case the delay was greater than 200 sec which indicates that all roundabouts were serving in a poor level of service.

And also the output of the analysis indicates that the overall level of service of all roundabouts were F, which means the roundabouts were serving at a poor level of service which indicates that the quality of service were the worst, and vehicles were moving extremely at low speeds which cause high delays and high volumes especially in the peak hour.

There were factors that contribute for the cause of delay in these roundabouts like unbalance flow, pedestrian volume at the entry & exit and pavement conditions for Ayat roundabout.

The traffic flow in the study area was high in one direction. During the morning time the flow was high in east west direction and at night the flow changes its direction & become west east direction. Akeclik on his paper agreed that unbalance traffic flow limit the capacity of the roundabout. When one entry has very heavy flow and the entry immediately before it on the roundabout has light flow the performance of the roundabout likely influenced. And pedestrian interfaces with vehicles at the entry of the roundabout have significant effect on the entry capacity. The three roundabouts have high pedestrian movement especially in Sahilitmiheret and Ayat roundabout. And a research had done by Nyantakyi *et al.*, 2013 strongly agreed to separate the pedestrian movement from the traffic flow at the approaches of the roundabouts by providing Foot Bridge on all legs of the roundabouts Since they cause significant delay to the road user.

And a research done by Temesgen in 2015 in Addis Ababa also agreed unbalance traffic flow, in adequate number of lanes, pavement conditions and pedestrian conflicts with vehicles at approaches reduce speed and increase delay at junctions by lowering the LOS of the roundabout.

If any long term measurement is not taken to these road segments the road traffic performance will become totally out of control. Because the population number in this road segment increases dynamically, rapid urban sprawl exists and there are a lot of sites in the east direction which is not occupied by the residents.

The SIDRA intersection Software output for each roundabout was summarized as follow:

4.1.1 Sahilitmiheret Roundabout

Table 4.2 Movement output summary of Sahilitmiheret roundabout

Movement performance vehicles						
Mov. ID	***Turn***	***Demand flow (Veh/hr)***	***Deg.Of saturation (v/c)***	***Average delay (Sec)***	***Level of service***	***95% Back of queue vehicle (Veh)***
South: Figa entry						
1	L	888	2.219	579.3	LOS F	159
2	R	209	1.595	306.4	LOS F	76
3	T	384	1.595	306.4	LOS F	76
Approach		1480	2.219	488.3	LOS F	159
East: Ayat entry						
4	L	663	1.458	241.9	LOS F	73
5	R	2818	2.124	533.1	LOS F	175
6	T	117	2.124	533.4	LOS F	169
Approach		3598	2.124	479.4	LOS F	175
North: 02 entry						
7	L	250	2.022	511.1	LOS F	78
8	R	300	2.022	509.6	LOS F	86
9	T	398	2.022	506.5	LOS F	86
Approach		948	2.022	508.7	LOS F	86
West: Megenagna entry						
10	L	223	0.388	12.1	LOS B	2
11	R	608	0.529	15.7	LOS C	2
12	T	341	0.571	16.6	LOS C	3
Approach		1173	0.571	15.3	LOS C	3
All vehicle		7178	2.219	405.2	LOS F	175

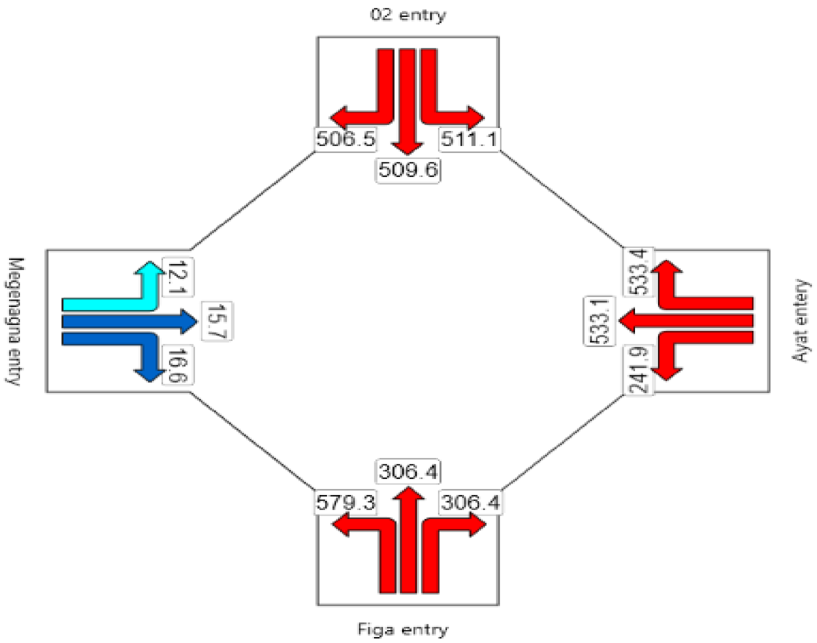

Fig 4.1 Delay analysis output of Sahilitmiheret roundabout of SIDRA intersection software

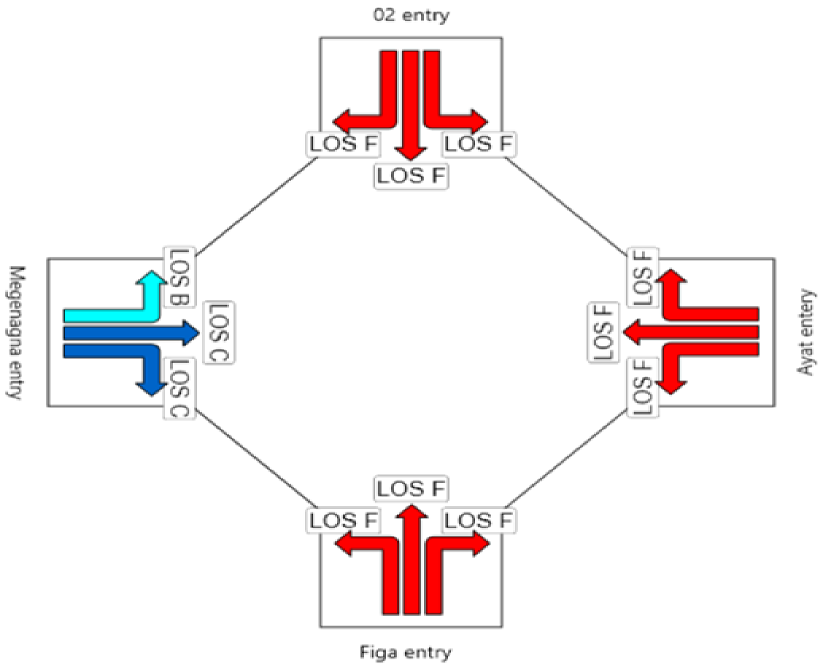

Fig 4.2 LOS analysis output of Sahilitmiheret roundabout of SIDRA intersection software

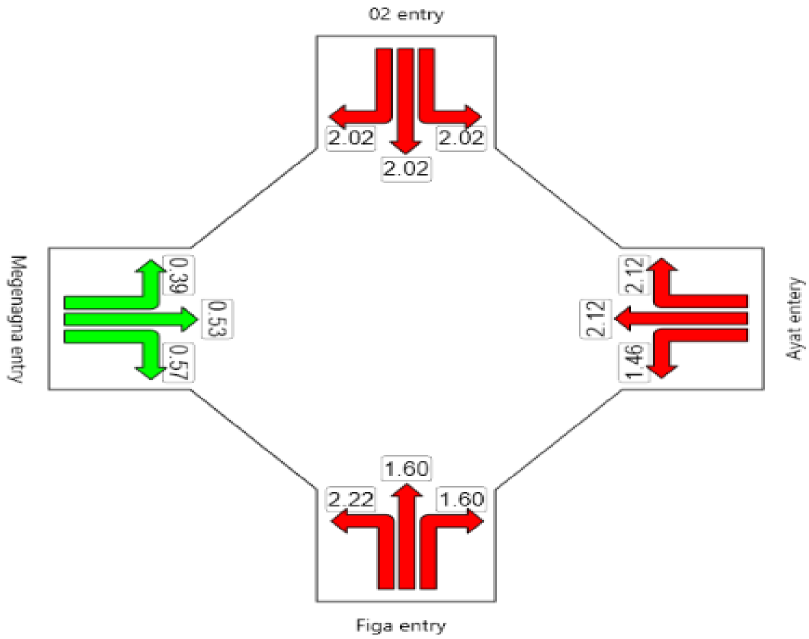

Fig 4.3 Degree of saturation analysis output of Sahilitmiheret roundabout of SIDRA intersection software

The result of the analysis indicates that the overall level of service (LOS) of Sahilitmiheret roundabout was “F” and it is noticed that all approaches except Megenagna entry had LOS F but Megenagna approach had LOS C because the high volume movement was from east-west direction during morning peak hour. In the night session the result were reversed because the direction of the high volume movement was changed. It became west to east direction i.e. the Megenagna approach was highly congested and the LOS & delay parameter were also change.

The railway has its own negative effect in the traffic movement. Comparatively Figa approach experience high traffic volume than 02 approach during the peak hour of morning and evening time.

The average V/C ratio was greater than 1 which was 2.2, which show that the road experience slow speed, significant delay which was averagely 405.2 sec and congestion.

Therefore, currently at peak hour Sahilitmiheret roundabout was not functioning well because of this traffic police man regulates traffic flow.

4.1.2 Yetebaberute Roundabout

Table 4.3 Movement output summary of Yetebaberute roundabout

Movement performance vehicles						
Mov. ID	***Turn***	***Demand flow (Veh/hr)***	***Deg.of saturation (v/c)***	***Average delay (Sec)***	***Level of service***	***95% Back of queue vehicle(Veh)***
South: summit entry						
1	L	686	1.643	317.0	LOS F	119
2	T	211	1.643	317.0	LOS F	119
3	R	293	0.560	18.1	LOS C	3
Approach		1190	1.643	243.4	LOS F	119
East: Ayat entry						
4	L	286	0.594	20.8	LOS C	2.0
5	T	2087	1.585	294.0	LOS F	100
6	R	235	1.585	294.4	LOS F	96
Approach		2608	1.585	264.1	LOS F	100
North: Abem entry						
7	L	145	1.270	189.6	LOS F	27
8	T	171	1.270	189.6	LOS F	27
9	R	400	1.456	259.0	LOS F	45
Approach		715	1.456	228.4	LOS F	45
West: Megenagna entry						
10	L	298	0.369	11.0	LOS B	1.0
11	T	447	0.369	10.8	LOS B	1.0
12	R	181	0.369	11.0	LOS B	1.0
Approach		926	0.369	10.9	LOS B	1.0
All vehicle		5440	1.643	211.8	LOS F	119

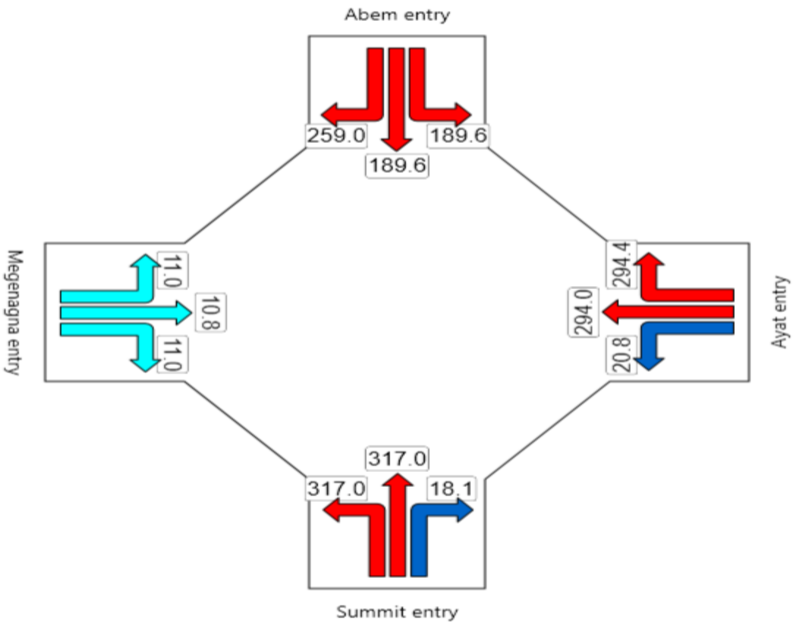

Fig 4.4 Delay analysis output of Yetebaberute roundabout of SIDRA intersection software

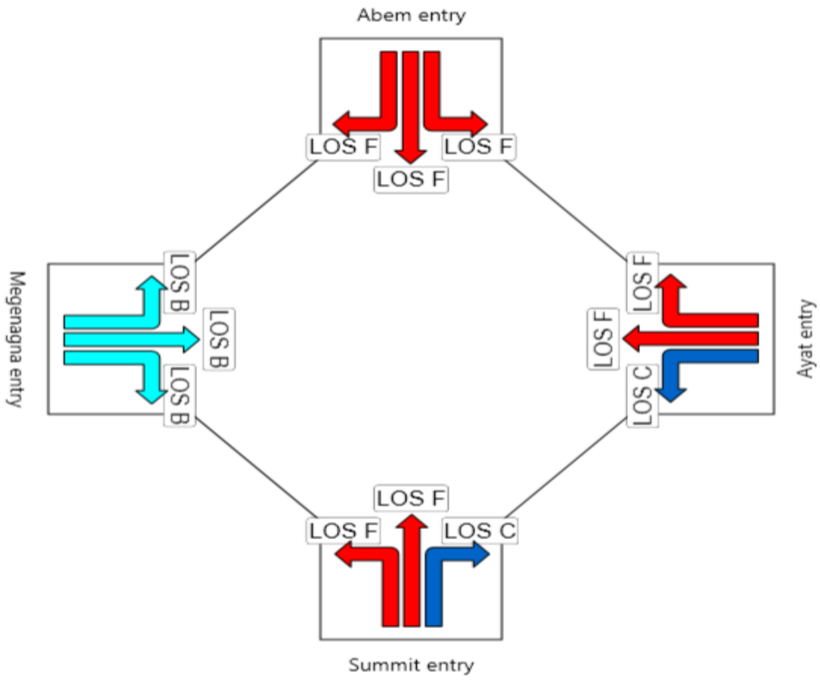

Fig 4.5 LOS analysis output of Yetebaberute roundabout of SIDRA intersection software

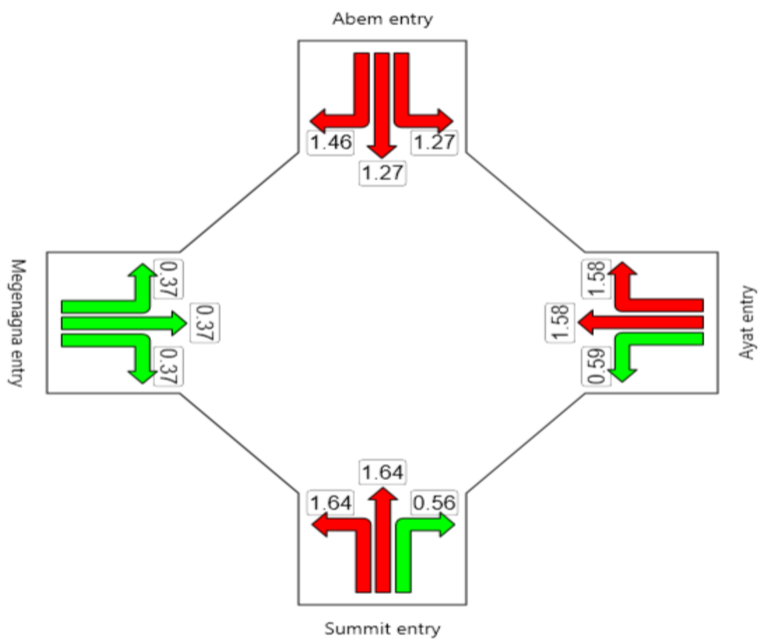

Fig 4.6 Degree of saturation analysis output of Yetebaberute roundabout of SIDRA intersection software

The result of the analysis indicates that the overall level of service (LOS) of Yetebaberute roundabout was “F” and it is noticed that all approaches except Megenagna entry had LOS F but Megenagna approach had LOS B. Comparatively from Sahilitmiheret roundabout of Megenagna entry, Yetebaberute roundabout Megenagna entry perform good because a number of vehicles change their direction to Figa around Sahilitmiheret and most vehicles spent their time on Yetebaberute to Sahilitmiheret road segment due to the commerciality of the area & the presence of Michael church around CMC. This results shows that the movements during the peak morning session. In the night session the result was reversed because the high volume movement was change the direction. It became west to east direction i.e. the Megenagna approach was highly congested and the LOS & delay parameter also change. And the railway has its own negative impact on the traffic movement.

The average V/C ratio was greater than 1 which was 1.643, which show that the road experience noticeable delay which was around 211.8 second on average, the area become congested and the speed of the vehicles slows down.

During the peak hour of the morning the highest traffic volume was from Ayat entry. In the night peak hour the direction of high volume changed to Megenagna approach. From summit entry and Abem entry, summit entry experience high traffic.

4.1.3 Ayat Roundabout

Table 4.4 Movement output summary of Ayat roundabout

Movement performance vehicles						
Mov. ID	***Turn***	***Demand flow (Veh/hr)***	***Deg. Of saturation (v/c)***	***Average delay (Sec)***	***Level of service***	***95% Back of queue vehicle(Veh)***
South: summit entry						
1	L	178	0.584	21.7	LOS C	3
2	T	258	0.584	21.0	LOS C	3
3	R	100	0.584	20.7	LOS C	3
Approach		535	0.584	21.2	LOS C	3
East: Ayat 49 entry						
4	L	221	1.677	336.7	LOS F	102
5	T	1170	1.677	336.0	LOS F	106
6	R	132	1.677	335.5	LOS F	106
Approach		1522	1.677	336.1	LOS F	106
North: Tafo entry						
7	L	157	1.193	138.6	LOS F	31
8	T	328	1.193	138.6	LOS F	31
9	R	1048	2.453	681.1	LOS F	203
Approach		1532	2.453	509.6	LOS F	203
West: Megenagna entry						
10	L	529	0.800	27.6	LOS D	5
11	T	515	0.385	10.8	LOS B	2
12	R	63	0.129	7.1	LOS A	1
Approach		1107	0.8	18.6	LOS C	5
All vehicle		4697	2.453	282.0	LOS F	203

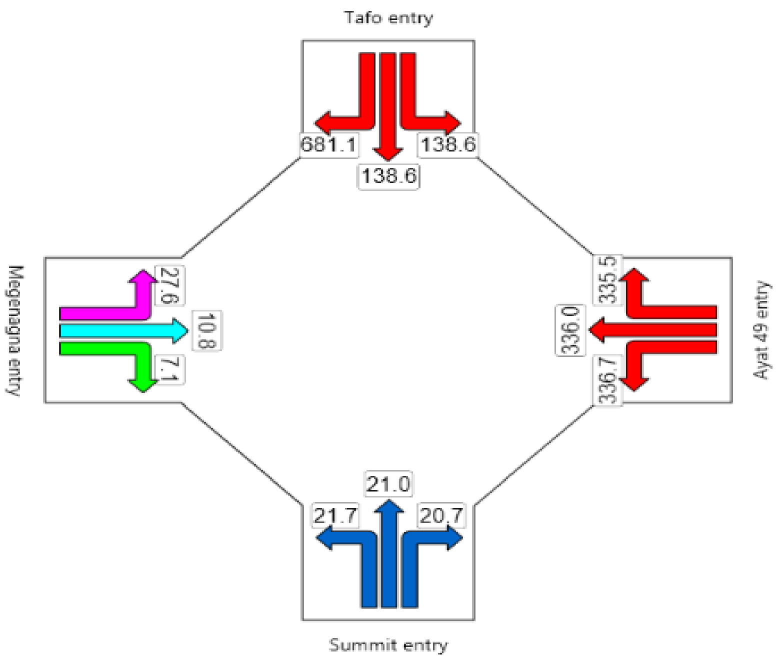

Fig 4.7 Delay analysis output of Ayat roundabout of SIDRA intersection software

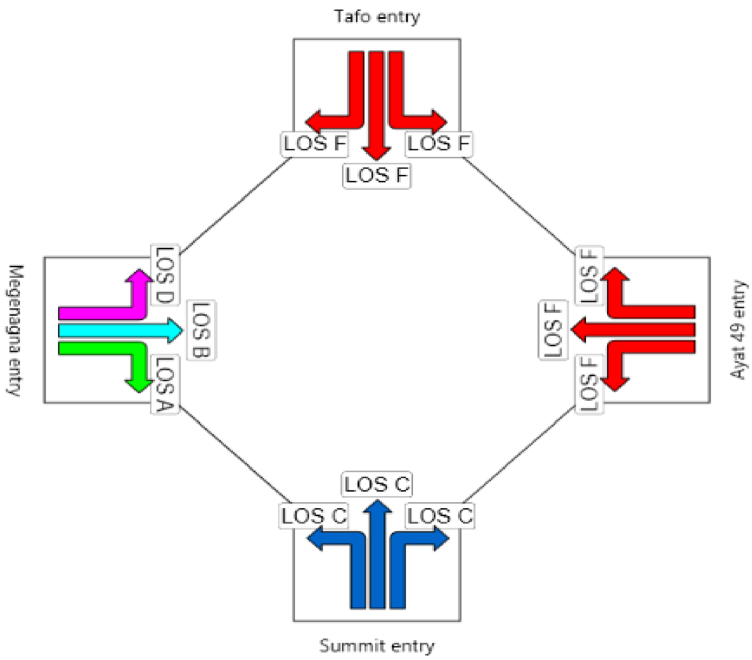

Fig 4.8 LOS analysis output of Ayat roundabout of SIDRA intersection software

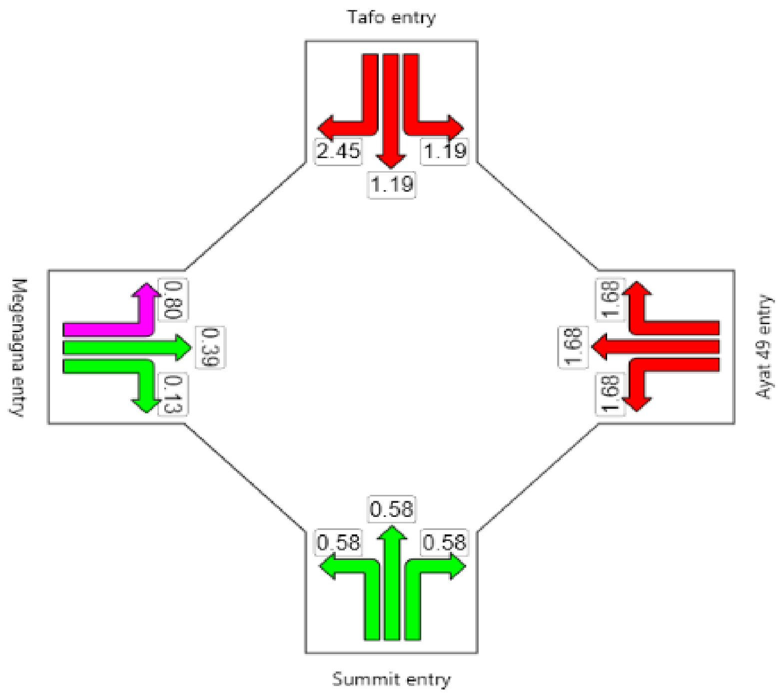

Fig 4.9 Degree of saturation analysis output of Ayat roundabout of SIDRA intersection software

In this roundabout the highest traffic volume was from Ayat 49 entry in the morning. Tafo entry also has high traffic volume both peak hours in the morning and evening. Megenagna approach experience highest traffic volume during the night session.

The result of the analysis indicates that the overall level of service (LOS) of Ayat roundabout was “F” and it was noticed that all approaches except Megenagna entry have LOS F but Megenagna approach has LOS D. This results shows that the movements during the peak morning session. In the night session the result became reversed because the high volume movements change the direction. It became west to east direction i.e. the Megenagna approach become highly congested and the LOS & delay parameter also changed.

The average V/C ratio was greater than 1 which was 2.453, with the average delay 310.2 sec which show that the road experience significant delay, the speed of the vehicle become slowdown and the area become congested.

Therefore, currently at peak hour Ayat roundabout was not functioning well because of this traffic police man forced to regulates the traffic flow.

4.2 LOS of the Road Segment

4.2.1 Ayat to Yetebaberute Road Segment

Based on the traffic volume data, the road segment experienced high traffic movement at 7:00 to 3:00 am (Ayat to Yetebaberute direction) and 5:00 to 7:00 pm time (Yetebaberute to Ayat direction). At the mid-day the traffic volume decreased.

In this road segment at Meri station there was high number of pedestrian movement which cause some delay to traffic movement. By direct observation and measurement in the site the minimum delay that one vehicle experience was seven minute. By taking the through delay from SIDRA output, the travel speed was determined as 11.60 km/hr which became 30.08 percentage of the free flow speed. And the volume to capacity ratio of the through movement at downstream boundary intersection (Yetebaberute roundabout) was 1.55 which was greater than 1. So according to HCM 2010, the LOS of the road segment became F. And the traveler perception score was greater than 5 which show the traveler perceived the worst service.

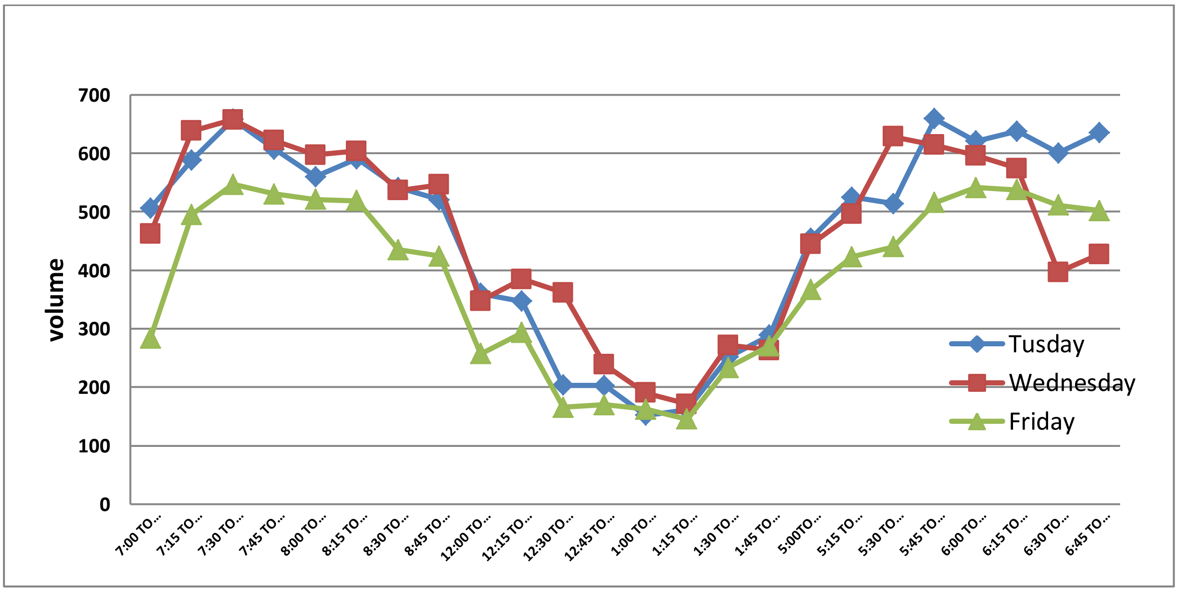

Fig 4.10 Traffic volume of Ayat to Yetebaberute road segment

4.2.2 Yetebaberute to Sahilitmiheret Road Segment

In this road segment at the mid-block of Michael there was high number of pedestrian movement due to the crossing area existence, commerciality of the area and the presence of St. Michael church, which cause high delay for the traffic movement.

The minimum delay for the normal day at peak hour was measured as eighteen minute and greater. The travel speed became 6.3km/hr in the road segment which was 26.14 percent of the free flow speed. And the downstream intersection (Sahilitmiheret roundabout) volume to capacity ratio of the through movement was 2.124 which was greater than 1. According to HCM 2010, the LOS of the road segment became F. And the traveler perceived worst service since perception score was greater than 5.

Fig 4.11 Traffic volume of Yetebaberute to Sahilitmiheret road segment

4.2.3 Sahilitmiheret to Megenagna Road Segment

In this road segment at Gurd Shola station there was high number of pedestrian movement due to the crossing area existence, commerciality of the area and the presence of different institutions on both side. And near to century mall it allows U-turn movements which add additional delay for the traffic stream. The minimum delay for the normal day at peak hour was measured as twenty five minute and greater. And the average travel speed became 5.45km/hr in the road segment which was 22.59 percent of the free flow speed. According to HCM 2010, the LOS of the road segment became F since the percent of the free flow speed was less than 30 percent.

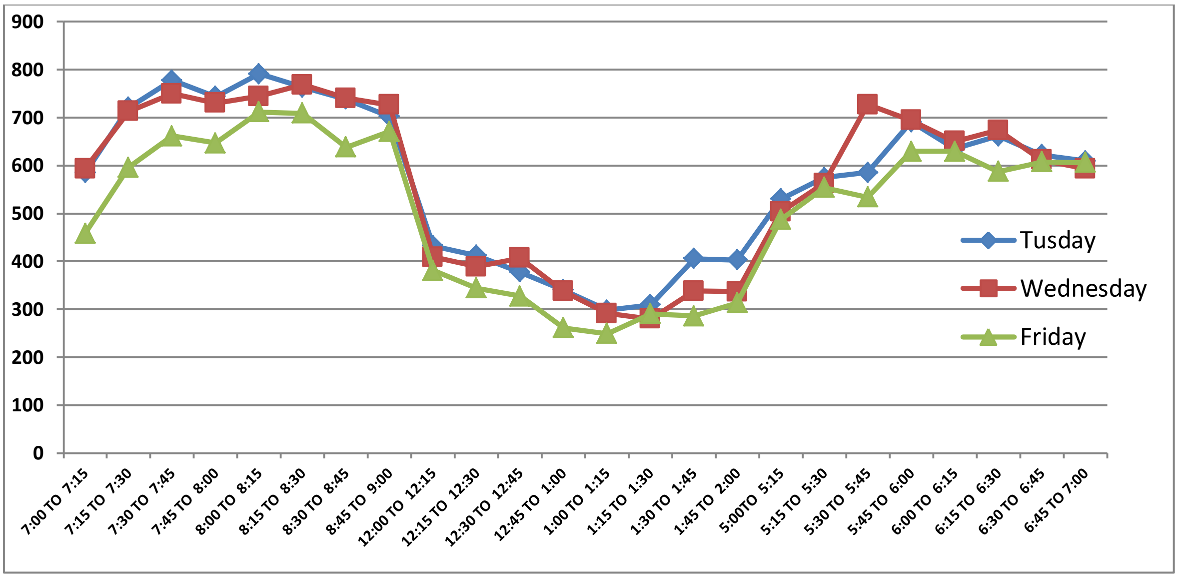

Fig 4.12 Traffic volume of Sahilitmiheret to Megenagna road segment

4.3 Regression Analysis

4.3.1 Regression Analysis of Questionnaires

The equation to be modeled was $Y=B_O+B_1X_1+B_2X_{2+}$ B_3X_{3+} B4X4+e

In order to proceed to the regression analysis, the independent variables must be checked weather or not they were highly correlated to each other which mean their Pearson correlation must not be greater than 0.75 in order to proceed (Jason & Elaine, 2002). Based on the table 4.5 their Person correlation was less than 0.75 & their p-value was less than 0.05 which indicate that the independent variables each other were not correlated and they were significant to cause the traffic crowding respectively.

Table 4.5 Correlation of independent variables of questionnaires

		Pedestrian effect	*Shortage of mass transport effect*	*Imbalance of capacity & volume*	*Parking effect*
Pedestrian effect	Person correlation	1	-0.583	-0.324	-0.324
	Sig.		0.000	0.000	0.000
	N	306	306	306	306
Shortage of mass transport	Person correlation	-0.583	1	-0.270	-0.270
	Sig.	0.000		0.000	0.000
	N	306	306	306	306
Imbalance of capacity & volume	Person correlation	-0.324	-0.270	1	-0.150
	Sig.	0.000	0.000		0.008
	N	306	306	306	306
Parking effect	Person correlation	-0.324	-0.270	-0.150	1
	Sig.	0.000	0.000	0.008	
	N	306	306	306	306

Based on ANOVA table 4.6, the null hypothesis was failed to accept since the p-value is less than 0.01. So the conclusion become there was difference between the factors that contribute for the poor traffic movement. The regression analysis was also significant.

Table 4.6 ANOVA result of questionnaires

Model		*Sum of square*	*df*	*Mean Square*	*F*	*Sig.*
1	*Regression*	4825.186	3	1608.395	6.809	.000
	Residual	71337.232	302	236.216		
	Total	76162.418	305			

From the model summary table 4.7 the R value indicates there was 98.6% of correlation between the independent and dependent variables. The estimated strength of the relationship between the regression model and the independent variable was explained by R square value. So the regression model was correctly explained by its independent variable since the R square value was greater than 70% which is 97.1%.

Table 4.7 Model summary of questionnaires

Model	*R*	*R^2*	*Adj. R^2*	*Std. Error*	*Sig. F change*
1	0.986	0.971	0.971	1.7404	0.000

From the questionnaire; the effect of the pedestrian, shortage of mass transport, parking and the imbalance of volume & demand were treated as categorical variables which were in nominal measurement. The regression of categorical variable was done with reference to base line. In this condition the base line was taken as parking effect.

Table 4.8 Travel time model regression output of questionnaires

Model	*Unstandardized coefficient*		t	Sig.
	Beta	Std. Error		
Constant (B_o)	144.482	0.894	161.606	.000
Pedestrian effect (P)	1.036	0.329	3.148	.002
Shortage of mass transport effect(SMT)	0.682	0.341	2.001	.046
Imbalance of capacity & volume effect (ICV)	1.018	0.393	2.590	.010
Speed (S)	-10.518	0.120	-87.560	.000

The multiple linear regression model become

Travel time= 144.482+1.036P+0.682SMT+1.018ICV-10.518S

Where: P-Pedestrian effect

SMT-Shortage of mass transport effect

ICV-Imbalance of capacity & volume effect

S-Speed

4.3.2.1 Model Interpretation

In the above equation, the variables pedestrian effect, Shortage of mass transport effect, imbalance of capacity & volume effect and parking effect were taken as dummy variables. From the above result, the p-value of all predictor variables was less than the significance level, $P<0.05$. Hence, all predictor variables, when added, they showed statistically significant to the prediction of the variable.
The model shows, pedestrian effect compared to parking effect, the pedestrian effect increased by 1.036 units on the travel time than the parking effect. And the effect of shortage of mass transport and the imbalance of volume & demand also increased by 0.682 and 1.018 units on the travel time compared with the parking effects respectively.

And also the model shows that travel time and speed were inversely related. When the speed increase the time it takes to travel decreased by 10.518 units.

To identify which factor contributes more for crowding, comparison was done for each factor with the dependent variable of travel time.

4.3.2.2 Ranking the Factors

Based on table 4.9, all the independent variables are significant to increase the travel time. Imbalance of capacity & volume and Pedestrian effect contribute more for the poor traffic performance than the others two factors. Shortage of mass transport effects followed by parking was the 3rd & 4th factor respectively for the contribution of traffic congestion compared to the Pedestrian effect and imbalance of volume & demand.

Table 4.9 Summarized ANOVA result of questionnaires

		Sum of Squares	*df*	*Mean Square*	*F*	*Sig.*
Pedestrian effect	*Between Groups*	814.240	1	814.240	8.001	0.005
	Within Groups	26255.375	258	101.765		
	Total	27069.615	259			

Shortage of mass transport	*Between Groups*	510.067	1	510.067	4.955	.027
	Within Groups	26559.549	258	102.944		
	Total	27069.615	259			
Imbalance of volume & demand	*Between Groups*	2209.445	1	2209.445	22.930	.000
	Within Groups	24860.170	258	96.357		
	Total	27069.615	259			
Parking effect	*Between Groups*	414.615	1	414.615	4.013	.046
	Within Groups	26655.000	258	103.314		
	Total	27069.615	259			

4.3.3 Regression Analysis of Field Data

Average speed, volume, pedestrians and segment length were taken as independent variable. Number of lanes and width of lanes also taken as independent variables but the regression deletes these variables from the analysis since they were constant throughout the segment. The dependent variable was travel time. The equation to be modeled was

$Y=B_O+B_1X_1+B_2X_{2+}$ B_3X_{3+} B4X4+e

Table 4.10 Correlation coefficient of independent variables of field data

		Average speed	*Volume*	*Pedestrians*	*Segment Length*
Correlations	*Average speed(AS)*	1	-0.655	-0.429	-0.444
	Volume (V)	-0.655	1	0.587	0.094
	Pedestrians (P)	-0.429	0.587	1	0.382
	Segment Length(SL)	-0.444	0.094	0.382	1

Table 4.11 Model summary of field data

Model	*R*	*R^2*	*Adj. R^2*	*Std. Error*	*Sig. F change*
1	.883	.779	.770	283.05	0.000

Table 4.12 ANOVA of field data

Model		*Sum of square*	*df*	*Mean Square*	*F*	*Sig.*
1	*Regression*	29084201.23	4	7271050.308	90.750	0.000
	Residual	8252514.650	103	80121.501		
	Total	37336715.88	107			

Table 4.13 Trave ltime model regression output of field data

Model	*coefficients*				*Collinearity statistics*	
	Beta	*Std. Error*	*t stat*	*P-value*	*Tolerance*	*VIF*
Constant (B_o)	1187.882	996.047	1.193	0.236		
Average Speed (AS)	-44.798	4.277	-10.475	0.000	0.412	2.765
Volume (V)	0.848	0.266	3.188	0.002	0.362	1.881
Pedestrian (P)	1.414	0.660	2.143	0.034	0.532	1.881
Segment length (SL)	0.127	0.349	0.364	0.717	0.600	1.665

4.3.3.1 Model interpretation

Based on table 4.11 the independent variables were slightly correlated. The presence of multi Collinearity does not exist since the correlation between the independent variables was less than 0.75. As P value was less than 0.05 the parameters were statistically significant. Based on table 4.12 the correlation between dependent and independent variables was around 88.3% as indicated by R value. The proportion of variance explained by the model R^2 was around 77.9% which means the regression model was correctly explained by the independent variables. From the ANOVA table 4.13 the P –values were less than 0.05, which make the model significant at the 95% confidence level. From table 4.14 output of regression the model become

Travel time (sec) = 1187.822-44.798AS+0.848V+1.414P+0.127SL

Where AS: Average speed

V: Volume

P- Pedestrian

SL- Segment Length

The final regression analysis had been processed to predict travel time from the indicated predictors or independent variables. From the above results, the p-value of all predictor variables was less than the significance level, P<0.05. Hence, all predictor variables, when added, it showed statistically significant to the prediction of the variable except segment length.

In the model travel speed gives a negative influence. It can be considered the most important factor influencing travel time. When speed increase, travel time of vehicle reduce. Volume and travel time has positive relation. It has an additional impact on the flow. When volume increases the travel time also increases. Increase in volume will cause the congestion at the peak hour of traffic flow. When congestion increases, travel time of vehicle also increased. The length of a segment gives positive effect to travel time of vehicle. When length of the segment increases, the travel time of a vehicle also affected. An increase in the length of a segment will increase the vehicle travel time. Pedestrian and travel time also have a positive relation. When the number of pedestrians who cross the road increase, the crossing time of pedestrian also increase which cause delay to the traffic flow. In turn it increases the total travel time of vehicles.

A research done by Sathya & Samson, 2013 in Bharathidassan road in the direction of court to American hospital agreed that volume and length gives positive effects to the travel time and speed gives negative influence or inversely related to the travel time.

4.4 Proposed Solutions

From the distributed questionnaires the respondent suggests solution in order to improve the operational traffic performance in the study area. Accordance with decreasing number of respondents, the suggested solutions were

- Improving the use of mass transport
- Providing better pedestrian crossing facilities
- Improve parking management system
- Increasing the road capacity
- Alleviate illegal on street trade

The specific solutions suggested to the roundabouts and the road segments were:

4.4.1 For roundabouts

Due to the availability of spaces in north and south approaches of all roundabouts, adding one additional approaching leg will solve the problem with providing pedestrians overpass at the entry & exit of the roundabouts.

4.4.1.1 For Ayat roundabout

From the traffic volume data and the analysis, the two approaches legs i.e. Tafo & Ayat 49 have high traffic volume and perform poor than the other two approaches. They have high delay, queue and degree of saturation greater than 2. So if the number of pedestrians decreased by 75% by providing overpassing crossing or by prohibiting mini markets at the medians and adding one additional approaching leg only to north and east approaches

- The overall roundabout delay will decrease by 65.39% and to Ayat 49 & Tafo entry it decreased by 49% & 78.96% respectively.
- The overall degree of saturation will change to 1.33 from 2.453 which mean it show 45.78% change.
- The LOS of Ayat 49 right turn will change to LOS B from LOS F.
- The 95% back of Queue of the overall roundabout will decrease by 68.44% and Ayat 49 & Tafo entry it decreased by 39.51% & 85.6% respectively.

4.4.1.2 For Yetebaberute roundabout

Adding one additional approaching leg only to the north and south approaches since they have wide medians and if the number of pedestrians decreased by 75% by providing pedestrians overpass at the entry & exit of the roundabout, the performance of the roundabout will change by:

- The overall delay of the roundabout will improve by 38% and for Ayat & summit entry it will improve by 32.79% & 72.76% respectively.
- The overall 95% back of queue will improve by 44.42% and for Ayat & summit entry it will be improved by 41.66% & 69.9% respectively.

4.4.1.3 For Sahilitmiheret roundabout

Adding one additional approaching leg only to the north and south approaches and decreasing the number of pedestrians by 75% by providing pedestrians overpass at the entry & exit of the roundabout, the performance of the roundabout will change by:

- The overall delay of the roundabout will improve by 54.46% and for Ayat, Figa and 02 entry it improved by 60.13%, 58.8% & 26.24% respectively.
- The overall degree of saturation will improve by 27.04%
- The overall 95% back of queue will improve by 37.79% and for Ayat, Figa and 02 entries it will be improved by 60.54%, 31.22% & 50% respectively.

4.4.2 For Road Segments

For the road segments the proposed solutions are:

- improving the capacity and efficiency of the LRT
- improving the access of LRT ticket like by providing offices on both side or E-ticketing system in order to decrease the pedestrian crossing numbers
- improving the intelligent transport system
- providing pedestrian overpass crossing at Meri, Michael and Gurd Shola stations

- prohibiting on street parking on the entire route in peak hours (this solution is started to implement by the traffic managements of the governments which is appreciable and must be continue)
- providing off street parking
- make the schools to use school bus and their own parking area/ not to park on the street during peak hours
- strong enforcement to clear the walkway from different obstacles
- Prohibiting left turns during peak hours in case of Sahilitmiheret to Megenagna road segment.
- relocating construction material ware houses
- providing Taxi byes/terminals
- providing separate lane to taxies and buses by prohibiting others vehicles from using this lane during the peak hours
- Prohibiting cars with empty chair not to pass during peak hours.
- Constructing another street to improve the road network & access of alternative routes.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the result of the study the following conclusions were drawn:

The operational performance of the roundabouts were measured based on three performance measures namely average delay, degree of saturation & LOS. Based on the analysis, the roundabouts were performing above their capacity since its capacity ratio is almost greater than 1 and the level of service is F and they cause significant delay for the user. Therefore the roundabouts were over congested and the operational characteristics of the roundabouts were unsatisfactory. And it indicates that efficiency of the roundabouts contributes significantly towards the efficiency of the whole urban network. In case of Sahilitmiheret and Yetebaberute roundabout the interaction of LRT was the additional reason for the problem of traffic congestion since the road & the LRT were at the same grade. And It is recognizable to see that at peak hours, the traffic polices have to regulates the traffic situations at mid-blocks & intersection since the traffic flow cannot function by its own.

Based on the traffic flow data, the flow was high in one direction. In the morning the flow was high in east-west direction and at the night the direction reversed. Comparatively the traffic flow was high in the morning peak hour than the night. Since almost all users of the road corridor tend to use the corridor at the same time. And the LOS of the three segments was F and the traveler perception score of the segments were greater than 5 which show that the traveler perceive the worst service in the segment. Therefore the flow of traffic on the selected road network was very congested since it is the crucial link that connects the highly densely populated residential areas of eastern part to the center of the city & western part.

Based on the modeled equation ($TT=1187.822-44.798AS+0.848V+1.414P+0.127SL$) pedestrians and traffic volume were the significant effect to increase the travel time. So, pedestrian were the important component for urban network. Hence the entire operational performance of a network was greatly affected due to the pedestrians by causing delay to the traffic movement.

5.2 Recommendations

The following recommendations were proposed.

- In order to improve the whole network of the study area, improvements must be done for the roundabouts.
- To improve the segment performance it is better to provide overpass for the pedestrians especially for the three stations (Meri station, Michael station & Gurd shola stations) which had high number of pedestrian interface with the vehicle.
- Priorities need to be given for pedestrians rather than vehicles and it is better to separate pedestrians from vehicular traffic at mid-block and at the roundabouts since they affect the normal traffic flows.

Recommendation for future study

- The study does not consider the effect of the railway at the roundabouts and the measurement taken by the government to use the opposite side. So further research should be done to consider the effect of LRT on the performance of the roundabouts.
- The current method adopted by this research is based on the HCM. Yet, The HCM is the capacity analysis manual developed in the United States. And the manual is based on the traffic condition of United States and do not consider local traffic condition in Ethiopia. Therefore, to overcome this problem further study need to be carried out to develop the Ethiopian Highway Capacity Manual.

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ANNEXES

Annex A: Traffic volume data's

TableA1 15-min traffic volumes of Sahilitmiheret to Megenagna road segment

Time (15 Min Interval)	Tuesday		Wednesday		Friday	
	Total	PCU	Total	PCU	Total	PCU
7:00 to 7:15	540	585	546	593	438	459
7:15 to 7:30	670	721	659	713	572	596
7:30 to 7:45	729	778	702	750	638	662
7:45 to 8:00	696	744	682	730	622	647
8:00 to 8:15	708	791	684	768	639	712
8:15 to 8:30	683	763	654	745	642	709
8:30 to 8:45	645	738	645	741	566	667
8:45 to 9:00	585	703	606	726	563	638
9.00 to 10.00						
10.00 to 11.00						
11.00 to 12.00						
12:00 to 12:15	391	432	370	409	341	381
12:15 to 12:30	384	412	361	389	316	344
12:30 to 12:45	339	378	364	407	292	327
12:45 to 1:00	315	340	310	338	242	261
1:00 to 1:15	287	298	279	292	238	249
1:15 to 1:30	291	309	261	280	273	291
1:30 to 1:45	378	406	319	338	265	286
1:45 to 2:00	384	403	316	337	289	314
2.00 to 3.00						
3.00 to 4.00						
4.00 to 5.00						
5:00to 5:15	495	530	474	503	469	487
5:15 to 5:30	537	575	524	563	530	554
5:30 to 5:45	541	586	683	727	513	534
5:45 to 6:00	644	691	646	694	610	630
6:00 to 6:15	613	662	603	650	604	631
6:15 to 6:30	588	635	624	674	583	607
6:30 to 6:45	582	622	564	611	586	606
6:45 to 7:00	578	609	551	594	564	587

Table A2 Hourly traffic volume of Sahilitmiheret to Megenagna road segment

Time (1hr Interval)	Tuesday Total volume	Wednesday Total volume	Friday Total volume
7:00 to 8:00	2827	2786	2363
7:15 to 8:15	3034	2961	2616
7:30 to 8:30	3076	2992	2729
7:45 to 8:45	3036	2983	2705
8:00 to 9:00	2995	2979	2726
9:00 to 10:00			
10:00 to 11:00			
11:00 to 12:00			
12:00 to 1:00	1562	1542	1313
12:15 to 1:15	1428	1425	1181
12:30 to 1:30	1325	1316	1128
12:45 to 1:45	1353	1247	1087
1:00 to 2:00	1415	1246	1139
2:00 to 3:00			
3:00 to 4:00			
4:00 to 5:00			
5:00 to 6:00	2381	2487	2204
5:15 to 6:15	2513	2634	2347
5:30 to 6:30	2573	2745	2745
5:45 to 6:45	2609	2629	2629
6:00 to 7:00	2527	2528	2528

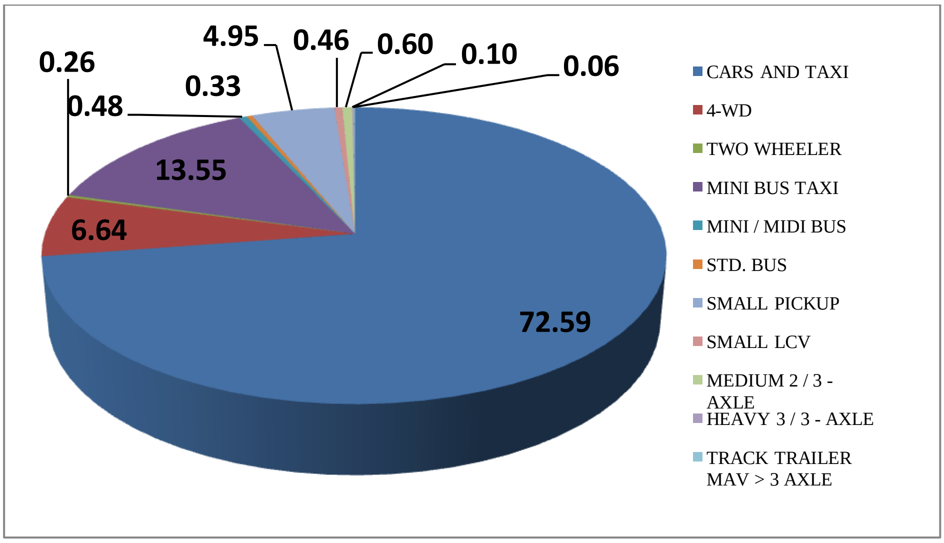


Fig A1 vehicle composition of Sahilitmiheret to Megenagna road segment.

Table A3 15-min traffic volumes of Yetebaberute to Sahilitmiheret road segment.

Time (15 Min Interval)	Tuesday		Wednesday		Friday	
	Total	PCU	Total	PCU	Total	PCU
7:00 to 7:15	497	542	548	603	372	392
7:15 to 7:30	603	653	638	688	525	546
7:30 to 7:45	656	710	669	725	570	594
7:45 to 8:00	653	699	631	676	547	570
8:00 to 8:15	618	672	618	659	552	579
8:15 to 8:30	557	618	603	649	550	581
8:30 to 8:45	540	615	516	563	474	504
8:45 to 9:00	514	571	524	569	472	496
9.00 to 10.00						
10.00 to 11.00						
11.00 to 12.00						
12:00 to 12:15	369	405	288	306	293	313
12:15 to 12:30	364	397	358	383	290	312
12:30 to 12:45	283	310	350	370	194	211
12:45 to 1:00	291	309	276	296	193	210
1:00 to 1:15	278	291	200	209	210	219
1:15 to 1:30	240	247	182	196	185	196
1:30 to 1:45	282	300	236	253	266	283
1:45 to 2:00	379	399	249	265	265	286
2.00 to 3.00						
3.00 to 4.00						
4.00 to 5.00						
5:00to 5:15	441	468	446	474	430	444
5:15 to 5:30	503	537	491	525	488	508
5:30 to 5:45	524	561	631	672	480	503
5:45 to 6:00	637	681	628	675	574	592
6:00 to 6:15	606	651	589	638	568	588
6:15 to 6:30	618	651	569	614	559	583
6:30 to 6:45	583	635	561	604	545	561
6:45 to 7:00	572	614	548	589	544	564

Table A4 Hourly traffic volumes of Yetebaberute to Sahilitmiheret road segment.

Time (1hr Interval)	Tuesday Total volume	Wednesday Total volume	Friday Total volume
7:00 to 8:00	2603	2692	2102
7:15 to 8:15	2681	2748	2289
7:30 to 8:30	2698	2709	2324
7:45 to 8:45	2603	2547	2233
8:00 to 9:00	2476	2439	2159
9:00 to 10:00			
10:00 to 11:00			
11:00 to 12:00			
12:00 to 1:00	1420	1355	1046
12:15 to 1:15	1306	1258	951
12:30 to 1:30	1156	1071	835
12:45 to 1:45	1146	954	906
1:00 to 2:00	1236	922	982
2:00 to 3:00			
3:00 to 4:00			
4:00 to 5:00			
5:00 to 6:00	2246	2345	2046
5:15 to 6:15	2430	2510	2190
5:30 to 6:30	2544	2598	2265
5:45 to 6:45	2618	2531	2323
6:00 to 7:00	2550	2444	2295

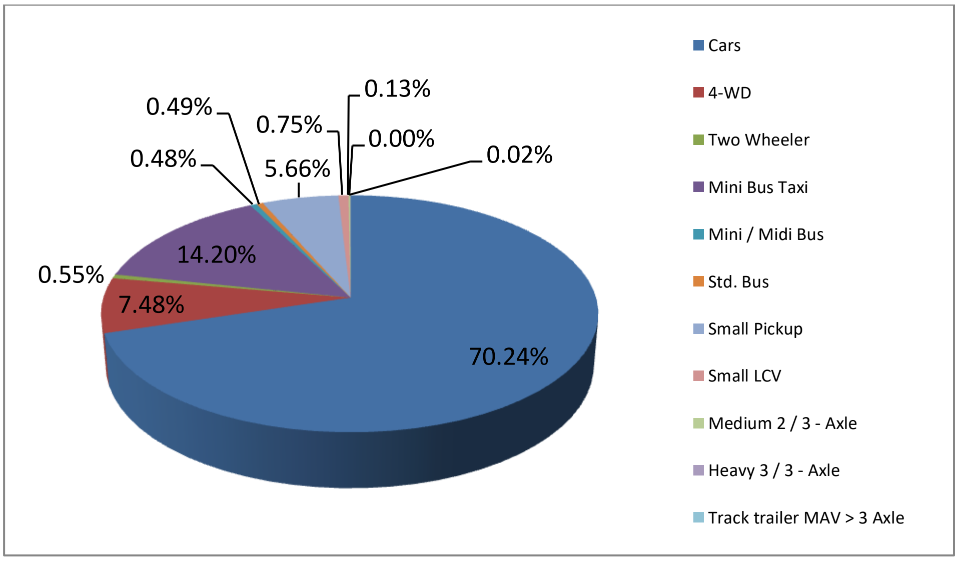


Fig A2 vehicle composition of Yetebaberute to Sahilitmiheret road segment.

Table A5 15-min traffic volumes of Ayat to Yetebaberute road segment.

Time (15 Min Interval)	Tuesday		Wednesday		Friday	
	Total	PCU	Total	PCU	Total	PCU
7:00 to 7:15	462	506	418	463	270	284
7:15 to 7:30	544	589	591	638	477	495
7:30 to 7:45	611	658	612	657	528	547
7:45 to 8:00	565	607	579	622	513	530
8:00 to 8:15	544	591	546	597	502	521
8:15 to 8:30	512	560	541	604	491	519
8:30 to 8:45	473	541	466	537	411	435
8:45 to 9:00	466	526	489	546	404	424
9.00 to 10.00						
10.00 to 11.00						
11.00 to 12.00						
12:00 to 12:15	312	360	298	347.5	238	257
12:15 to 12:30	316	346.5	343	384.5	272	293
12:30 to 12:45	181	203.5	327	361.5	149	166
12:45 to 1:00	184	202.5	214	238.5	157	170
1:00 to 1:15	145	152	169	190	158	162
1:15 to 1:30	144	161.5	148	171	140	145
1:30 to 1:45	223	251.5	240	271.5	217	234
1:45 to 2:00	267	288.5	241	263	253	271
2.00 to 3.00						
3.00 to 4.00						
4.00 to 5.00						
5:00to 5:15	429	454	418	444	358	367
5:15 to 5:30	493	525	464	495.5	408	423
5:30 to 5:45	477	514	590	628.5	420	440
5:45 to 6:00	617	659	573	614	501	516
6:00 to 6:15	574	620.5	578	623	523	541
6:15 to 6:30	597	637.5	550	595	516	538
6:30 to 6:45	562	600.5	549	596.5	499	511
6:45 to 7:00	603	635	518	558	485	502

Table A6 Hourly traffic volume of Ayat to Yetebaberute road segment.

Time (1hr Interval)	Tuesday	Wednesday	Friday
	Total volume	Total volume	Total volume
7:00 to 8:00	2360	2379	1856
7:15 to 8:15	2444	2514	2093
7:30 to 8:30	2416	2479	2116
7:45 to 8:45	2278	2359	2005
8:00 to 9:00	2197	2283	1899
9:00 to 10:00			
10:00 to 11:00			
11:00 to 12:00			
12:00 to 1:00	1113	1332	886
12:15 to 1:15	905	1175	791
12:30 to 1:30	720	961	643
12:45 to 1:45	768	871	711
1:00 to 2:00	854	896	811
2:00 to 3:00			
3:00 to 4:00			
4:00 to 5:00			
5:00 to 6:00	2152	2182	1745
5:15 to 6:15	2319	2361	1920
5:30 to 6:30	2431	2461	2034
5:45 to 6:45	2518	2429	2105
6:00 to 7:00	2494	2494	2091

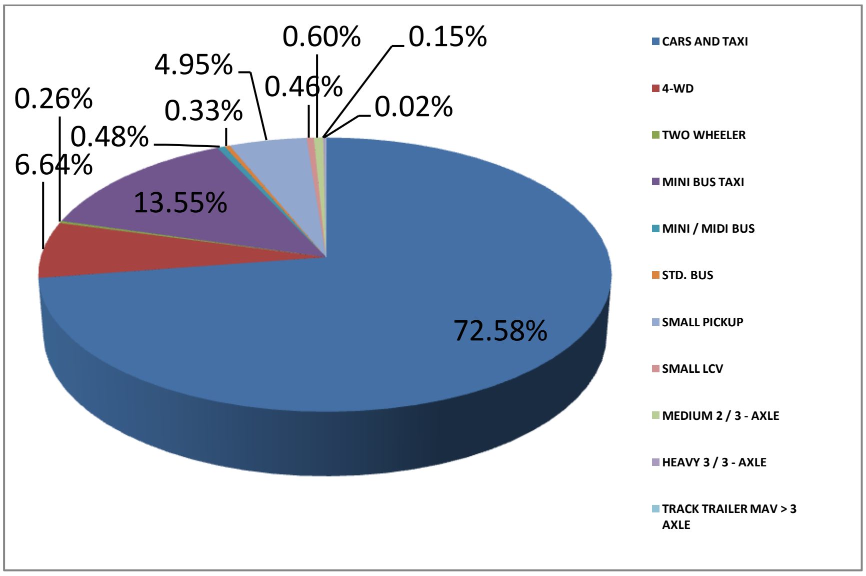


Fig A3 vehicle composition of Ayat to Yetebaberute road segment.

Annex B. Roundabout analysis

B.1 Sahilitmiheret roundabout analysis

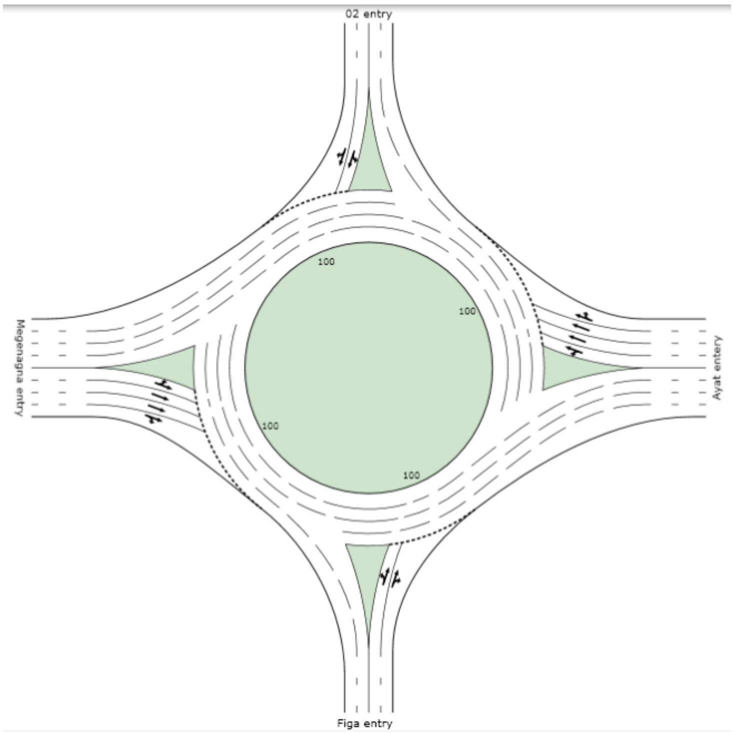


Fig B 1 layout of Sahilitmiheret roundabout

Table B1 Movement summary of Sahilitmiheret roundabout

Movement Performance - Vehicles											
Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Prop. Queued	Effective Stop Rate per veh	Average Speed km/h
South: Figa entry											
1	L	868	0.0	2.219	579.3	LOS F	158.2	1093.5	1.00	12.90	3.8
2	T	209	0.0	1.595	306.4	LOS F	75.3	527.1	1.00	8.80	5.5
3	R	384	0.0	1.595	306.4	LOS F	75.3	527.1	1.00	8.80	5.2
Approach		1460	0.0	2.219	468.3	LOS F	158.2	1093.5	1.00	11.23	4.2
East: Ayat entery											
4	L	663	0.0	1.458	241.9	LOS F	72.4	506.6	1.00	7.98	7.5
5	T	2818	1.0	2.124	533.1	LOS F	174.9	1234.4	1.00	12.75	3.4
6	R	117	0.0	2.124	533.4	LOS F	168.9	1191.2	1.00	12.60	3.2
Approach		3598	0.8	2.124	479.4	LOS F	174.9	1234.4	1.00	11.87	3.9
North: 02 entry											
7	L	250	0.0	2.022	511.1	LOS F	77.3	541.4	1.00	5.94	4.3
8	T	300	0.0	2.022	509.6	LOS F	85.4	597.9	1.00	6.13	3.6
9	R	398	0.0	2.022	506.5	LOS F	85.4	597.9	1.00	6.50	3.5
Approach		948	0.0	2.022	508.7	LOS F	85.4	597.9	1.00	6.23	3.7
West: Megenagna entry											
10	L	223	0.0	0.388	12.1	LOS B	1.2	8.2	0.54	0.73	28.8
11	T	608	1.0	0.529	15.7	LOS C	1.9	13.5	0.60	0.81	28.3
12	R	341	0.0	0.571	16.6	LOS C	2.1	14.7	0.59	0.74	29.1
Approach		1173	0.5	0.571	15.3	LOS C	2.1	14.7	0.59	0.77	28.6
All Vehicles		7178	0.5	2.219	405.2	LOS F	174.9	1234.4	0.93	9.18	4.6

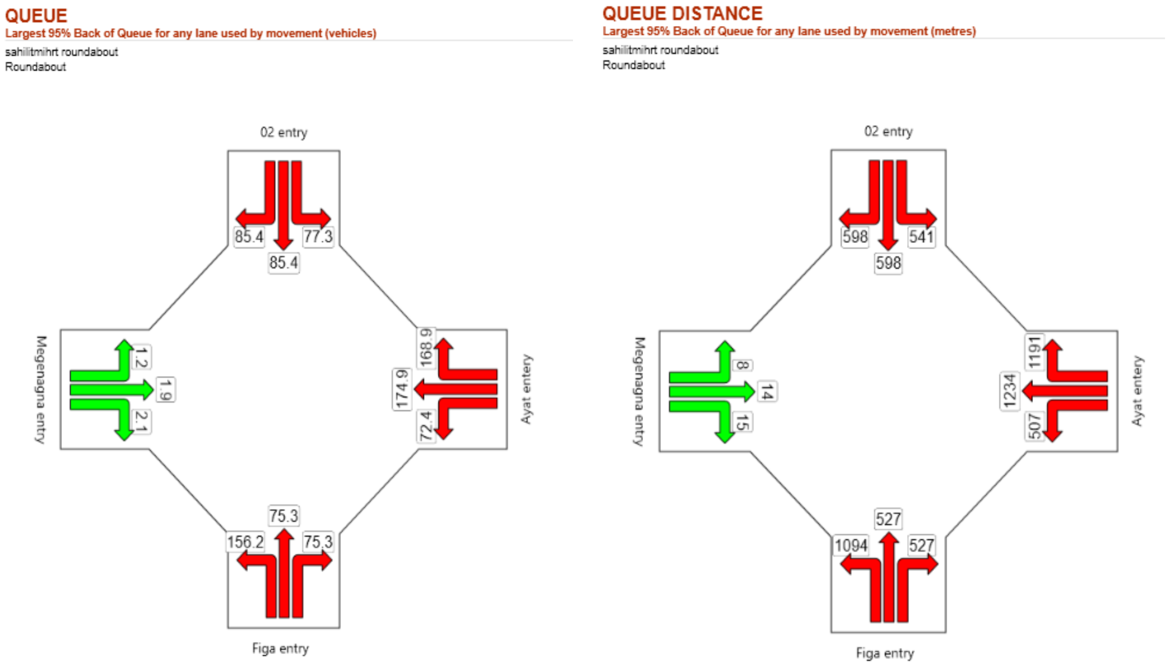
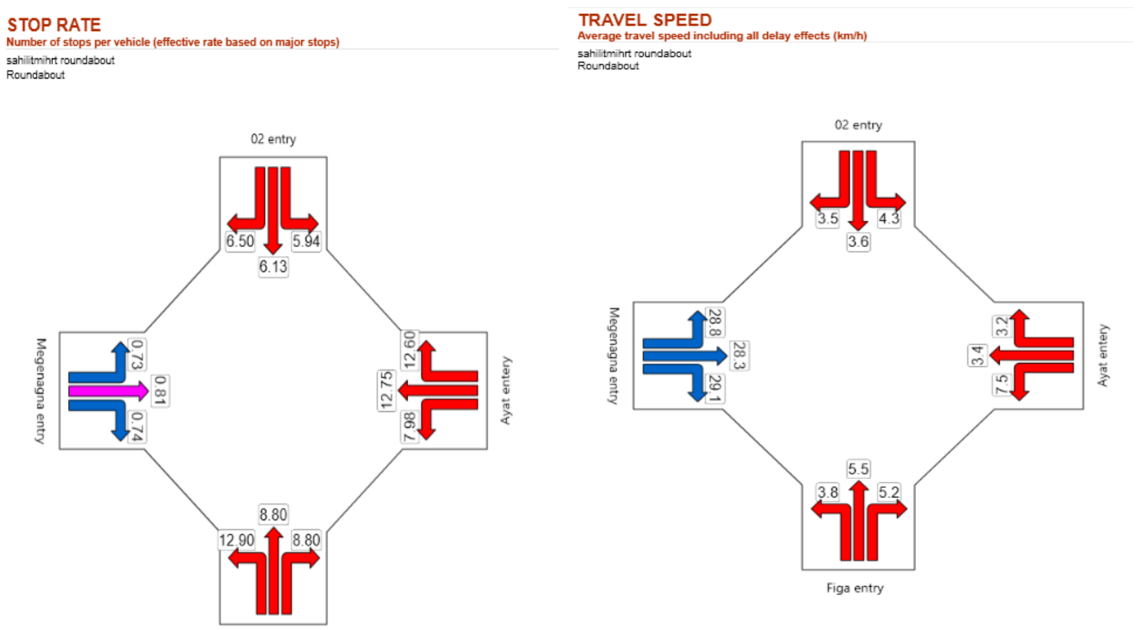


Fig B2 Queue & Queue distance of Sahilitmiheret roundabout



	South	East	North	West	Intersection
Travel Speed	4.2	3.9	3.7	28.6	4.6

Fig B 3 Stop rate & Travel speed of Sahilitmiheret roundabout

Table B2 lane summary of Sahilitmiheret roundabout

LANE SUMMARY

Site: Sahilitmihrt roundabout

sahilitmihrt roundabout
Roundabout

Lane Use and Performance

	Demand Flows L veh/h	T veh/h	R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
South: Figa entry																
Lane 1	866	0	0	866	0.0	390	2.219	100	579.3	LOS F	156.2	1093.5	500	-	0.0	38.2
Lane 2	0	209	384	594	0.0	372	1.595	72[5]	306.4	LOS F	75.3	527.1	500	-	0.0	6.6
Approach	866	209	384	1460	0.0		2.219		468.3	LOS F	156.2	1093.5				
East: Ayat entery																
Lane 1	663	0	0	663	0.0	455	1.458	69[5]	241.9	LOS F	72.4	506.6	500	-	0.0	5.4
Lane 2	0	966	0	966	1.0	455	2.124	100	533.4	LOS F	168.9	1192.4	500	-	0.0	45.5
Lane 3	0	1003	0	1003	1.0	472	2.124	100	532.6	LOS F	174.9	1234.4	500	-	0.0	49.2
Lane 4	0	849	117	966	0.9	455	2.124	100	533.4	LOS F	168.9	1191.2	500	-	0.0	45.4
Approach	663	2818	117	3598	0.8		2.124		479.4	LOS F	174.9	1234.4				
North: 02 entry																
Lane 1	250	198	0	448	0.0	222	2.022	100	511.1	LOS F	77.3	541.4	500	-	0.0	7.4
Lane 2	0	102	398	500	0.0	247	2.022	100	506.5	LOS F	85.4	597.9	500	-	0.0	10.5
Approach	250	300	398	948	0.0		2.022		508.7	LOS F	85.4	597.9				
West: Megenagna entry																
Lane 1	223	0	0	223	0.0	576	0.388	68[5]	12.1	LOS B	1.2	8.2	500	-	0.0	0.0
Lane 2	0	304	0	304	1.0	576	0.529	93[5]	15.7	LOS C	1.9	13.5	500	-	0.0	0.0
Lane 3	0	304	0	304	1.0	576	0.529	93[5]	15.7	LOS C	1.9	13.5	500	-	0.0	0.0
Lane 4	0	0	341	341	0.0	597	0.571	100	16.6	LOS C	2.1	14.7	500	-	0.0	0.0
Approach	223	608	341	1173	0.5		0.571		15.3	LOS C	2.1	14.7				
Intersection				7178	0.5		2.219		405.2	LOS F	174.9	1234.4				

B2. Yetebaberute roundabout analysis

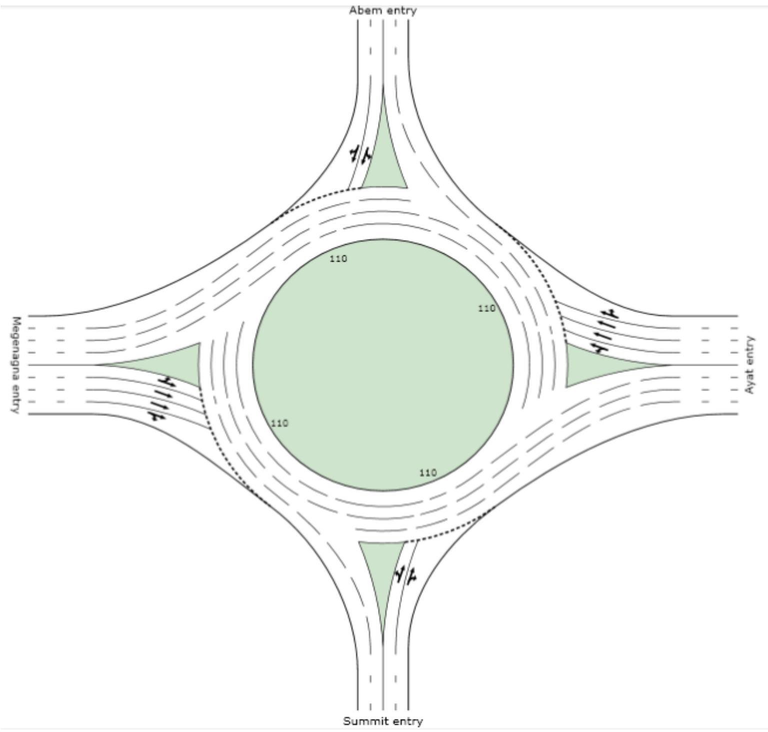


Fig B 4 layout of Yetebaberute roundabout

Table B3 Movement summary of Yetebaberute roundabout

MOVEMENT SUMMARY

Site: yetebaberute roundabout

yetebaberute
Roundabout

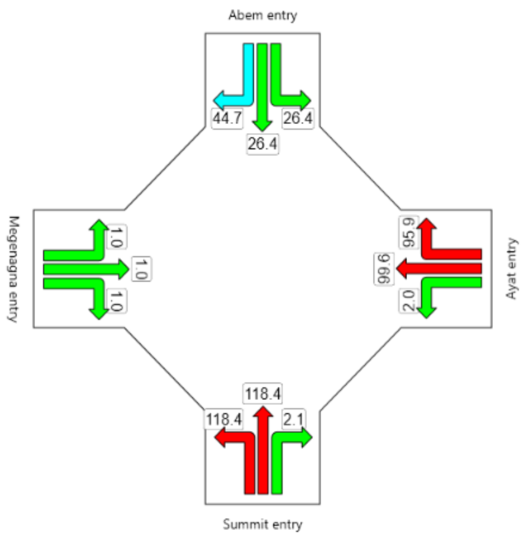
Movement Performance - Vehicles

Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Prop. Queued	Effective Stop Rate per veh	Average Speed km/h
South: Summit entry											
	L	686	1.0	1.643	317.0	LOS F	118.4	836.0	1.00	7.93	6.6
	T	211	1.0	1.643	317.0	LOS F	118.4	836.0	1.00	7.93	5.5
	R	293	1.0	0.560	18.1	LOS C	2.1	14.5	0.64	0.86	27.6
Approach		1190	1.0	1.643	243.4	LOS F	118.4	836.0	0.91	6.19	7.5
East: Ayat entry											
4	L	286	0.0	0.594	20.8	LOS C	2.0	14.0	0.63	0.86	26.2
5	T	2087	1.0	1.585	294.0	LOS F	99.6	703.1	1.00	7.41	5.9
6	R	235	0.0	1.585	294.4	LOS F	95.9	675.3	1.00	7.30	5.7
Approach		2608	0.8	1.585	264.1	LOS F	99.6	703.1	0.96	6.68	6.5
North: Abem entry											
7	L	145	0.0	1.270	189.6	LOS F	26.4	184.6	1.00	3.25	9.7
8	T	171	0.0	1.270	189.6	LOS F	26.4	184.6	1.00	3.25	8.4
9	R	400	0.0	1.456	259.0	LOS F	44.7	312.9	1.00	4.42	6.3
Approach		715	0.0	1.456	228.4	LOS F	44.7	312.9	1.00	3.90	7.4
West: Megenagna entry											
10	L	298	1.0	0.369	11.0	LOS B	1.0	7.2	0.47	0.67	29.0
11	T	447	1.0	0.369	10.8	LOS B	1.0	7.2	0.46	0.66	30.4
12	R	181	0.0	0.369	11.0	LOS B	1.0	7.2	0.47	0.67	30.7
Approach		926	0.8	0.369	10.9	LOS B	1.0	7.2	0.47	0.66	29.9
All Vehicles		5440	0.7	1.643	211.8	LOS F	118.4	836.0	0.87	5.18	8.0

QUEUE

Largest 95% Back of Queue for any lane used by movement (vehicles)

yetebaberute
Roundabout



QUEUE DISTANCE

Largest 95% Back of Queue for any lane used by movement (metres)

yetebaberute
Roundabout

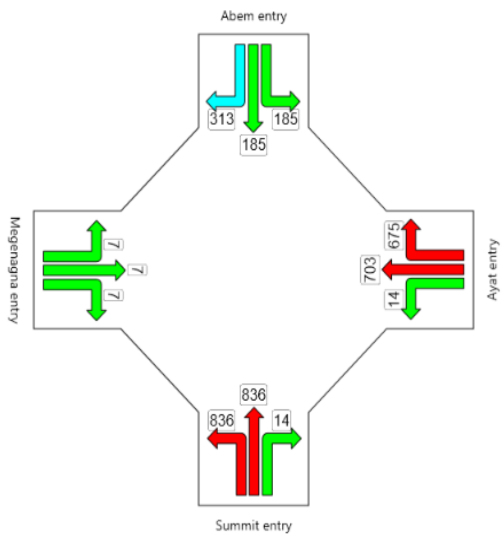
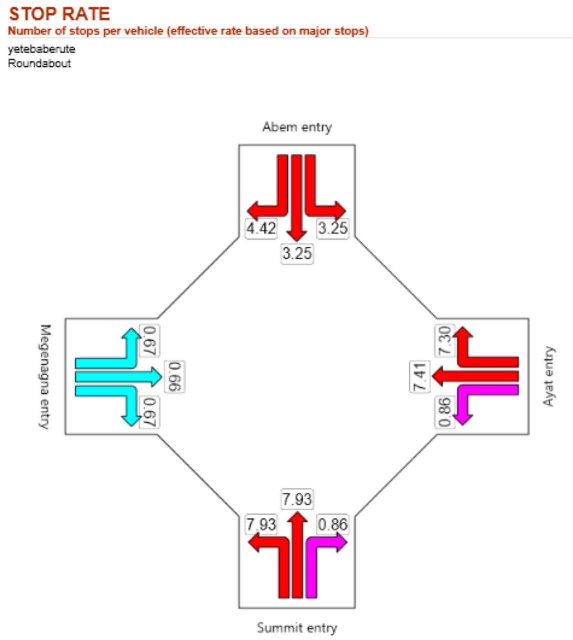


Fig B5 Queue & Queue distance of Yetebaberute roundabout



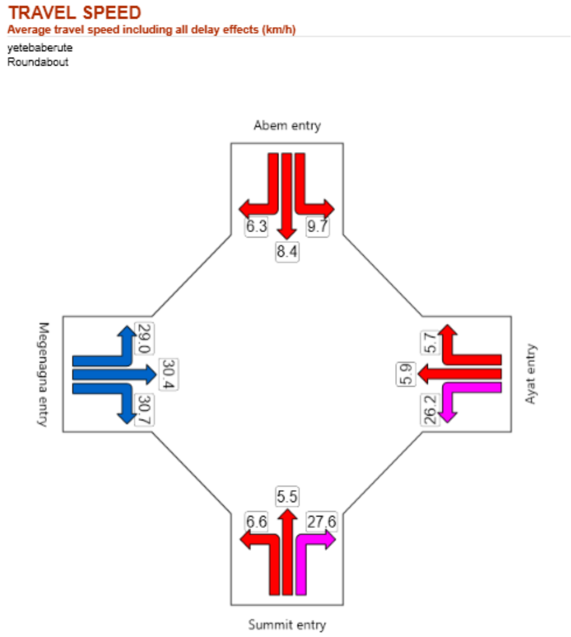


Fig B 6 Stop rate & Travel speed of Yetebaberute roundabout

Table B4 Lane summary of Yetebaberute roundabout

LANE SUMMARY

Site: yetebaberute roundabout

yetebaberute
Roundabout

Lane Use and Performance

	Demand Flows L veh/h	Demand Flows T veh/h	Demand Flows R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
South: Summit entry																
Lane 1	686	211	0	897	1.0	546	1.643	100	317.0	LOS F	118.4	836.0	500	-	0.0	23.2
Lane 2	0	0	293	293	1.0	523	0.560	100	18.1	LOS C	2.1	14.5	500	-	0.0	0.0
Approach	686	211	293	1190	1.0		1.643		243.4	LOS F	118.4	836.0				
East: Ayat entry																
Lane 1	286	0	0	286	0.0	482	0.594	37[5]	20.8	LOS C	2.0	14.0	500	-	0.0	0.0
Lane 2	0	763	0	763	1.0	482	1.585	100	294.4	LOS F	95.9	677.1	500	-	0.0	14.8
Lane 3	0	796	0	796	1.0	502	1.585	100	293.4	LOS F	99.6	703.1	500	-	0.0	16.2
Lane 4	0	528	235	763	0.7	482	1.585	100	294.4	LOS F	95.9	675.3	500	-	0.0	14.7
Approach	286	2087	235	2608	0.8		1.585		264.1	LOS F	99.6	703.1				
North: Abem entry																
Lane 1	145	171	0	315	0.0	248	1.270	100	189.6	LOS F	26.4	184.6	500	-	0.0	0.0
Lane 2	0	0	400	400	0.0	275	1.456	100	259.0	LOS F	44.7	312.9	500	-	0.0	0.0
Approach	145	171	400	715	0.0		1.456		228.4	LOS F	44.7	312.9				
West: Megenagna entry																
Lane 1	230	0	0	230	1.0	623	0.369	100	11.0	LOS B	1.0	7.2	500	-	0.0	0.0
Lane 2	68	162	0	230	1.0	623	0.369	100	11.0	LOS B	1.0	7.2	500	-	0.0	0.0
Lane 3	0	236	0	236	1.0	640	0.369	100	10.7	LOS B	1.0	6.8	500	-	0.0	0.0
Lane 4	0	49	181	230	0.2	623	0.369	100	11.0	LOS B	1.0	7.2	500	-	0.0	0.0
Approach	298	447	181	926	0.8		0.369		10.9	LOS B	1.0	7.2				
Intersection				5440	0.7		1.643		211.8	LOS F	118.4	836.0				

B3. Ayat roundabout analysis

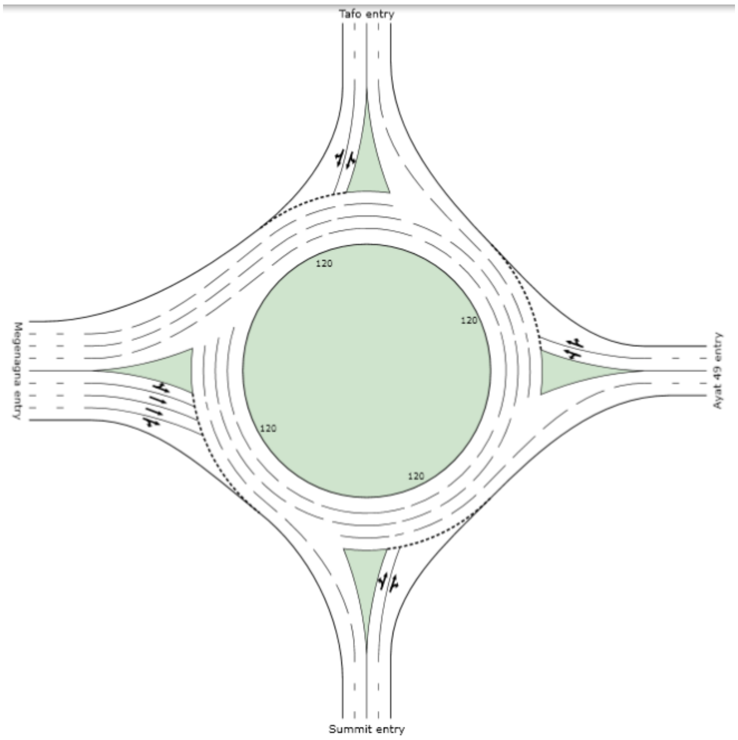


Fig B 7 layout of Ayat roundabout

Table B5 Movement summary of Ayat roundabout

MOVEMENT SUMMARY — Site: Ayat roundabout

Ayat roundabout
Roundabout

Movement Performance - Vehicles

Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Prop. Queued	Effective Stop Rate per veh	Average Speed km/h
South: Summit entry											
1	L	178	0.0	0.584	21.7	LOS C	2.2	15.6	0.76	0.99	29.7
2	T	258	0.0	0.584	21.0	LOS C	2.2	15.6	0.75	1.00	31.9
3	R	100	0.0	0.584	20.7	LOS C	2.2	15.1	0.74	0.87	35.6
Approach		535	0.0	0.584	21.2	LOS C	2.2	15.6	0.75	0.97	31.6
East: Ayat 49 entry											
4	L	221	0.0	1.677	336.7	LOS F	101.2	712.9	1.00	7.63	6.3
5	T	1170	1.0	1.677	336.0	LOS F	105.8	745.6	1.00	7.81	5.2
6	R	132	0.0	1.677	335.5	LOS F	105.8	745.6	1.00	7.95	5.1
Approach		1522	0.8	1.677	336.1	LOS F	105.8	745.6	1.00	7.80	5.4
North: Tafo entry											
7	L	157	0.0	1.193	138.6	LOS F	30.9	216.6	1.00	4.19	11.6
8	T	328	0.0	1.193	138.6	LOS F	30.9	216.6	1.00	4.19	10.1
9	R	1048	0.8	2.453	681.1	LOS F	202.8	1429.5	1.00	12.14	2.7
Approach		1532	0.5	2.453	509.6	LOS F	202.8	1429.5	1.00	9.63	3.6
West: Megenagna entry											
10	L	529	0.0	0.800	27.6	LOS D	4.6	32.4	0.67	0.96	24.5
11	T	515	1.0	0.385	10.8	LOS B	1.1	8.0	0.48	0.61	31.5
12	R	63	0.0	0.129	7.1	LOS A	0.3	2.1	0.41	0.39	34.8
Approach		1107	0.5	0.800	18.6	LOS C	4.6	32.4	0.57	0.76	27.4
All Vehicles		4697	0.5	2.453	282.0	LOS F	202.8	1429.5	0.87	5.96	6.3

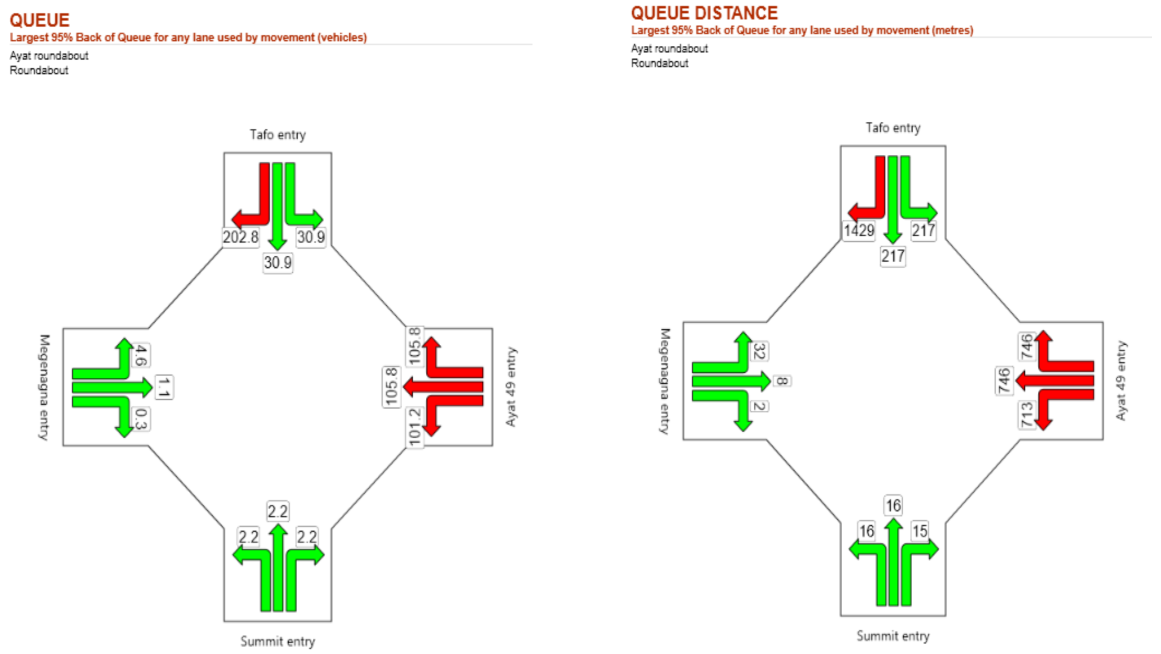


Fig B8 Queue & Queue distance of Ayat roundabout

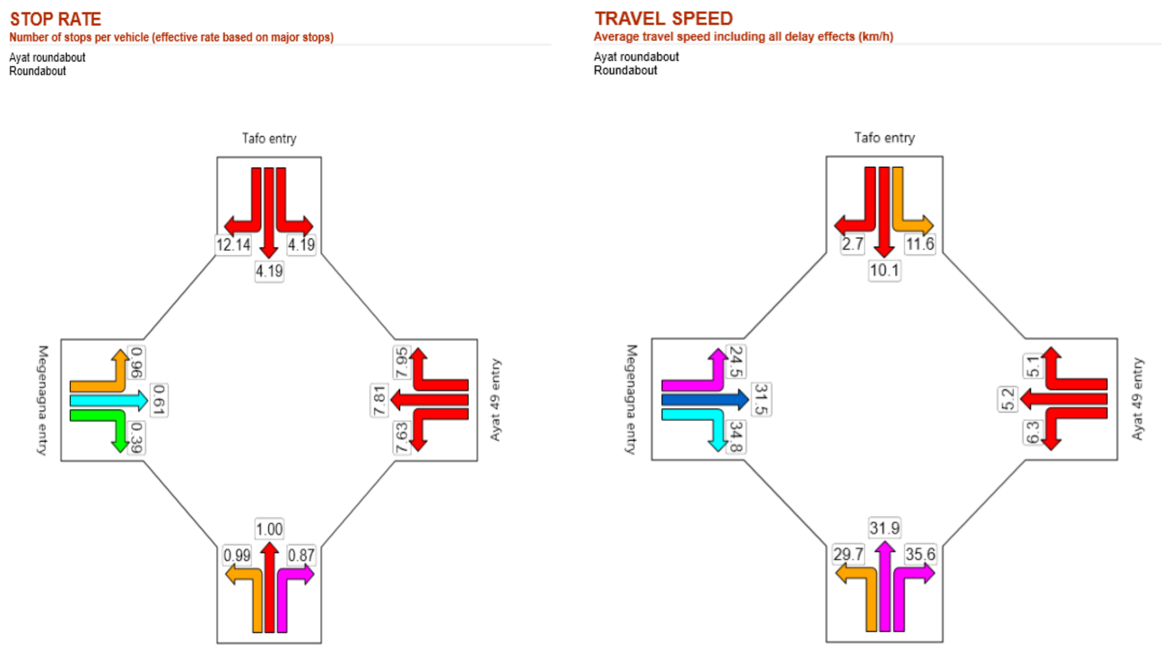


Fig B9 Stop rate & Travel speed of Ayat roundabout

Table B6 Lane summary of Ayat roundabout

LANE SUMMARY

Site: Ayat roundabout

Ayat roundabout
Roundabout

Lane Use and Performance

	Demand Flows L veh/h	T veh/h	R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
South: Summit entry																
Lane 1	178	82	0	260	0.0	445	0.584	100	21.7	LOS C	2.2	15.6	500	-	0.0	0.0
Lane 2	0	176	100	276	0.0	472	0.584	100	20.7	LOS C	2.2	15.1	500	-	0.0	0.0
Approach	178	258	100	535	0.0		0.584		21.2	LOS C	2.2	15.6				
East: Ayat 49 entry																
Lane 1	221	522	0	743	0.7	443	1.677	100	336.7	LOS F	101.2	712.9	500	-	0.0	16.7
Lane 2	0	648	132	780	0.8	465	1.677	100	335.5	LOS F	105.8	745.6	500	-	0.0	18.4
Approach	221	1170	132	1522	0.8		1.677		336.1	LOS F	105.8	745.6				
North: Tafo entry																
Lane 1	157	328	0	484	0.0	406	1.193	49[5]	138.6	LOS F	30.9	216.6	500	-	0.0	0.0
Lane 2	0	0	1048	1048	0.8	427	2.453	100	681.1	LOS F	202.8	1429.5	500	-	0.0	79.9
Approach	157	328	1048	1532	0.5		2.453		509.6	LOS F	202.8	1429.5				
West: Megenagna entry																
Lane 1	529	0	0	529	0.0	661	0.800	100	27.6	LOS D	4.6	32.4	500	-	0.0	0.0
Lane 2	0	248	0	248	1.0	643	0.385	48[5]	11.0	LOS B	1.1	8.0	500	-	0.0	0.0
Lane 3	0	248	0	248	1.0	643	0.385	48[5]	11.0	LOS B	1.1	8.0	500	-	0.0	0.0
Lane 4	0	20	63	83	0.2	643	0.129	16[5]	7.1	LOS A	0.3	2.1	500	-	0.0	0.0
Approach	529	515	63	1107	0.5		0.800		18.6	LOS C	4.6	32.4				
Intersection				4697	0.5		2.453		282.0	LOS F	202.8	1429.5				

Annex C: Questionnaire

Questionnaire for a research titled ‘EVALUATING THE TRAFFIC OPERATIONAL PERFORMANCE IN ADDIS ABABA: A CASE OF MEGENAGNA TO AYAT ROAD SEGMENT’**.** This questionnaire aims to study the overall performance of the road network and the factors that affect the traffic performance in Addis Ababa. The data gathered from you will be only used for academic purpose, for M.Sc. thesis in Civil Engineering under Road and Transport Engineering

Please cooperate by filling the following questionnaire with facts, having in mind that this information will be treated confidentially.

Thank you for your cooperation

By Bethlehem Tilahun

Instruction: Please answer all questions by putting an “X” mark on your choice and write your opinion for others. You do not need to write your name.

Part I:-PERSONAL INFORMATION

1. Sex ☐ Male ☐ Female
2. Age group ☐ 18-30 ☐ 30-50 ☐ >50
3. Educational level

   ☐ Primary level ☐ Secondary level ☐ Diploma ☐ Degree

   ☐ Masters and above
4. Type of occupation

   ☐ Public employed ☐ private-employed ☐ self-employ ☐ Student

Part II.

1. What type of travel mode mostly prefer in your day to day activities?

   ☐ Personal/private vehicle ☐ Public transport

   ☐ Taxi ☐ Other

2. How do you see the current vehicle traffic movement along the street?

☐ No congestion ☐ Low congestion

☐ Congested ☐ Very high congestion

3. The time it takes to travel from your origin to destination?

From____________________ to ______________________

Time it takes __________________________

4. If you are a driver, what are your travel speed and the time it takes during peak hour & off peak hour?

Origin to destination	At peak hour		Off peak hour	
	speed	Time	Speed	Time
Ayat to Meri				
Meri to Yetebaberute				
Yetebaberute to CMC(Michael)				
CMC to Sahilitmiheret				
Sahilitmiheret to Gurd Shola				
Gurd shola to Megenagna				

5. In your view what is the requirement to say the road is efficient (the traffic performance is good) for the road user?

____

____

____

6. In your view, what are the factors that contribute for the traffic crowding? (Rank)

☐ Imbalance of vehicle volume and road capacity
☐ On street vehicle parking
☐ Shortage of mass transport
☐ Poor vehicle condition
☐ Poor traffic management
☐ Pedestrian interference with vehicles

- [ ] In-formal on street trading
- [ ] Bottlenecks
- [ ] Traffic accidents

Other____

7. What do you suggest to minimize problems related with traffic movement along the street? (rank)
    - [ ] Use mass transport
    - [ ] Improve the road capacity
    - [ ] Providing better pedestrian crossing facilities
    - [ ] Improve parking management
    - [ ] Mitigate street on street trade
    - [ ] Improve traffic management strategy
    - [ ] Improve light rail way transportation

    Other measure____

8. Any alternative you use when the road network is congested(perform poor)
    - [ ] Changing the route (using the other alternative route)
      If yes, which route?___________________________
    - [ ] Changing the mode of travel to walking
    - [ ] Waiting longer time

    Other option______________________________________

9. Anything you want to say?

    ____
    ____
    ____
    ____