



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

ASSESSMENT OF CONGESTION AND PERFORMANCE
EVALUATION OF ROUNDABOUTS ON CMC-
MEGENAGNA ROAD

A Thesis submitted to
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Msc Thesis On
ASSESSMENT OF CONGESTION AND PERFORMANCE EVALUATION
OF ROUNDABOUTS ON CMC-MEGENAGNA ROAD

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Assessment of Congestion and Performance Evaluation of Roundabouts on
CMC-Megenagna road

DECLARATION

I certify that this research work titled “ASSESSMENT OF CONGESTION AND PERFORMANCE EVALUATION OF ROUNDABOUTS ON CMC-MEGENAGNA ROAD” is my own work. The work has not been presented elsewhere for assessment and award of any degree or diploma. Where material has been used from other sources it has been properly acknowledged/ referred.

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Signature

Date

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LIST OF ACCRONYMS

AACRA	Addis Ababa City Roads Authority
DOT	Department of Transportation
FHWA	Federal Highway Administration
HCM	Highway Capacity Manual
ITS	Intelligent Transportation System
LOS	Level of Service
LCV	Light Commercial Vehicle
LRT	Light Rail Transit
MUTS	Manual on Uniform Traffic Studies
MOE	Measure of Effectiveness
NCHRP	National Cooperative Highway Research Program
PCE	Passenger Car Equivalent

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ABSTRACT

Traffic congestion is one of the major problems that is being faced by developed and developing countries around the world. Addis Ababa being the capital city and the busiest city in the country, traffic congestion is a common phenomenon in the day to day activity. This study mainly focuses on assessing the traffic congestion by taking the road section from CMC to Megenagna as a case study. This road section is one of the most complained road section by road users. There are two roundabouts along the study road which are congested during the peak hours of the day. The performance of the roundabouts was evaluated using SIDRA INTERSECTION software as a tool. Also in order to see the level of congestion it is important to quantify the traffic congestion. Travel time approach is used to measure the congestion intensity and reliability.

The result showed that both roundabouts are performing below the satisfactory level in terms of capacity and delay performance measures. High demand flow on one or two approaches, high circulating flows and the existence of heavy vehicles during the peak periods contributed for the poor performance of the roundabouts. Using this road in the morning peak hours causes a traveler to spend 13.1 minutes per kilometer of delay on average and should reserve maximum 14 times the off peak travel time to reach on time.

CHAPTER ONE: Introduction

1.1. Background of the study

Traffic congestion is one of the major problems that is being faced by developed and developing countries around the world. As a result of traffic congestion at intersections delay and long queues are observed repeatedly during peak hours.

Traffic congestion affects travelers both directly and indirectly. Increasing travel time, excessive delay in a queue, increasing fuel cost, delay, loss in productive hours are among the direct effects and it indirectly affects the living standard and the environment (1). The overall effects of traffic congestion can broadly be categorized under; Health effects, Environmental effects, and Economy effect. Congestion can be manifested through a number of problems which include; Inability to forecast travel time accurately, leading to drivers allocating more time to travel and less time on productive activities, wastage of fuel and increasing air pollution, Wear and tear on vehicles as a result of idling in traffic and frequent acceleration and braking, leading to more frequent repairs and replacements, Stress and frustration: discomfort that comes from waiting time of the traffic congestion cause discomfort of passengers and motorists m. Congestion increases the tendency of collision which may lead to series of injuries and fatality, perishing of some agricultural produce etc (2).

Recently the demand for transport vehicles and the number of motor vehicles is growing fast in Ethiopia, but the rate of growth is higher in the capital city Addis Ababa where large proportion of vehicles found.

1.2. Statement of the problem

Currently, traffic congestion is one of the major issues in Addis Ababa city. Even though there are works to expand the road network in the city, vehicle ownership is growing fast not proportional with the road infrastructure development. There is traffic congestion in the city at peak hours causing critical delays for commuters and impacting the city's economy significantly. In this particular study road congestion is a critical problem especially at peak hours of the day. Identifying the causes will have a great value to propose possible solutions by the responsible body.

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Also knowing the extent of the problem will create awareness to the responsible body to take actions giving priority from other projects. This will be done by quantifying the congestion using travel time approach on selected road segments and from the results of roundabout performance evaluation.

There are two roundabouts along the study road which are thought to be over capacitated at their two legs during the peak hours. At peak hours of the day the traffic police have to intervene in the situation to regulate the traffic flow and the performance of these two roundabouts will be determined.

1.3. Research Hypothesis

- The roundabouts found along the study road are performing poorly.
- There are problems like capacity and unbalanced traffic flow at intersections causing the traffic congestion on the study road section.
- The traffic congestion causes a significant delay on the vehicular traffic.

1.4. Objective of the research

1.4.1. General Objectives

The general objective of this thesis is to determine the level of congestion on the study road that starts at CMC and ends at Megenagna.

Most of the congestion studies in the city are conducted through observation and the solutions are management measures based on this observation. Quantifying congestion through engineering measurements is not a widely conducted method of studying congestion. In this study by quantifying congestion and identifying the problematic areas the outputs are believed to help decision makers in comparing this road section with other congested areas and give priority in giving solutions.

1.4.2. Specific Objectives

- To determine the capacities and performance measures, majorly focusing on vehicular delay, of the two roundabouts which are located along the study road.

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- The additional delay caused by the LRT line crossing the roundabouts will be determined.
- To determine the level of congestion intensity, extent and reliability based on different parameters identified, segments are selected and travel time study will be conducted.
- To quantify the effect of congestion on selected segments of the road in terms of delay.

1.5. Scope, Significance and Limitations of the Research

1.5.1. Scope of the research

In this study, traffic congestion on a selected road section, CMC to Megenagna, will be assessed by analyzing the performance of roundabouts and quantifying congestion on mid blocks.

This research focuses on showing the extent of the problem and identifying problems that create the congestion on the road section. Solutions to the problem are not addressed in depth but are pointed out as recommendations and made open for further studies.

1.5.2. Significance of the research

This research will have a practical contribution in a way that it helps to know the extent of the problem in a quantified manner. This will be important to compare it with other similar situations and to make priorities in giving solution to the problem.

The theoretical contribution of the research will be that the methodology followed here can be applied for other similar researches or can be used as a starting point to do other studies.

1.5.3. Limitations of the research

As for the limitations of the research, when considering the LRT line, the SIDRA INTERSECTION 8 software allows LRT input but in this study's case the LRT passes through the median of the road and also passes crossing the roundabouts. Unfortunately the software doesn't allow such kind of movement therefore the additional delay caused by the at grade crossing LRT line is determined separately by collecting frequency and closure time of the train crossing manually.

CHAPTER TWO: Literature Review

2.1. Introduction

The Federal Highway Administration (FHWA) defines traffic congestion as “the level at which transportation system performance is no longer acceptable due to traffic interference” and that “the level of system performance may vary by type of transportation facility, geographic location (metropolitan area or sub - area, rural area), and/or time of day” (3).

Traffic congestion studies can be conducted using different types of measures such as volume based, service based (LOS), travel time and delay based, speed based and cost based measures. These studies tried to address the causes of traffic congestion, the solutions to the problem and the effect of the problem on different parties. Traffic congestion studies have been made on intersections, road corridors and network wide mostly concentrating on one type of mode which is vehicles. There are also multimodal delay studies most of which are done by using simulation softwares that use travel time approach.

Addis Ababa being the capital city of Ethiopia and the biggest city in the country, extensive use of highways for transportation is a common phenomenon. Following this, and high rate of population growth in the city, traffic congestion has become one of the chronic problems in Addis Ababa. This literature review is used to assess the different methodologies used to do similar researches and to explore what studies have been made on this topic.

2.2. Causes of Traffic Congestion

There are a number of causes of traffic congestion which are different for different countries. Increase in population living in urban areas and a number of vehicles per household lead to increase in demand for roads. Weak public transportation encourages people to use their cars instead, adding to the demand for roads. Moreover, increases in job opportunities, inadequate parking spaces, poor urban planning, economic growth, signal failure, and other important factors contribute in increasing demand for road usage (4).

Traffic incidents such as crashes and vehicle breakdowns, work zones, bad weather, special events and poorly timed traffic signals reduce physical capacity of a roadway to a great extent. All the cases in Network Overload fall where the road congestion is caused either

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by decreased capacity of the road or increased demand for transportation (5). In other words, contributors to network overloads can be divided in supply factors and demand-increase factors (4).

Another physical factor of traffic congestion is road intersections. Urban road intersections easily become the worst hit of traffic delay. This is because, at intersections, vehicular flows from several different approach (link/edge) making either left-turn, through and right-turn movements seek to occupy the same physical space at the same time. In addition to vehicular flows, there are also pedestrians who need space to pass the street thereby making the situation even worse. The presence of heavy transport vehicles can be considered physical factor of traffic delay. Due to the number of stops that buses have to make throughout their daily routine, and the fact that the majority of the time there are no designated lanes for buses, they end up unintentionally delaying vehicles behind them, thereby adding to traffic congestion (4).

The above mentioned causes of traffic congestion can be applicable to Addis Ababa city. The rate at which transportation demand increases exceeds the rate at which transportation facility supply increases. Also high rate of heavy vehicles on the road during peak hours and absence of bus lanes on the road affects the traffic flow. Therefore the mitigation measures that should be taken should concentrate around these areas.

2.3. Roundabout performance Evaluation Methodologies

The following literatures review the different methods for analyzing the operation of an existing roundabout. An operational analysis produces two kinds of estimates (6):

- The capacity of a facility (i.e., the ability of the facility to accommodate various streams of users) and
- The level of performance, often using one or more measures of effectiveness, such as delay and queues.

There exist two distinct theories upon which roundabout capacity/delay equations are based. These theories are the analytical or gap acceptance based method, and the empirical method, which is based on geometrics and regression (7).

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Tanner models use the gap-acceptance theory (or critical headway) to simulate the behavior of entering vehicles and vehicles circulating within the roundabout. Finding a safe gap (or headway) within circulating traffic stream to enter the roundabout is the controlling variable that determines the ability of approach vehicles to enter the roundabout. Research work on roundabout models mostly concentrates on determining the capacity of an approach based on the entering and circulating flows. Approach capacity is calculated as a mathematical function of critical headway and follow-up headway. This method is not sensitive to roundabout geometric parameters such as inscribed circle diameter, entry angle, etc. In addition, the level of traffic stream performance itself can influence driver behavior and increasing the complexity of modeling roundabout operations. Critical headway and follow-up headway are two important parameters to perform operational analyses of roundabout (7).

The Highway Capacity Manual (HCM 2010) roundabout tanner capacity model is an analytical (exponential regression) model with clear basis in gap acceptance theory. The HCM 2010 requires the following input data to analyze roundabouts.

1. Number and configuration of lanes on each approach;
2. Either of the following:
 - a. Demand volume for each vehicular movement and each pedestrian crossing movement during the peak 15 min, or
 - b. Demand volume for each vehicular movement and each pedestrian crossing movement during the peak hour and the peak hour factor for the hour;
3. Percentage of heavy vehicles;
4. Volume distribution across lanes for multilane entries; and
5. Length of analysis period, generally a peak 15 min with in the peak hour. Any 15 min period can be analyzed however.

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Step 1: Convert movement demand volumes to flow rates

Step 2: Adjust flow rates for heavy vehicles

Step 3: Determine flow rates for heavy vehicles

Step 4: Determine circulating and exiting flow rates

Step 5: Determine the capacity of each entry lane and bypass

lane as appropriate in passenger car equivalents

Step 6: Determine pedestrian impedance to vehicles

Step 7: Convert lane flow rates and capacities into vehicles per hour

Step 8: Compute the volume-to-capacity ratio for each lane

Step 9: Compute the average control delay for each lane

Step 10: Determine LOS for each lane on each approach

Step 11: Compute the average control delay and determine

LOS for each approach and the roundabout as a whole

Step 12: Compute 95th percentile queues for each lane

While the database on which the procedure in the HCM 2010 are based is most comprehensive developed for U.S. conditions, it does not cover all situations that may be encountered in practice. The methodology applies to isolated roundabouts with up to two entry lanes and up to one bypass lane per approach. In this study the roundabouts encountered have multilane approaches, which is not covered in the HCM 2010 roundabout performance evaluation method. Therefore other methodologies and tools need to be assessed.

2.3.1. Performance Evaluation of intersections using software packages

Traffic simulation models can be classified as either microscopic, mesoscopic, or macroscopic. Microscopic models are models that continuously or discretely predict the state of individual vehicles. Microscopic measures are individual vehicle speeds and locations. Macroscopic models aggregate the description of traffic flow. Macroscopic measures of effectiveness are speed, flow

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and density. Mesoscopic models are models that have aspects of both macro and microscopic models. In addition, simulation models are classified by functionality i.e. signal, freeway, or integrated (8).

Traffic simulation models are becoming an increasingly important tool for traffic control. Simulators are needed, to assess the benefits of ITS (Intelligent Transportation Systems) in a planning mode, to generate scenarios, optimize control, and predict network behavior at the operational level. They can give the traffic engineer an overall picture of the traffic and the ability to assess current problems and project possible solutions immediately. Using traffic simulations experimental or new techniques can be tried and tested without any disturbing the traffic in a real network (8).

Many of the formulations to determine roundabout capacity constitute elements of different software packages that evaluate roundabouts and traffic corridors or networks on macroscopic or microscopic levels. A variety of deterministic software methods are available that are anchored to international research and practice. These methods model vehicle flows as flow rates and are commonly sensitive to various flow and geometric features of the roundabout, including lane numbers and arrangements and/or specific geometric dimensions (e.g., entry width, inscribed circle diameter) (6).

A case study was conducted on East Dowling Road Roundabouts in Anchorage, Alaska, which were operating with extensive queues during the evening peak hours. This research used multiple video camcorders to capture vehicle turning movements at the roundabouts as well as the progression of vehicle queues at the roundabout entrance approaches. This study shows that unbalanced entrance flow patterns (i.e., one entrance has significant higher flow than others) can intensify the queue and delay for the overall roundabouts. Then various software packages including RODEL, SIDRA and VISSIM were used to estimate several performance measurements, such as capacity, queue length, and delay, compared with the collected field data. With the comparison, it is found that all the three software packages overestimate multi-lane roundabout capacity before calibration. With default parameters, SIDRA and VISSIM tend to underestimate delays and queue lengths for the multi-lane roundabouts under congestion, while RODEL results in higher delay and queue length estimations at most of the entrance approaches. (9)

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Another study evaluates the performance of a multi-lane four legged modern roundabout operating in Muscat using SIDRA model. The performance measures include Degree of Saturation (DOS), average delay, and queue lengths. The geometric and traffic data were used for model preparation. Gap acceptance parameters, critical gap and follow up headway, were used for calibration of SIDRA model. The results from the analysis showed that currently the roundabout is experiencing delays up to 610 seconds per vehicle with DOS 1.67 during peak hour (10).

The SIDRA INTERSECTION software is an advanced lane-based micro-analytical tool for design and evaluation of individual intersections and networks of intersections including modeling of separate Movement Classes (Light Vehicles, Heavy Vehicles, Buses, Bicycles, Large Trucks, Light Rail/Trams and so on). It estimates capacity, level of service and a wide range of performance measures including delay, queue length and stops for vehicles and pedestrians, as well as fuel consumption, pollutant emissions and operating cost (11).

The SIDRA INTERSECTION software is a unique lane based analytical road Network model that (11):

- Helps the traffic engineering profession to find and implement measures to alleviate congestion and handle complicated network design, planning and operation cases with greater confidence and in an efficient way;
- Helps to achieve road network performance improvements that will deliver large economic and community benefits;
- Provides the functionality to model movement classes to enable the traffic engineering and transport planning profession design and assess such measures as bus priority lanes, bicycle lanes, tram/light rail lanes and signals;

The SIDRA standard roundabout capacity model option offers additional features like the effect of roundabout geometry parameters (roundabout size, circulating road width, entry radius and angle, etc.) on capacity and Critical Gap and Follow-Up Headway Reduction with increasing demand flows in design life analysis. (11).

Based on the above reviewed literatures, SIDRA INTERSECTION software is selected to analyze the roundabouts in this study.

2.4. Measuring Traffic Congestion

Several congestion measurement techniques have been used to address both technical and nontechnical audiences with the necessary information needs. Among many LOS is one of the commonly used congestion measures. The LOS is defined in terms of density for freeways, average stopped delay for intersections, and average speed for arterials. The LOS measure ranges from A (best service) to F (worst service) (12). Traditionally, the LOS metric has been focused on assessing automobile oriented measures. There is no generally accepted method for combining auto, transit, bicycle, and pedestrian modes into a unique performance measure (13). The main concern of this study is vehicular traffic performance measures.

There are also other approaches in measuring traffic congestion. The four components that interact in a congested roadway or system are duration, extent, intensity and reliability (3).

Duration: - This is defined as the amount of time congestion affects the travel system. The peak hour has expanded to a peak period in many corridors, and congestion studies have expanded accordingly.

Extent: - This is described by the number of people and vehicles affected by congestion, and by the geographic distribution of congestion.

Intensity: - This is the severity of the congestion that affects travel. It is typically used to differentiate between levels of congestion on transportation systems and to define the total amount of congestion.

Reliability: - This key component of congestion estimation is described as the variation in the other three elements. Daily congestion delay caused by excessive traffic volume is relatively stable and somewhat predictable. Non-recurrent (due to accidents, vehicle breakdown, weather etc.) delay causes much greater variation in the amount of congestion and is much less easily predicted. Reliability is the impact of non-recurrent congestion on the transportation system.

The Manual on Uniform Traffic Studies (MUTS), defines the Travel Time and Delay Study as a method “to evaluate the quality of traffic movement along a route and determine the locations, types, and extent of traffic delays by using a test vehicle, vehicle observation, or probe vehicle”. The quality of traffic movement is determined by computing a series of MOE’s using the field data collected manually or by the instruments installed in a test vehicle. All of the MOE’s listed

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below are used to identify problematic locations with high traffic congestion and serve as a basis for evaluations of transportation improvements (14).

The typical MOE's used on Travel Time and Delay Studies are (14):

- Average Travel Time: The average time needed to travel a highway segment under consideration, including all stopped delay times.
- Average Travel Speed: Calculated by dividing the distance of a highway segment under consideration by the Average Travel Time.
- Average Number of Stops: The average number of stops encountered along the highway segment under consideration.
- Average Stop Time: The average time experienced by a driver while they are traveling below 5 mph.
- Level of Service (LOS): A quality measure describing operational conditions within the traffic stream. The roadway LOS is calculated using "Revised Version of the Automobile Level-of-Service Methodology for Urban Streets in the Highway Capacity Manual 2010".
- Fuel Consumption: The amount of fuel consumed during the travel of a highway segment.

The use of travel time and travel rate data is appropriate to analyze roadway sections. Congestion on short sections can be identified by comparing actual travel rates to acceptable rates. The NCHRP Report 398 suggests appropriate measures for short roadway sections that include the average travel rate, delay rate, total person or vehicle delay, delay ratio, and the relative delay rate. It is indicated in the report that these measures would provide useful information at this level of analysis. The average travel rate and delay rate can be used on absolute terms, or can be used to compare similar classes of facilities. The relative delay rate, the delay ratio, and total delay can be used to compare different classes of facilities. The following quick reference guide can be used to measure congestion (3).

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Table 1: Quick Reference Guide to measure Congestion

TRAVEL RATE	Travel Rate (minutes per mile)	=	$\frac{\text{Travel Time (minutes)}}{\text{Segment Length (mile)}}$	=	$\frac{60}{\text{Average Speed (mph)}}$
DELAY RATE	Delay Rate (minutes per mile)	=	Average Travel Rate (minutes per mile)	-	Acceptable Travel Rate (minutes per mile)
TOTAL DELAY	Total Segment Delay (Vehicle-minutes)	=	$[\text{Actual Travel Time (minutes)} - \text{Acceptable Travel Time (minutes)}]$	x	Vehicle Volume (Vehicles)
RELATIVE DELAY RATE	Relative Delay Rate	=	$\frac{\text{Delay Rate}}{\text{Acceptable Travel Rate}}$		
DELAY RATIO	Delay Ratio	=	$\frac{\text{Delay Rate}}{\text{Actual Travel Rate}}$		

Another congestion estimation measure is travel time reliability. Travel time reliability refers to the consistency or dependability in travel times, as measured day-to-day or across different times of the day. The U.S. Department of Transportation (DOT) recommended 90th or 95th percentile travel time, buffer index, planning time index, and frequency of congestion for travel time reliability measures (15). The reliability of travel time estimates on a given corridor may be more important for travelers, shippers, and transport managers than the travel time itself. The buffer index is used to prioritize freeway corridors according to travel time reliability. Metropolitan planning organizations should use travel time reliability in the following ways: incorporate it as a system-wide goal, evaluate roadway segments according to travel time reliability measures, and prioritize roadway segments using those measures (16).

For this study three reliability measures are chosen namely: 95th percentile travel time, buffer index and planning time index.

2.5. Effect of Urban Road-Rail at grade crossings on congestion

It is generally discouraged to locate any intersection near at-grade railroad crossing. However, this is sometimes unavoidable and roundabouts are occasionally used near railroad–highway at-grade crossings. Rail transit, including stations, has also successfully been incorporated into the medians of approach roadways to a roundabout, with the tracks passing through the central island. In such situations, the roundabout either operates partially during train passage or is completely closed to allow the guided vehicles or trains to pass through (6).

In a study made on Melbourne’s 152 at grade rail crossings, aggregate estimates of the impacts of removing the large number of at-grade rail crossings was conducted on peak vehicular traffic and congestion. A new method including micro-simulation of a range of rail crossing configurations is used to inform a network model which makes aggregate estimates of impacts on all traffic. Relationships between train frequency and percentage change in vehicle travel time and volume respectively were explored. These equations can predict change in travel time/traffic flow caused by at-grade rail crossings based on estimated rail crossing closure time and train frequency (17).

Another study conducted in UK used literature review and stakeholders consultation to investigate traffic delays at level crossings. The research is aimed to investigate road traffic delays at level crossings, scope potential routes to reduce delays and propose key areas that would benefit from further research. Among the findings of this research; manually controlled barrier crossings seem to produce most traffic delays, while various highway and railway interventions at or around level crossings may have a small effect on traffic delays, none have been designed with primary aim of reducing delay and also delay is a concern at a level crossing when high traffic coincides with high train frequency. It is pointed out that under some circumstances, there is little point in taking action; reducing delay at level crossing where there is already serious congestion in the surrounding network may be a fruitless exercise (18).

Addis Ababa’s Light Rail transit is the first light rail and rapid transit in eastern and sub-saharan Africa. It has two rail lines that extend east-west and north-east. Of the two line rail lines, the east-west line extends 17.4 kilometers (10.8 mi), stretching from Ayat Village to Torhailoch, and passing through Megenagna, Meskel Square, Legehar and Mexico Square. The north-south line,

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which is 16.9 kilometres (10.5 mi) in length, passes through Menelik II Square, Merkato, Lideta, Legehar, Meskel Square, Gotera and Kaliti. However, the two lines have a common track of about 2.7 km. The common track is the elevated section which runs east to west across the southern edge of the CBD from Meskel Square to Mexico Square, and onwards to Lideta (19).

From the two railway lines the east-west line passes through the study road section. This line crosses the two roundabouts i.e. CMC and Sealite Mihiret, at-grade. There are future plans for extensions in all four directions and the Ethiopian government indicated that any new line built should be completely grade-separated. The trams traverse the city from 6:00 AM in the morning to 10:00 PM in the evening with headway time for peak hours and off peak hours 12 minutes and 15 minutes respectively (19).

Currently feasibility study is being undertaken to construct 15 bridges that can enable cars and pedestrians to cross roads and ease the current traffic congestion in some areas (19). This traffic congestion is caused majorly on at-grade rail crossings and at train stations because of the pedestrians crossing the road to access the train. This study tries to determine the additional delay caused by at-grade crossings at roundabouts.

In the assessment of impact of traffic congestion due to the new LRT system conducted by Yilikal Endeshaw, the result revealed that there is an additional delay to the normal control delay at the three junctions (Beshale Hotel (Sealite Mihiret Roundabout), CMC Roundabout and Ayat Roundabout) where the LRT crosses at-grade. As stated in the literature, with the existing geometric condition and future projected traffic, in 2016 the left turn movements will face about 41.7 sec/vehicle of additional average delay after the introduction of Light Rail transit. On the other hand, the through traffic of North -South direction at these locations will experience more additional delays of about 47.7 sec/vehicle on average (20). In this study when analyzing Sealite Mihiret (Beshale) roundabout and CMC roundabout, the effect of the LRT that crosses them at-grade will be considered for the current traffic conditions.

2.6. Summary of Literature Review

This literature review is going to be used to identify the best methodology to address the objectives of the research and to see researches that have been done on this location with the same objectives.

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The literature review first introduces traffic congestion and its study methods. Then it explores the different causes of congestion around the world and relates these causes with the current condition of the study location. The literature reviews the methodologies that are used to evaluate roundabout performance and chooses the best method that suits the roundabouts in this study. Measuring the traffic congestion on the selected road section is the other objective of this study. Congestion measures that have been used to quantify traffic congestion have been explored and reviewed. The final part of the literature review the effect of at grade rail crossing on congestion and how it has been addressed is explored.

This study combines the above mentioned methodologies to assess the traffic congestion on the study road which hasn't been done in such way since. This study will help to see the level of traffic congestion on this location clearly and compare its intensity with other locations in the city.

CHAPTER THREE: Methodology

3.1. Introduction

This chapter explains the methodology used in this thesis to collect the required data and to analyze the data. The research approach and design used are explained together with the study subjects. The study area is described from the general location to specific areas it crosses. The research is conducted by dividing it in two major cases which are roundabout performance evaluation and quantifying congestion on selected road segments.

In the data collection procedures section traffic volume, pedestrian volume, geometric data, travel time and LRT data collection methods and procedures are explained. Finally the research analysis methodology is explained for both roundabouts performance determination and travel time approach to quantify congestion on selected road segments.

3.2. Research Approach and Design

In order to answer the research questions of the thesis both qualitative and quantitative approaches were followed. Quantitative data and analysis were used to determine the capacity of roundabouts and travel time to quantify the level of congestion. Secondary data and direct field measurements were the major data sources. As a qualitative data in order to determine the significance of the congestion on the selected road the day to day experience of the researcher and to select the road segments for travel time study observation was used.

The research design is case study since it focuses on a single road section in the city to assess the level of traffic congestion. Subjects of the study in this research include but not limited to: traffic volume, travel time, geometry of roundabouts, frequency of trains crossing per hour and train crossing closure times of roundabouts.

3.3. Research process

The scientific method for approaching a problem in drawing multiples of conclusions has a procedure; which include stating the problem, formulating hypothesis, designing the experiment or survey, making observations, interpreting data and drawing Conclusions. This procedure was followed in this research by first stating the problem which is traffic congestion on the study

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road. This problem was selected for research mainly since it is the day to day experience of the researcher and also one of the major problems in the city of Addis Ababa.

The hypothesis or research questions were raised that whether intersections on the selected road section are performing poorly or not and how severe is the congestion on the road. Then to answer these questions the necessary data (traffic volume, travel time, roundabout geometric parameters etc.) were collected by using different methods and procedures as explained in the following sections. The data collected were arranged and observed to make interpretations and some tools and mathematical formulas from guide books were used to analyze the data. Finally from the results found in the analysis conclusions were drawn.

3.4. Description of the study Area

Addis Ababa serves as the capital city of Ethiopia. The city is located at the southern foot of Mount Entoto, in the Entoto Mountains, at an elevation of about 8000 feet (2440 meters) above sea level (21). The rapid increase of the Addis Ababa's population is the main cause of the increased demand for transportation in the city. This is creating high levels of congestion especially at peak hours.

In order to meet the objective of the research which is to evaluate roundabout performance and quantify the level of traffic congestion, a study road section was selected which is part of the east west corridor that extends from CMC to Megenagna.

3.4.1. General description of the study Road

The study road extends from CMC to Megenagna which is about 5.93 km. The Northing and easting of the road are $9^{\circ}01'148''$ N and $38^{\circ}44'24''$ E (22). The East-West line of the LRT passes through this road section.

Recently a high degree of congestion is being observed on this road section during peak hours of the day. This is mainly because the Eastern part of the route is dominated by pure residential developments such as condominiums, real states, apartments, and private houses and almost all the working areas are located after the Western end of the route Megenagna, which is a distribution area. This segregation of residence and working area arouses high travel demand. The transport delivery couldn't meet this demand and resulted in complain of the community.

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

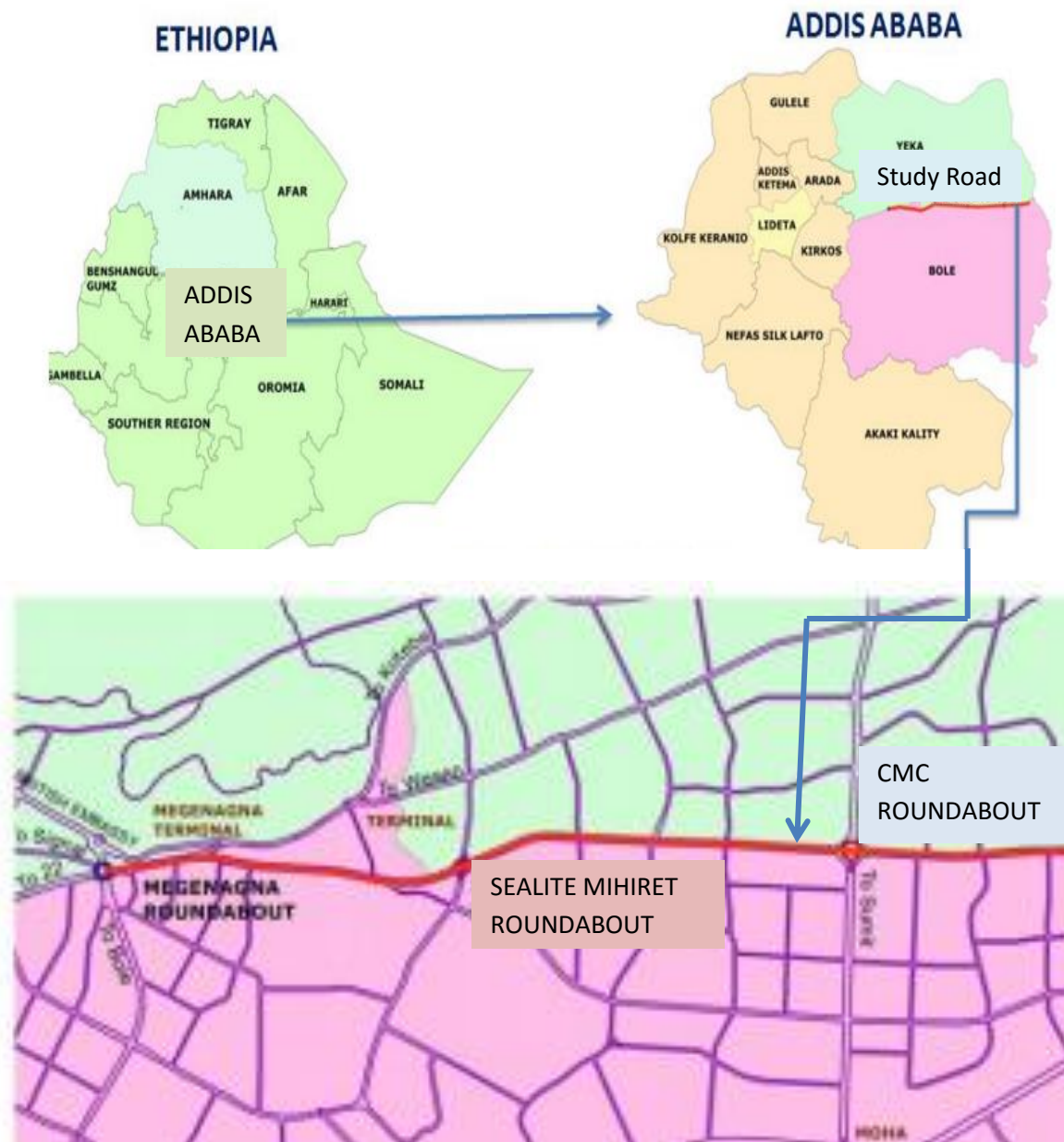


Figure1: Location Map

(Source: Road Traffic Management Agency, Road Traffic Study of Megenagna to Ayat Route)

3.4.2. Traffic and Transport Operations of the study area

There are high density pure residential areas such as condominium (Summit, Ayat, Ayat 2 & Ayat Chefe etc), Apartments like CMC, real states (Sunshine, Tsehay, Ayat etc) in the Eastern part of the route whereas the working areas and social services like schools are located at the western side in the way that demands travelling. This caused the residents to come to the center of Addis Ababa to work in the morning and go back home in the afternoon. Since there is no alternative route all are forced to use this route. In addition to this, it serves as alternative route for the road to Kotebe which is currently under construction and the road to Wossen Grocery which is highly congested. Moreover in the southern part of the route the only route that can serve as an alternative is that goes from Ayat to summit, Goro then to Tulu dimtu or to megenagna through Sealite Mihret back to this route or through Jacros which is seriously congested. But this road is not finished around Ayat (23).

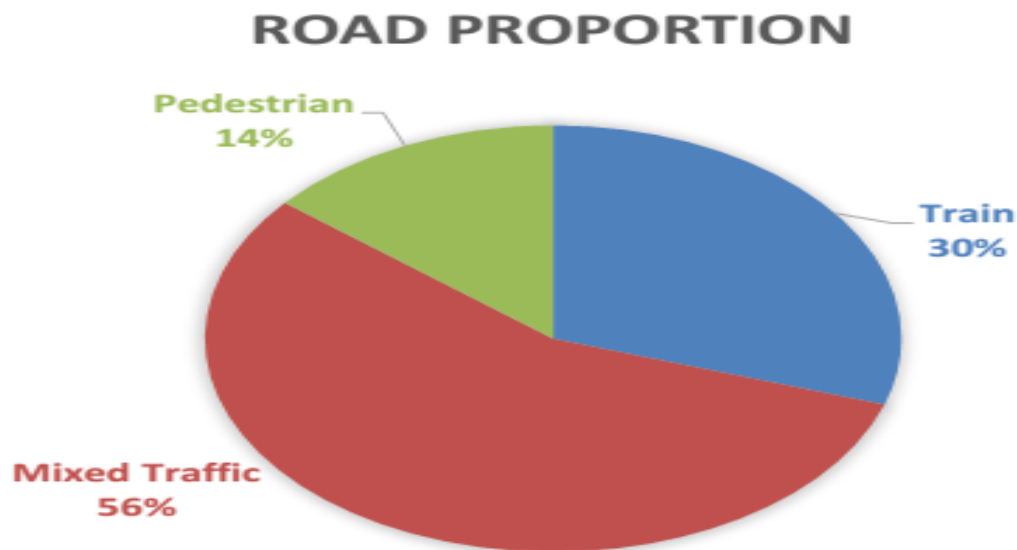


Figure 2: Road usage proportion

(Source: Road Traffic Management Agency, Road Traffic Study of Megenagna to Ayat Route)

An average of 134,056 people per day travels using Code1, Code 3, Hyger, Sheger, Anbessa and Alliance. On the other hand, in the East West line there are six couple trains and two single trains which have a capacity of 430 persons (23).

3.5. Methods of Data collection

To achieve the objective of the study both primary and secondary data were used.

3.5.1. Primary Data

The primary data used in this research are listed as follows:

- Traffic and pedestrian data (Count from Video recordings made on site)
- Train crossing closure times and train frequency per hour throughout the day at the Road-Rail grade crossings.
- Travel time data using License plate matching method using pen and paper and stop watches.

3.5.2. Secondary Data

- Geometric data measurements
 - Design documents from AACRA office and
 - Google earth

3.6. Roundabout Traffic and Pedestrian Volume Data Collection

Traffic Volume data for the two study roundabouts was collected manually using video recorder. One suitable spot (building roof tops) was selected for each roundabout which enables all the approaches and vehicle movements visible. The data was collected for three days (Tuesday, Wednesday and Thursday) for morning and afternoon peak hours. These days were selected in order to make the data representative since traffic counts during a Monday morning rush hour and a Friday evening rush hour may show exceptionally high volumes and are not normally used in analysis; therefore, counts are usually conducted on a Tuesday, Wednesday, or Thursday. The peak day was selected in order to get the maximum traffic volume for each approach (24).

The morning peak period is for two hours from 7:00 AM to 9:00AM and the afternoon peak period is from 4:00 PM to 6:00 PM.

The roundabouts which were selected for performance analysis are shown in the following table and figures.

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Table 2: Study roundabouts

Intersection Type	Intersection Name	Date of Recording	Time of Recording	Number of Approaches	Video Camera Set-up Location
Roundabout	Sealite Mihiret	26/03/2019 (Tuesday)	7:00 AM - 9:00 AM and 4PM - 6:00PM for all three days	4	On the last floor of a new building under construction at the corner of Wossen Approach and CMC approach.
		27/03/2019 (Wednesday)			
		28/03/2019 (Thursday)			
Roundabout	CMC	26/03/2019 (Tuesday)	7:00 AM - 9:00 AM and 4PM - 6:00PM for all three days	4	On the ninth floor of a new building under construction at the right side of Ayat Approach.
		27/03/2019 (Wednesday)			
		28/03/2019 (Thursday)			



Figure 3: CMC Roundabout
(Source: Google Earth, March, 2015)

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road



Figure 4: Sealite Mihiret Roundabout

(Source: Google Earth, March, 2015)

Traffic volume count was made separately for the reversible lane to determine the percentage of volume it carries and to determine its usage. Then the counted volume was added on the approach volume. The volume for the reversible lane was counted separately during data extraction for analysis purpose. It was found that taking the average of the two roundabouts' volume count, in the Morning peak period 14% of the approach volume (for CMC to Megenagna direction) and in the afternoon peak period 27.5% of the approach volume (for Megenagna to CMC direction) is carried by the reversible lane.

Pedestrian data was adopted from the traffic count videos and the number of pedestrians crossing each approach was counted for each 15 min in the peak period. The peak hour pedestrian volume and Peak Hour Factor are used as input in SIDRA INTERSECTION software which has an effect on the capacity of approaches.

The other required data is PCE factors for different traffic compositions. A passenger car unit is essentially the impact that a mode of transport has on traffic variables (such as headway, speed, density) compared to a single car. Passenger car equivalents are used in order to determine the percentage of heavy vehicles. In HCM 2010 PCE equals 2.0 for heavy vehicles and this value is used for this study.

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Vehicle class input data for SIDRA INTERSECTION software is given in the movement definitions, movement class tab that is used to calculate the percentage of heavy vehicles. The passenger-Car-Equivalent factors are given in the parameter settings, model parameters tab. The software uses these data to calculate the heavy vehicle percentage as shown in the results section. CMC roundabout has 4.9% heavy vehicles in the morning peak hour and 4.2% in the afternoon peak hour while Sealite Mihiret roundabout results in 4.8% of heavy vehicles in the morning peak hour and 5.2% in the afternoon peak hour.

The following table shows sample summary of 15 min traffic volume data and pedestrian volume data for each approach leg. The data is peak hourly data collected during the morning and afternoon peak hours.

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Table 3: Sample Summarized vehicle and pedestrian volume data at peak period

Time	Karalo Approach				Ayat Approach				Megenagna Approach				Summit Approach			
	LT	RT	TH	PED	LT	RT	TH	PED	LT	RT	TH	PED	LT	RT	TH	PED
7:00-7:15 AM	23	141	37	12	47	9	186	72	38	74	146	250	143	12	35	98
7:15-7:30 AM	26	159	42	10	74	34	316	111	41	76	164	312	292	20	72	165
7:30-7:45 AM	20	126	32	11	128	40	510	120	23	58	96	365	210	44	52	102
7:45-8:00 AM	33	190	48	7	128	47	504	98	48	107	201	221	196	52	44	145
8:00-8:15 AM	35	216	57	15	96	36	459	141	49	51	197	196	176	68	40	123
8:15-8:30 AM	35	215	52	10	106	36	432	162	47	60	211	177	186	66	46	120
8:30-8:45 AM	25	162	39	8	108	30	454	118	51	76	202	125	132	60	32	114
8:45-9:00 AM	32	205	53	9	91	37	362	81	37	47	154	117	99	53	28	92
4:00 - 4:15 PM	126	30	86	11	124	41	211	159	124	142	471	320	152	75	41	152
4:15 - 4:30 PM	90	19	56	14	120	39	209	108	107	142	435	275	149	75	38	136
4:30 - 4:45 PM	80	16	52	11	109	35	193	102	99	127	397	192	136	68	39	121
4:45 - 5:00 PM	69	14	43	8	134	41	234	85	88	115	360	102	128	63	36	91
5:00 - 5:15 PM	67	16	45	13	115	41	208	140	77	103	329	242	151	71	43	108
5:15 - 5:30 PM	74	13	44	9	135	46	234	168	110	146	447	363	173	84	48	110
5:30 - 5:45 PM	92	21	62	14	95	34	165	71	122	142	478	185	135	66	35	87
5:45 - 6:00 PM	69	14	39	7	100	33	174	62	116	147	462	113	148	73	43	79

3.7. Roundabout Geometric data collection

The SIDRA INTERSECTION software uses different input data to analyze roundabouts which geometric parameters of roundabout is one of them. As illustrated in Figure 7 the required geometric parameters are:

- Inscribed diameter
- central island diameter
- circulating road width
- entry lane width
- number of entry lanes
- number of circulating lanes
- entry angle and entry radius and also
- grade of the approach legs

To determine the above listed parameters measurements from design documents and Google earth were used.

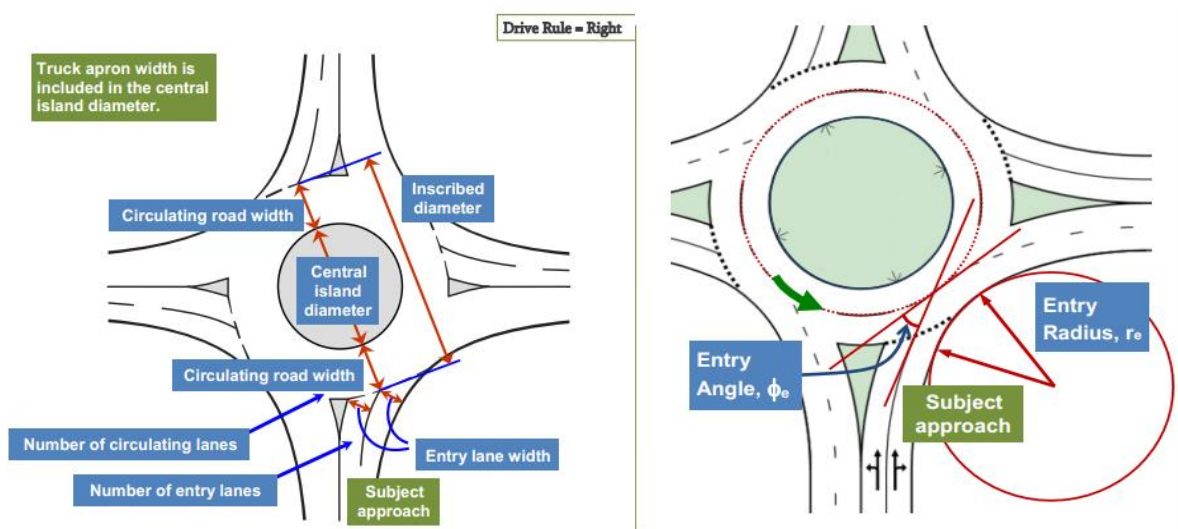


Figure 5: Roundabout Geometry parameters

(Source: SIDRA Intersection 8.0 Software manual)

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

The design document which was found from AACRA office and the design was done by Core Consulting Engineers is only for Megenagna-Ayat road therefore the geometric data for the other approaches were obtained from Google earth.

Table 4: Geometric Parameters for CMC Roundabout

Approach	Central Island Diameter	Insc Dia	Circ Road width	Entry lane width	Number of circ. lanes	Number of entry lanes	Entry Angle	Entry Radius	Grade
Ayat	132 m	173 m	20.5 m	4.2 m	4	4	40°	93m	0%
megenagna				4.2 m	4	4	40°	93m	0%
karalo				4.1 m	4	2	4°	75m	2.9%
Summit				4.1 m	4	2	3°	75m	-2.8%

Table 5: Geometric Parameters for Sealite Mihret Roundabout

Approach	Central Island Diameter	Insc Dia	Circ Road width	Entry lane width	Number of circ. lanes	Number of entry lanes	Entry Angle	Entry Radius	Grade		
CMC	Longer side 100m	Longer side 128m	14 m	5.5m	4	4	30°	27m	-4.17%		
Megenagna				5.3 m	4	4	30°	23.2m	4.17%		
Wossen				Shorter side	Shorter side	5.6 m	4	3	2°	64.5m	0%
Jacros				60.15 m	88.2 m	6.4 m	4	3	2°	69.5m	0%

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

The program will determine the values of the Critical Gap and Follow-up headway parameters as a function of the roundabout geometry, circulating flow rate and other factors such as environmental factors (11). Therefore the above roundabout geometry data were used as input in the SIDRA INTERSECTION software roundabout data tab which the software uses to calculate Critical Gap and Follow-up headway parameters.

Environment Factor in SIDRA model allows calibration of capacity model for less restricted (higher capacity) and more restricted (lower capacity) environments. A value in the range 0.5 to 2.00 can be specified, the standard default value being 1.0. The Environment Factor characterizes the general roundabout environment in terms of roundabout design type, visibility, significant grades, operating speeds, size of light and heavy vehicles and other movement classes, driver aggressiveness and alertness, pedestrians, heavy vehicle activity, parking maneuvers, etc. which affect the vehicle movements on approach and exit sides as well as at circulating road as relevant (11).

SIDRA INTERSECTION manual recommends the default Environmental Factor for multi-lane roundabouts (both approach and circulating road have two or more lanes) is set as 1.2, if the SIDRA Standard roundabout capacity model is chosen.

3.8. Light Rail Transit train frequency and closure time at the roundabouts

In order to determine the additional delay caused by the railway line on the roundabouts, different data were collected. These data are frequency of the current trains crossing and closure times of the roundabouts.

The frequency of the train was collected for a full day in order to determine the average service frequency per hour. This was done from 7:00 AM to 6:00 PM. For each train crossing the roundabout, the closure time is recorded in order to obtain the average crossing closure time. This data collection was conducted through a field survey. The following table shows the frequency of train passing for each hour and the closure time recorded for each train passing.

For both roundabouts the closure time is taken as the average of the time spent by the train on the circulating road at the east approach and the west approach of the roundabouts.

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Table 6: CMC roundabout frequency of trains and closure time

Time of the day	Frequency of trains per hour	Closure time in sec per hour	Remarks
7:00-8:00 AM	8	232	* The closure time includes single trains, coupled trains and overlaps of trains * Both Train directions are considered
8:00-9:00 AM	5	182	
9:00-10:00 AM	10	135	
10:00-11:00 AM	7	186	
11:00-12:00 AM	10	220	
12:00-1:00 PM	10	201	
1:00-2:00 PM	8	236	
2:00-3:00 PM	6	171	
3:00-4:00 PM	8	127	
4:00-5:00 PM	10	215	
5:00-6:00 PM	9	154	
Average	8	187	

Table 7: Sealite Mihiret roundabout frequency of trains and closure time

Time of the day	Frequency of trains per hour	Closure time in sec per hour	Remarks
7:00-8:00 AM	8	150	* The closure time includes single trains, coupled trains and overlaps of trains * Both Train directions are considered
8:00-9:00 AM	5	116	
9:00-10:00 AM	10	194	
10:00-11:00 AM	7	144	
11:00-12:00 AM	10	240	
12:00-1:00 PM	10	205	
1:00-2:00 PM	8	169	
2:00-3:00 PM	6	124	
3:00-4:00 PM	8	150	
4:00-5:00 PM	10	207	
5:00-6:00 PM	9	180	
Average	8	171	

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3.9. Travel Time data collection on selected road segments

Travel time is the time necessary to traverse a route between any two points of interest. Travel time contains running time, or time in which the mode of transport is in motion, and stopped delay time, or time in which the mode of transport is stopped (or moving sufficiently slow as to be stopped, i.e., typically less than 8 kph, or 5 mph) (25).

3.9.1. Data collection methods and Locations

Travel time data was collected manually on three segments of the study road which are located sequentially. License plate matching method was used to collect the travel time data using pen and paper to record the plate numbers and a stop watch to lap the arrival times. For convenience and close observation of plate numbers, railway stations to railway station segments were selected. These segments were selected on the basis of their traffic characteristics: the first segment is where the vehicles leave an intersection (CMC roundabout), the second segment is uninterrupted road section and the third segment is where the vehicles join an intersection (Sealite Mihiret roundabout).

The segments selected with their respective distance and locations are shown in the following table and figures.

Table 8: Travel time data

Location	Segment Length (meter)	Time of Data collection
From Sealite Mihiret Station to Civil Service station	770	Morning Peak (7 AM - 9 AM)
		Off peak (10:00 AM - 11:00 AM)
From Civil Service station to Saint Michael station	870	Morning Peak (7 AM - 9 AM)
		Off peak (1:00 PM - 3:00 PM)
From Saint Michael station to CMC station	930	Morning Peak (7 AM - 9 AM)
		Off peak (1:00 PM - 3:00 PM)

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For travel time studies that are focused on identifying congestion trends and problems, the above time periods are recommended by the travel time handbook used in this study as a reference. Off-Peak Period- includes periods of free-flow traffic during the middle of the day or late in the evening, typically between 10 a.m. and 11 a.m., 1 p.m. to 3 p.m., or after 7 p.m. The hours before and after 12 noon (11 a.m. to 1 p.m.) should be avoided if the “lunch hour” traffic is significant. Off-peak travel times are used to establish free-flow conditions for calculating congestion measures (25). For the purpose of this study the off peak period travel times are taken as acceptable travel times to compare with peak period travel times.

According to the hand book, the results of the license matching process will be individual vehicle speeds at Different times throughout the data collection time period. These speeds can be Travel Time Data Collection averaged for the entire time period (i.e., peak hour or peak period), or for smaller intervals of the entire time period (e.g., 15- or 30-minute summaries) (25). For this particular study, the peak period is used to collect the travel time data for the determined sample size and the average travel time is taken.

3.9.2. Description of the selected segments

The segment from Sealite Mihiret Station to Civil Service station is one of the approaches of Sealite Mihiret roundabout which is 770 m long. In the morning peak period a major bottleneck is observed on this segment. There is one pedestrian crossing at the train station that interrupts this segment near Sealite Mihiret Roundabout.



Figure 6: Segment 1 (Sealite Mihiret Station to Civil Service station), 0.77 KM

(Source: Google Earth, March, 2015)

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

The segment from Civil Service station to Saint Michael station is uninterrupted midblock section which is 870 m long. Pedestrian crossings at train stations with high pedestrian volume are found on this segment.



Figure 7: Segment 2 (From Civil Service station to Saint Michael station), 0.87 KM

(Source: Google Earth, March, 2015)

The segment from Saint Michael station to CMC station is one of the approaches of CMC roundabout which is 930 m long. On this segment there is one pedestrian crossing at CMC train station which also has high pedestrian volume.



Figure 8: Segment 3 (From Saint Michael station to CMC station), 0.93 KM

(Source: Google Earth, March, 2015)

3.9.3. Sampling

The required minimum sample sizes for license plate matching are calculated using Equation - 1 found in the travel time data collection handbook (25). This equation is used in combination with travel time variability estimates to produce illustrative license matching sample sizes that are given in Table 4-3 in the travel time data collection handbook.

$$\text{Sample Size, } n = \left(\frac{txc.v.}{e}\right)^2 \approx \left(\frac{zxc.v.}{e}\right)^2 \text{ if estimated sample size is greater than 30..... (1)}$$

Therefore for 90% confidence interval and $\pm 10\%$ Error for congested traffic for 1 to 2 hour period with Coefficient of interval value 35% sample size of 34 is used.

3.10. Data analysis Methodology

3.10.1. Roundabout performance Evaluation

The first method of analysis is by using SIDRA INTERSECTION software as a tool for analysis. By giving the software input values such as traffic volume, geometric measurements of roundabouts, analysis model type etc the software will analyze the intersection to give outputs such as delay, capacity, LOS etc.

The SIDRA INTERSECTION software is an advanced lane-based micro-analytical tool for design and evaluation of individual intersections and networks of intersections including modeling of separate Movement Classes (Light Vehicles, Heavy Vehicles, Buses, Bicycles, Large Trucks, Light Rail/Trams and so on). It provides estimates of capacity, level of service and a wide range of performance measures including delay, queue length and stops for vehicles and pedestrians, as well as fuel consumption, pollutant emissions and operating cost (11).

The SIDRA standard roundabout capacity model option offers additional features such as the effect of roundabout geometry parameters (roundabout size, circulating road width, entry radius and angle, etc.) on capacity and Critical Gap (11). The SIDRA standard capacity model and SIDRA standard delay model that includes geometric delay, which are built-in models of the software are used for analysis. The performance measures used here are Vehicle to capacity ratio, Average Delay and LOS.

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

3.10.1.1. Impact of LRT line on delay at the roundabouts

The additional delay caused by the LRT line on left turns for all approaches and the through movements of opposed approaches (north-south and northeast-southwest in this case) is determined using the closure time of train crossing and train frequencies manually. Then the total aggregated delay on the two roundabouts in vehicle-hrs is determined.

This analysis methodology is used since the roundabouts are already congested with high traffic flow and the frequency of trains is low currently. Delay is a concern at a level crossing when high traffic coincides with high train frequency. But in the future when the frequency and the number of trains increases another methodology should be used like simulation models that incorporates the LRT in to the intersection model.

3.10.2. Quantifying congestion on segments

The other method of analysis is using the quick reference guide from NCHRP report 398 which is used to measure the traffic congestion using the travel time data and traffic volume data collected on selected road segments. The NCHRP Report 398 suggests appropriate measures for short roadway sections that include the average travel rate, delay rate, total person or vehicle delay, delay ratio, and the relative delay rate. It is indicated in the report that these measures would provide useful information at this level of analysis. Travel time reliability measures such as buffer index and planning time index are used to determine the reliability of using this road section.

CHAPTER FOUR: Results and Discussion

4.1. Demand Flow Analysis

The traffic demand volume is analyzed for the two roundabouts and is presented below for morning and afternoon peak periods separately.

4.1.1. Demand Flow at CMC Roundabout

Peak hour in the morning peak period is found to be from 7:30 AM to 8:30 AM with volume of 5303 veh/hr with 4.9% of heavy vehicles. The flow at the roundabout approaches in the morning peak hour in ascending order is as follows: North, West, South and East with the number of vehicles in each direction 962, 1075, 1097 and 2170 respectively. The turning movements showed that the through movement is the highest for East and West approaches, left movement is the highest for south approach and right movement is the highest for north approach. This roundabout represents unbalanced traffic flow in the morning peak hour the east approach demanding more attention.

The peak hour in the Afternoon peak period is found to be from 4:00 PM to 5:00 PM with volume of 4988 veh/hr with 4.2% of heavy vehicles. The flow at the roundabout approaches in the Afternoon peak hour in ascending order is as follows: North, South, East and West with the number of vehicles in each direction 527, 833, 1250 and 2378 respectively. The turning movements showed that the through movement is the highest for East and West approaches and left movement is the highest for south and north approaches. This roundabout represents unbalanced traffic flow the west approach demanding more attention.

The traffic volume for each approach by movement type and vehicle type is presented below. Pedestrian flow rate at roundabout legs is specified for each leg as it was explained in the methodology section. Pedestrian volume has effect on entry lane capacity and its effect decreases with increased circulating flow rate. The peak hour pedestrian flow rates are shown in Table 9 & 10 below.

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

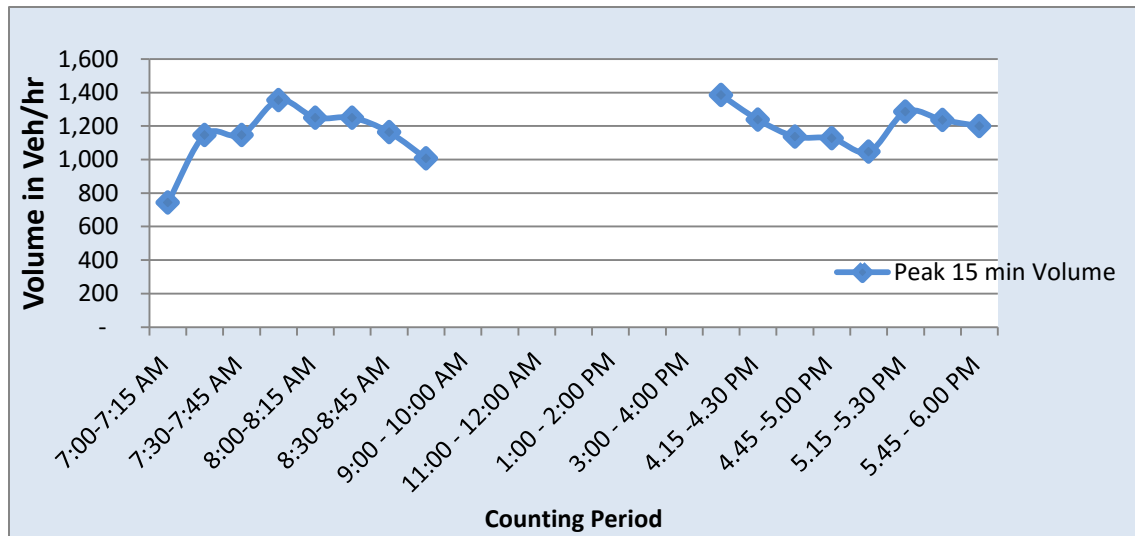


Figure 9: 15-min peak period traffic volume (CMC Roundabout)

The following tables show the traffic composition and traffic volume for the peak hour, morning and afternoon, with their respective movements. As can be seen from the tables; cars, taxi and pickups hold the highest percentage of the vehicle composition and heavy vehicles hold the lowest percentage of the vehicle composition at this roundabout.

The peak hour factors were calculated by first determining the peak hour volume and peak 15 minute volume then dividing the peak hour volume by 4 times the peak 15 minute volume.

Table 9: Peak hour volume (CMC Roundabout Morning peak hour)

Approach	60 min Morning Peak volume in Veh/hr												Ped (per s/hr)	PHF
	Cars, Taxi and Pick ups			Mini Bus, Mid bus and LCvs			Standard Bus			Medium and Heavy Truck				
	LT	RT	TM	LT	RT	TM	LT	RT	TM	LT	RT	TM		
East (Ayat Approach)	328	110	1323	58	18	237	8	2	48	6	5	27	521	0.91
West (Megenagna Approach)	117	175	466	42	53	171	3	6	13	3	7	19	401	0.93
North (Karalo approach)	99	575	148	9	55	14	0	2	0	6	43	11	42	0.90
South (Summit Approach)	661	89	165	86	25	21	13	5	3	14	14	1	165	0.80

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Table 10: Peak hour volume (CMC Roundabout Afternoon peak hour)

Approach	60 min Afternoon Peak volume in Veh/h												Ped (pers/ hr)	PHF
	Cars, Taxi and Pick ups			Mini Bus, Mid bus and LCvs			Standard Bus			Medium and Heavy Truck				
	LT	RT	TM	LT	RT	TM	LT	RT	TM	LT	RT	TM		
East (Ayat Approach)	307	102	535	81	27	142	3	1	5	17	6	29	464	0.91
West (Megenagna Approach)	325	376	1250	59	74	235	3	8	17	0	7	19	625	0.89
North (Karalo approach)	223	54	145	40	13	27	1	0	1	12	3	8	44	0.72
South (Summit Approach)	329	164	87	103	50	27	20	10	5	20	10	5	132	0.92

4.1.2. Demand Flow at Sealite Mihiret Roundabout

The peak hour in the morning peak period is found to be from 7:15 AM to 8:15 AM with volume of 6794 veh/hr with 4.8% of heavy vehicles. The flow at the roundabout approaches in the morning peak hour in ascending order is as follows: North, South, West and East with the number of vehicles in each direction 615, 1,064, 1,284 and 3,831 respectively. The turning movements showed that the through movement is the highest for East and West approaches, left movement is the highest for south approach and right movement is the highest for north approach. This roundabout represents unbalanced traffic flow in the morning peak hour the east approach demanding more attention.

The peak hour in the Afternoon peak period is found to be from 4:00 PM to 5:00 PM with volume of 4975 veh/hr with 5.2% of heavy vehicles. The flow at the roundabout approaches in the Afternoon peak hour in ascending order is as follows: South, North, East and West with the number of vehicles in each direction 692, 705, 1,473 and 2,105 respectively. The turning movements showed that the through movement is the highest for East and West approaches and right movement is the highest for south and north approaches. This roundabout represents unbalanced traffic flow the west approach demanding more attention.

The traffic volume for each approach by movement type and vehicle type is presented below. As can be seen from the table cars, taxi and pickups hold the highest percentage of the vehicle

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composition and heavy vehicles hold the lowest percentage of the vehicle composition at this roundabout.

Pedestrian flow rate at roundabout legs is specified for each leg as it was explained in the methodology section. Pedestrian volume has effect on entry lane capacity and its effect decreases with increased flow rate. The peak hour pedestrian flow rates are shown in Table 11 & 12 below.

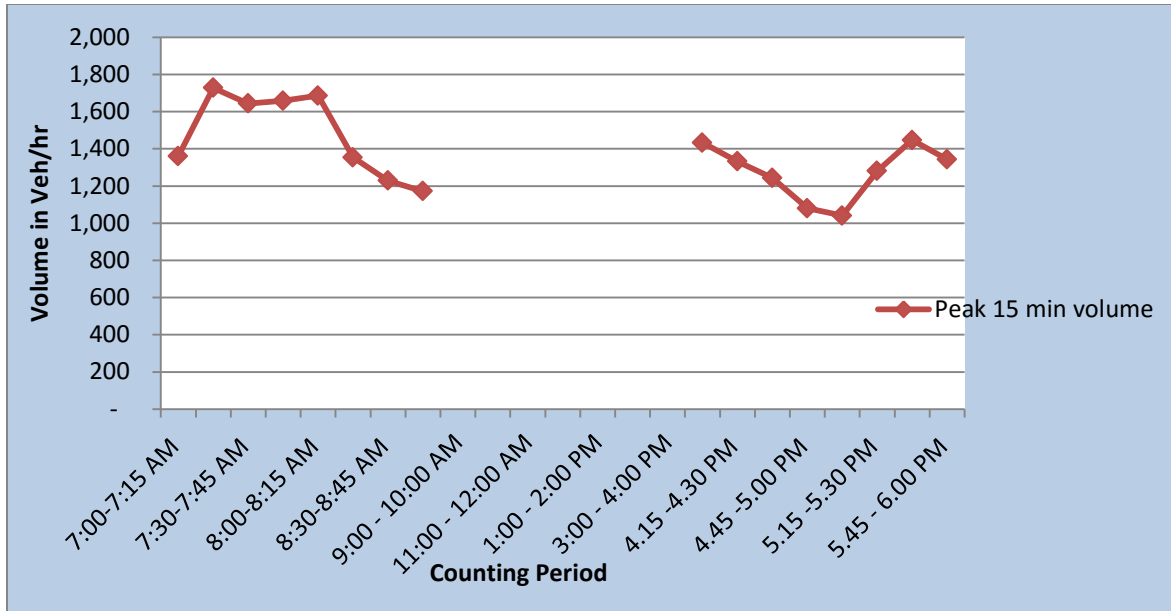


Figure 10: 15-min peak period traffic volume (Sealite Mihiret Roundabout)

The following tables show the traffic composition and traffic volume for the peak hour, morning and afternoon, with their respective movements. As can be seen from the tables; cars, taxi and pickups hold the highest percentage of the vehicle composition and heavy vehicles hold the lowest percentage of the vehicle composition at this roundabout.

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Table 11: Peak hour volume (Sealite Mihiret Roundabout Morning peak hour)

Approach	60 min Morning Peak volume in Veh/h												Ped (pers /hr)	PHF
	Cars, Taxi and Pick ups			Mini Bus, Mid bus and LCvs			Standard Bus			Medium and Heavy Truck				
	LT	RT	TM	LT	RT	TM	LT	RT	TM	LT	RT	TM		
East (CMC Approach)	579	264	2193	184	30	450	7	3	56	11	6	46	569	0.89
West (Megenagna Approach)	118	29	471	68	15	272	12	4	47	4	4	18	629	0.91
North (Wossen Approach)	50	249	200	10	49	40	0	0	4	2	9	7	216	0.93
South (Jacrose Approach)	624	147	171	150	60	39	31	10	5	33	6	6	248	0.91

Table 12: Peak hour volume (Sealite Mihiret Roundabout Afternoon peak hour)

Approach	60 min Afternoon Peak volume in Veh/h												Ped (per s/hr)	PHF
	Cars, Taxi and Pick ups			Mini Bus, Mid bus and LCvs			Standard Bus			Medium and Heavy Truck				
	LT	RT	TM	LT	RT	TM	LT	RT	TM	LT	RT	TM		
East (CMC Approach)	494	63	724	56	11	15	4	0	63	23	4	16	434	0.87
West (Megenagna Approach)	259	342	1080	63	52	216	6	8	24	8	20	27	523	0.88
North (Wossen Approach)	98	254	198	24	63	40	4	1	3	0	3	17	194	0.89
South (Jacrose Approach)	102	187	205	16	114	40	1	11	7	0	4	5	197	0.79

4.2. Performance Evaluation of the Roundabouts

The existing performances of the roundabouts were evaluated using SIDRA INTERSECTION 8 software and the results are presented below. The analysis was done for morning and afternoon peak hours for CMC and Sealite Mihiret roundabouts.

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The flow rates and performance of the CMC and Sealite Mihiret roundabouts for current traffic flow condition are discussed separately below.

4.2.1. CMC Roundabout performance analysis results

In the morning peak period East (Ayat) approach and South (Summit) approach have reached to their capacity and in the afternoon peak period West (Megenagna) approach and South (Summit) have reached to their capacity. Currently the roundabout is performing in congested condition with LOS F for East (Ayat) approach and South (Summit) approach in the morning peak hour and LOS F for West (Megenagna) approach and South (Summit) approach in the afternoon peak hour.

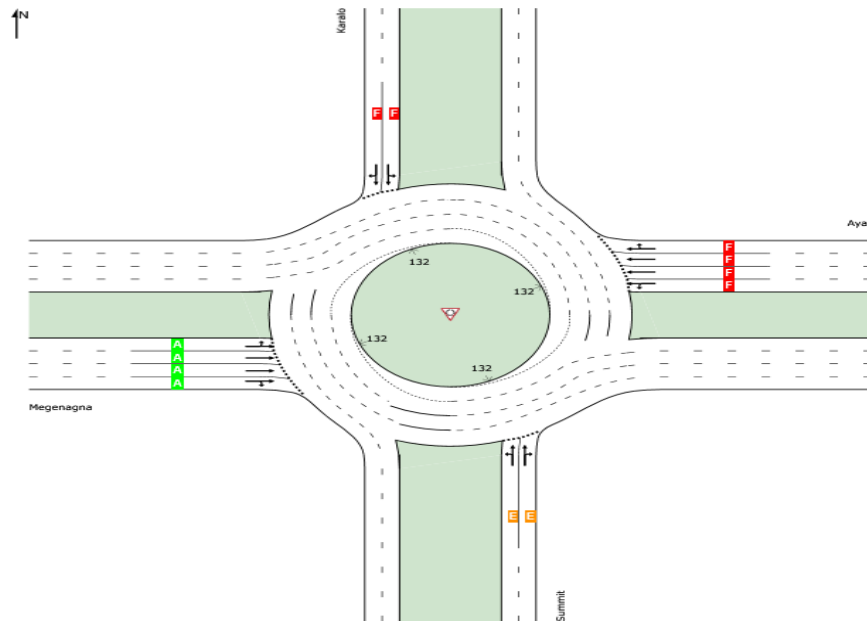
Table 13: Performance Results of CMC Roundabout

Performance Measure	Approach								Intersection	
	North (Karalo)		East (Ayat)		West (Megenagna)		South (Summit)			
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
Approach flow (veh/h)	1069	742	2385	1374	1156	2672	1371	896	5981	5683
HV%	6.4	4.6	4.4	4.6	4.7	2.4	4.6	8.6	4.9	4.2
V/C	1.67	0.975	1.269	0.642	0.489	1.366	1.109	1.597	1.67	1.597
LOS	F	D	F	A	A	F	E	F	F	F
Avg delay (Sec)	281.2	41	134.1	7.8	6	174.9	65.3	283.7	119.8	134.2

Overall, the roundabout is experiencing an average maximum delay of 134.2 seconds per vehicle in the afternoon peak hour with V/C ratio as 1.597 and LOS F. This V/C ratio value is more than the tolerable value 0.85 which indicates that the roundabout is performing over its capacity at this hour. The high delay per vehicle is due to the high approach flow on the intersection just by observing from the above table. Other factors will be discussed later in this chapter.

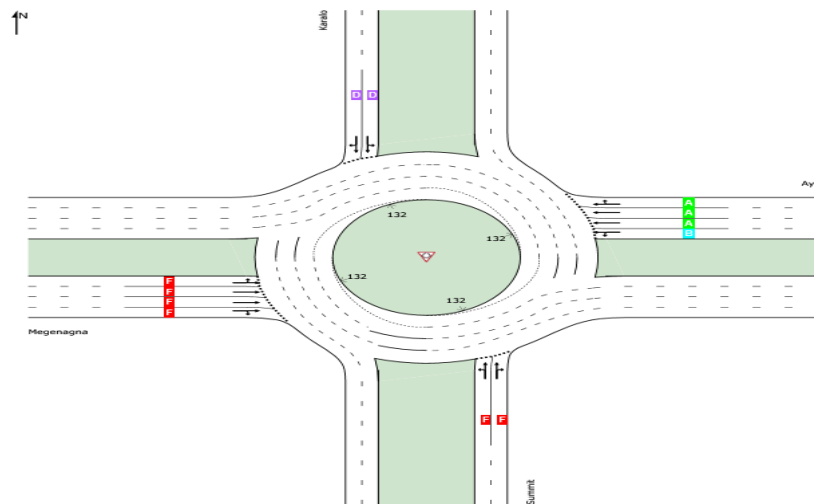
East (CMC) approach and West (Megenagna) approach become congested alternatively in the morning and afternoon peak hour respectively which shows a home to work trip situation. The following figures show lane LOS results for CMC roundabout.

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	Approaches				Intersection
	South	East	North	West	
LOS	E	F	F	A	F

Figure 11: Approach lanes and Intersection LOS (CMC Roundabout Morning peak hour)



	Approaches				Intersection
	South	East	North	West	
LOS	F	A	D	F	F

Figure 12: Approach lanes and Intersection LOS (CMC Roundabout Afternoon peak hour)

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4.2.2. Sealite-Mihiret Roundabout performance analysis results

In the morning peak hour East (CMC) approach reached to its capacity and in the afternoon peak period West (Megenagna) approach and South West (Jacros) approach reached to their capacity. Currently the roundabout is performing in congested condition with LOS F for East (CMC) approach in the morning peak hour and LOS D for West (Megenagna) approach in the afternoon peak hour which is relatively performing better than the morning peak hour.

Table 14: Performance Results of Sealite Mihiret Roundabout

Performance Measure	Approach								Intersection	
	North East (Wossen)		East (CMC)		West (Megenagna)		South West (Jacros)			
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
Approach flow (veh/h)	661	801	4304	1693	1157	2392	1412	844	7534	5730
HV%	3.3	4	3.4	7.5	8.4	4.4	7.1	4	4.8	5.2
V/C	0.083	0.537	1.497	0.722	0.586	1.039	0.74	0.862	1.947	1.039
LOS	B	B	F	A	A	D	B	B	F	C
Avg delay (Sec)	14.6	11.6	433.6	7.8	8	42.4	10.9	17.7	252.2	24.3

Overall, the roundabout is experiencing an average maximum delay of 252.2 seconds per vehicle in the morning peak hour with V/C ratio as 1.947 and LOS F. The intersection experiences high approach flow in the morning peak hour which causes the roundabout to perform over its capacity. The high delay per vehicle is due to the high approach flow on the intersection just by observing from the above table. Other factors will be discussed later in this chapter.

Here also, East (CMC) approach and West (Megenagna) approach become congested alternatively in the morning and afternoon peak hour respectively which shows a home to work trip situation. The following figures show lane LOS results for Sealite-Mihiret roundabout.

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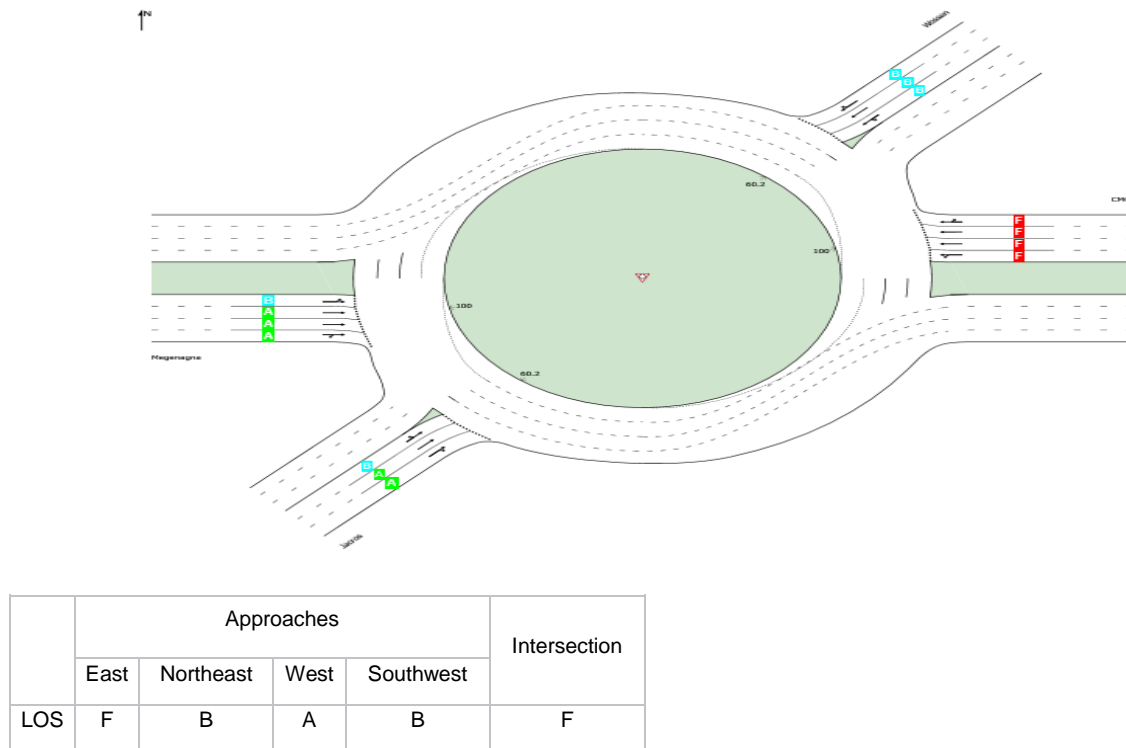


Figure 13: Approach lanes and Intersection LOS (Sealite Mihiret Roundabout Morning peak hour)

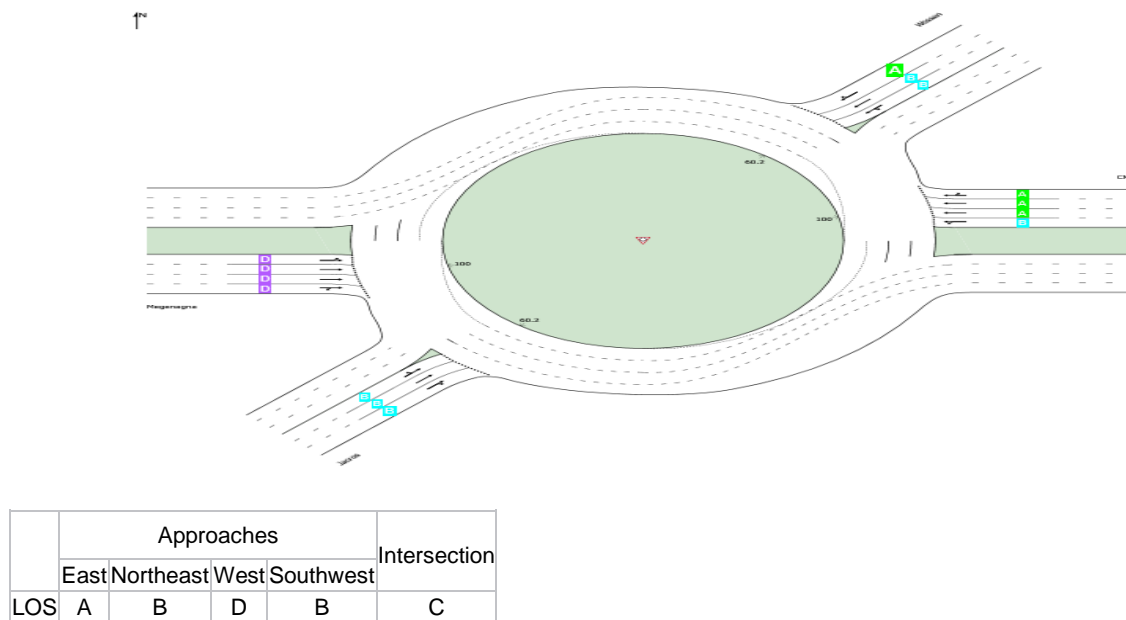


Figure 14: Approach lanes and Intersection LOS (Sealite Mihiret Roundabout Afternoon peak hour)

4.2.3. Vehicle to Capacity Ratio Analysis

The ratio of the demand at the roundabout entry to the capacity of the entry is sometimes referred to as degree of saturation. 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 vehicle to capacity ratio for an entry lane should be less than 0.85 for satisfactory operation. When the vehicle to capacity ratio exceeds this value, the operation of the roundabout will likely deteriorate rapidly, particularly over short periods of time. Queues may form and delay begins to increase exponentially (26).

The following graph shows the vehicle to capacity ratio results of the roundabouts. Both roundabouts are performing over capacity in the morning and afternoon peak hours as shown in the figure.

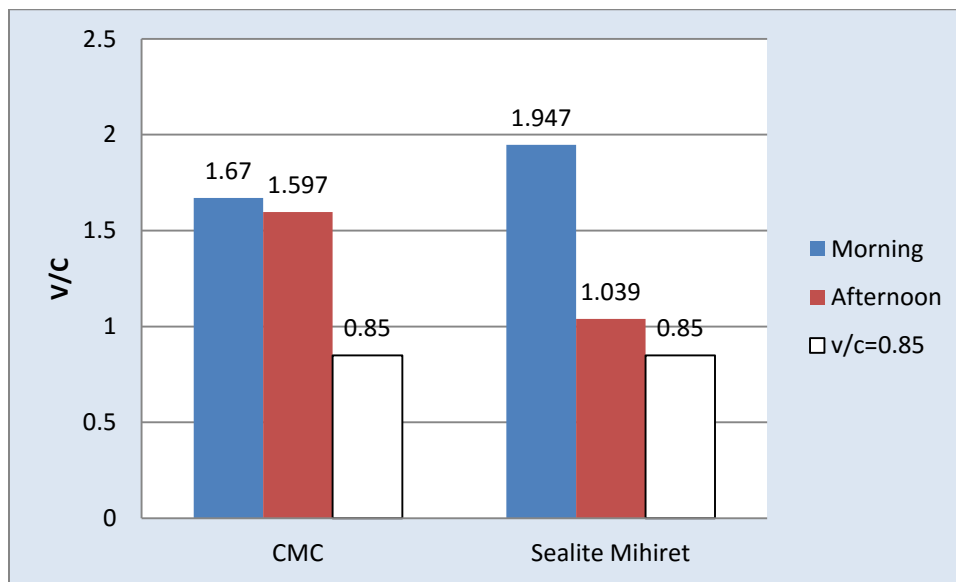


Figure 15: Vehicle to capacity ratio at Roundabouts

The effect of opposing circulatory flow on the capacity of the legs is observed and analyzed. Capacity at approaches depends on opposing circulatory flow, number of circulatory lanes, circulating road width, number of entry lanes and entry lane width and also gap acceptance parameters. The capacity results in this study are Sidra Standard capacity model results, which consider the above factors. The following graph shows the relationship between capacity at approaches and opposing circulatory flow for the two roundabouts.

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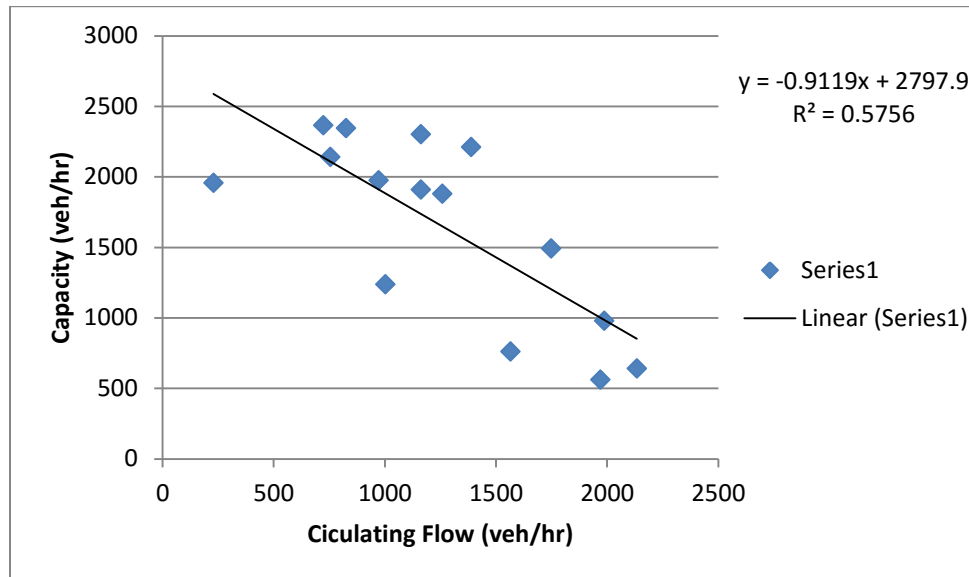


Figure 16: Approach Entry Capacities versus Circulating Flows (CMC and Sealite Mihiret Roundabouts)

The curve result in figure 16 above shows a negative linear relationship. The coefficient of determination 0.5756 (57.56%) does not show strong relationship between the two variables. But the curve shows a negative relationship where the capacity at legs tends to decrease as the circulating flow increases.

For the approaches with high opposing circulating flow the V/C ratio is higher since the capacity decreases.

4.2.4. Average Delay analysis

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 unsignalized 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. Control delay at an entry varies with entry capacity and circulating flow (26).

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Geometric delay is the additional time that a single vehicle with no conflicting flows spends slowing down to the negotiation speed, going through the intersection, and accelerating back to normal operating speed. 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 the roundabout geometry as it affects vehicle speeds during entry, negotiation, and exit (26).

The SIDRA INTERSECTION software gives options to use the HCM delay model or the Sidra standard delay model and also an option to include the geometric delay in the average delay results. The average delay results that are presented in Table 13 and 14 above are using the Sidra standard delay model and they include geometric delay. As traffic 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 other factors and the use of software is recommended (26).

The approach delay results are correlated with approach demand flow as shown on Figure 17 showing a positive relationship. In this graph the outliers are removed statistically to get a good fit. Also the average intersection delay results are correlated with heavy vehicle percentage from 0% to 10% with 2% interval which is shown in Figure 18 below.

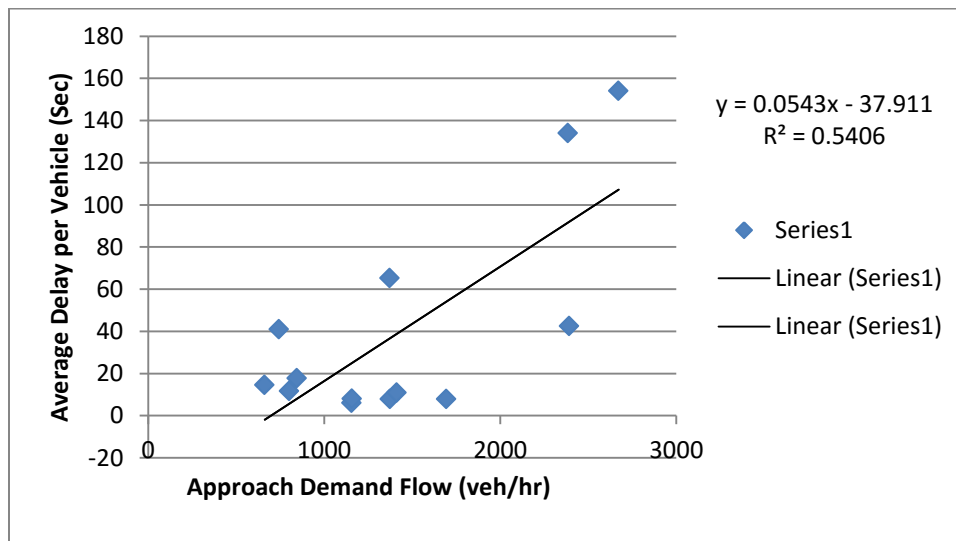


Figure 17: Approach demand flow versus Average delay per vehicle

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The correlation between approach demand flow and average delay per vehicle in the above graph doesn't show strong relation but it shows the increase in average delay per vehicle with an increase in approach demand flow.

Heavy Vehicles have limited maneuverability and acceleration/deceleration characteristics, and therefore, it is difficult for heavy vehicle drivers to adjust their speed according to the speed of surrounding traffic. This behavior of heavy vehicles creates delay on roads. In order to observe the effect of increase in heavy vehicle percentage on average delay, the roundabouts are analyzed for different heavy vehicle percentages which are from 0% to 10% with 2% interval. The heavy vehicle percentages are correlated with average delay per vehicle as shown in Figure 18 below.

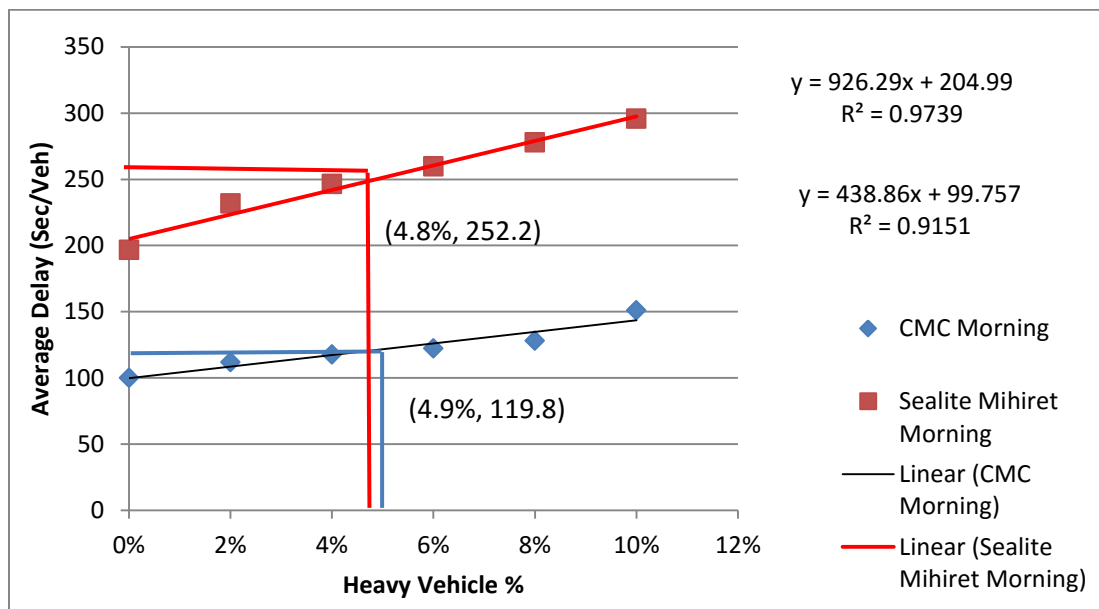


Figure 18: Heavy Vehicle percentage versus Average delay per vehicle

The correlation between heavy vehicle percentage and average delay per vehicle on the roundabouts shows a linear relationship. The above results are for the morning peak hour period since the roundabouts operate in the worst condition at this hour. The current condition of the roundabouts is indicated on the graph. In the case of CMC roundabout for an increase from 0% to 4.9% in heavy vehicles the delay at the roundabout increases about 17% which is an increase in total delay about 33 veh-hours per hour. In the case of Sealite Mihiret roundabout for an increase from 0% to 4.8% in heavy vehicles the delay at the roundabout increases about 28%

which is an increase in total delay about 117 veh-hours per hour. This results show the significance of heavy vehicle percentage on roundabout performance.

4.3. Additional delay caused by at-grade rail crossing at the roundabouts

The East-West LRT line crosses the two study roundabouts i.e. CMC and Sealite Mihiret through the central island. During the time the train crosses the roundabout the circulating traffic stops for a certain amount of time which causes delay only on some movements. This delay depends on the frequency of the trains and the closure time of the roundabout when a train passes.

The affected movements are left movements of all approaches and through movements of opposed approaches. Referring to Table 6 & 7 in the methodology section the average closure time of the two roundabouts for CMC and Sealite Mihiret roundabouts is 187 secs and 171 sec per hour respectively and the average train frequency is 8 trains per hour.

These additional delays found are added on the delays found previously during the analysis of the roundabouts using SIDRA with no at-grade rail crossing. The significance of this additional delay on the roundabouts performance is presented below by comparing the LOS for no at-grade rail crossing and with at-grade rail crossing cases. This is done for the morning and afternoon peak hours for both roundabouts.

To be consistent with the SIDRA methods the approach delay is calculated as weighted average of the delay for each movement on the approach divided by the sum of volume on each movement and roundabout delay is calculated as weighted average of the delay for each approach divided by the sum of volume on each approach. The following equations are used to calculate the approach and roundabout delays. The results are presented in the tables found in the next pages.

$$d_{app} = \frac{d_{lm} * v_{lm} + d_{rm} * v_{rm} + d_{tm} * v_{tm}}{v_{lm} + v_{rm} + v_{tm}}$$
$$d_{round} = \frac{\sum d_{appi} * v_{appi}}{\sum v_{appi}}$$

Where the notations;

d_{app} = delay of approach

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d_{round} = delay of roundabout,

d_{lm} = delay of left movement

d_{rm} = delay of right movement

d_{tm} = delay of through movement

v_{lm} = traffic volume for left movement

v_{rm} = traffic volume for right movement

v_{tm} = traffic volume for through movement

d_{appi} = delay of an approach i and

v_{appi} = traffic volume for approach i

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Table 15: Roundabout performance with and without at-grade rail crossing (CMC roundabout morning peak hour)

Movement Performance – Vehicles								
		No at Grade-Rail crossing					Have at Grade-Rail crossing	
Mov	Turn	Demand Flows		Deg.	Average	Level of	Average	Level of
ID		Total	HV	Satn	Delay	Service	Delay	Service
		veh/h	%	v/c	sec		sec	
South: Summit								
10	L2	418	3.6	1.109	70.1	LOS F	257.1	LOS F
11	T1	788	3	1.109	63.1	LOS E	250.1	LOS F
12	R2	166	14.3	1.109	64.1	LOS E	64.1	LOS E
Approach		1371	4.6	1.109	65.3	LOS E	229.7	LOS F
East: Ayat								
1	L2	440	3.5	1.269	139.7	LOS F	326.7	LOS F
2	T1	1797	4.6	1.269	133	LOS F	133	LOS F
3	R2	148	5.2	1.269	132	LOS F	132	LOS F
Approach		2385	4.4	1.269	134.1	LOS F	168.7	LOS F
North: Karalo								
4	L2	124	4.5	1.468	236.6	LOS F	423.6	LOS F
5	T1	317	6.3	1.468	230.4	LOS F	417.4	LOS F
6	R2	626	6.9	1.67	315.8	LOS F	315.8	LOS F
Approach		1067	6.5	1.67	281.2	LOS F	358.5	LOS F
West: Megenagna								
7	L2	177	3.6	0.489	11.5	LOS B	198.5	LOS F
8	T1	719	4.8	0.489	5.1	LOS A	5.1	LOS A
9	R2	259	5.4	0.489	4.8	LOS A	4.8	LOS A
Approach		1156	4.7	0.489	6	LOS A	34.7	LOS C
All Vehicles		5978	4.9	1.67	119.8	LOS F	190.6	LOS F

The performance of the CMC roundabout in the morning peak hour with and without at-grade rail crossing in Table 15 shows that even though the LOS is F in both cases, the delay increases by 1 minute per vehicle which will be 7058 veh-minutes increase in the total delay. Therefore the LRT line has significant effect on traffic congestion by increasing delay on certain movements on the roundabout. This effect will increase as the frequency of the trains increase in the future development plan which is 6 min headway and the frequency per hour in each direction becomes 10 trains. Assuming the current speed of the trains from the result we got 187 seconds and 171

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seconds of closure time for 8 trains per hour for the two roundabouts, the closure time for 20 trains per hour for the two roundabouts becomes 467.5 seconds and 427.5 seconds per hour respectively.

Similarly the results for CMC roundabout afternoon peak hour, Sealite Mihiret roundabout morning and afternoon peak hour are presented below in Table 16, 17 & 18 respectively and the affected movements are highlighted. From the results the additional delay caused by the at-grade rail crossing affects the performance of the sealite Mihiret roundabout in the afternoon peak hour whose LOS becomes F which was LOS C with no at-grade rail crossing.

Table 16: Roundabout performance with and without at-grade rail crossing (CMC roundabout afternoon peak hour)

Movement Performance - Vehicles		No at Grade-Rail crossing					Have at Grade-Rail crossing	
Mov	Turn	Demand Flows		Deg.	Average	Level of	Average	Level of
ID		Total	HV	Satn	Delay	Service	Delay	Service
		veh/h	%	v/c	sec		sec	
South: Summit								
10	L2	509	8.7	1.597	289.2	LOS F	476.2	LOS F
11	T1	138	10.2	1.576	276.5	LOS F	463.5	LOS F
12	R2	249	7.8	1.576	276.4	LOS F	276.4	LOS F
Approach		896	8.6	1.597	283.7	LOS F	418.7	LOS F
East: Ayat								
1	L2	446	4.9	0.642	12.2	LOS B	199.2	LOS F
2	T1	780	4.6	0.527	5.7	LOS A	5.7	LOS A
3	R2	147	3	0.527	5.6	LOS A	5.6	LOS A
Approach		1374	4.6	0.642	7.8	LOS A	68.5	LOS E
North: Karalo								
4	L2	392	5.4	0.975	42.5	LOS D	229.5	LOS F
5	T1	255	4.4	0.975	39.3	LOS D	226.3	LOS F
6	R2	96	1.5	0.975	39.4	LOS D	39.4	LOS D
Approach		742	4.6	0.975	41	LOS D	203.8	LOS F
West: Megenagna								
7	L2	436	0.8	1.366	180.4	LOS F	367.4	LOS F
8	T1	1711	2.4	1.366	174	LOS F	174	LOS F
9	R2	525	3.4	1.366	173.3	LOS F	173.3	LOS F
Approach		2672	2.4	1.366	174.9	LOS F	205.4	LOS F
All Vehicles		5683	4.2	1.597	134.2	LOS F	205.8	LOS F

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Table 17: Roundabout performance with and without at-grade rail crossing (Sealite Mihiret roundabout morning peak hour)

Movement Performance – Vehicles								
Mov	Turn	No at Grade-Rail crossing					Have at Grade-Rail crossing	
		Demand Flows		Deg.	Average	Level of	Average	Level of
ID		Total	HV	Satn	Delay	Service	Delay	Service
		veh/h	%	v/c	sec		sec	
East: CMC								
4a	L1	879	2.3	1.947	438.6	LOS F	609.6	LOS F
2	T1	3085	3.7	1.947	432.4	LOS F	432.4	LOS F
6b	R3	340	3	1.947	431.2	LOS F	431.2	LOS F
Approach		4304	3.4	1.947	433.6	LOS F	468.5	LOS F
NorthEast: Wossen								
24b	L3	62	0	0.083	22.7	LOS C	193.7	LOS F
25	T1	458	4	0.083	14.3	LOS B	185.3	LOS F
26a	R1	141	2.3	0.083	12.1	LOS B	12.1	LOS B
Approach		661	3.3	0.083	14.6	LOS B	149.1	LOS F
West: Megenagna								
10a	L1	221	7.9	0.586	12.9	LOS B	183.9	LOS F
8	T1	879	8	0.586	6.9	LOS A	6.9	LOS F
12b	R3	57	15.4	0.586	6.1	LOS A	6.1	LOS A
Approach		1157	8.4	0.586	8	LOS A	40.7	LOS F
SouthWest: Jacros								
30b	L3	396	7.5	0.74	17.9	LOS B	188.9	LOS F
31	T1	771	6.8	0.74	8.5	LOS A	179.5	LOS A
32a	R1	245	7.2	0.74	7.3	LOS A	7.3	LOS A
Approach		1412	7.1	0.74	10.9	LOS B	152.3	LOS F
All Vehicles		7534	4.8	1.947	252.2	LOS F	315.5	LOS F

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Table 18: Roundabout performance with and without at-grade rail crossing (Sealite Mihiret roundabout afternoon peak hour)

Movement Performance – Vehicles								
Mov ID	Turn	No at Grade-Rail crossing					Have at Grade-Rail crossing	
		Demand Flows		Deg.	Average	Level of	Average	Level of
		Total	HV	Satn	Delay	Service	Delay	Service
		veh/h	%	v/c	sec		sec	
East: CMC								
4a	L1	663	4.7	0.722	11.5	LOS B	182.5	LOS F
2	T1	940	9.7	0.498	5.5	LOS A	5.5	LOS A
6b	R3	90	5.1	0.498	5.4	LOS A	5.4	LOS A
Approach		1693	7.5	0.722	7.8	LOS A	74.8	LOS F
NorthEast: Wossen								
24b	L3	143	3.2	0.537	19.4	LOS B	190.4	LOS F
25	T1	357	6.4	0.537	10.8	LOS B	181.8	LOS F
26a	R1	301	1.5	0.537	8.9	LOS A	8.9	LOS A
Approach		801	4	0.537	11.6	LOS B	118.4	LOS F
West: Megenagna								
10a	L1	382	4.2	1.039	48.4	LOS D	219.4	LOS F
8	T1	1531	3.8	1.039	42	LOS D	42.0	LOS D
12b	R3	480	6.6	1.039	39.1	LOS D	39.1	LOS D
Approach		2392	4.4	1.039	42.4	LOS D	69.7	LOS E
SouthWest: Jacros								
30b	L3	145	0.8	0.663	21.7	LOS C	192.7	LOS F
31	T1	313	4.7	0.663	13.6	LOS B	184.6	LOS F
32a	R1	385	4.7	0.862	19.6	LOS B	19.6	LOS B
Approach		844	4	0.862	17.7	LOS B	110.6	LOS F
All Vehicles		5730	5.2	1.039	24.3	LOS C	84.1	LOS F

The total impact of at grade rail crossing on the two study roundabouts in terms of delay is presented in the Table 19 below. The total impact of at-grade rail crossing in the morning peak hour on delay is an increase in total delay from 726.26 Veh-hr to 976.93 Veh-hr (an increase of 34%) and in the afternoon peak hour an increase in total delay from 250.53 Veh-hr to 458.59 Veh-hr (an increase of 83%). The result shows that the increase in delay due to the presence of at-grade rail crossing is significant especially in the afternoon peak hour.

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Table 19: Impact of at-grade rail crossings on the study roundabouts

Roundabout	Peak hour time	Total Delay in veh-hr/hr			
		No at grade-rail crossing	Have at grade rail crossing	Absolute change	Change %
CMC	Morning	199.03	316.73	117.70	59%
	Afternoon	211.85	324.80	112.95	53%
Sealite Mihiret	Morning	527.73	660.20	132.47	25%
	Afternoon	38.68	133.79	95.11	246%
Total	Morning	726.76	976.93	250.17	34%
	Afternoon	250.53	458.59	208.06	83%

4.4. Quantifying Congestion using travel time approach

Travel time approach is used in order to quantify the congestion on the selected road segments. Average travel rate, delay rate, total vehicle delay, and delay ratio are used to analyze the congestion. Travel time reliability measures are also used to indicate how much reliable are the travel times for a traveler which is one of the measures of congestion. The congestion analysis for the three segments was done for the morning peak period as shown in the next sections.

4.4.1. Travel time

As it is defined in the NCHRP Report 398 Travel time is the time required to traverse a segment or complete a trip. Travel time data was collected for the three segments shown in the following table using license plate matching method as discussed in the methodology section. Average travel time for 34 vehicle matches was taken for each segment during the morning peak period and off peak period. The travel time data is shown in Appendix.

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Table 20: Summary of Average travel times

Location	Segment Length (meter)	Time of Data collection	Average Travel Time (minutes)
From Sealite Mihiret Station to Civil Service station	770	Morning Peak (7 AM - 9 AM)	9
		Off peak (10:00 AM - 11:00 AM) (Acceptable travel time)	1
From Civil Service station to Saint Michael station	870	Morning Peak (7 AM - 9 AM)	15
		Off peak (1:00 PM - 3:00 PM) (Acceptable travel time)	2
From Saint Michael station to CMC station	930	Morning Peak (7 AM - 9 AM)	15
		Off peak (1:00 PM - 3:00 PM) (Acceptable travel time)	2

4.4.2. Average Travel Rate and Delay rate

Travel rate, the inverse of travel speed has vital practical significance to understand the level of congestion on the selected corridor since it expresses travel time for a unit segment length. When comparing the travel rate for the three segments, the highest travel rate is 17.24 min/km which is from Saint Michael station to Civil Service station and on average 15.02 min to travel one kilometer is needed during the AM peak. These results are compared with the off peak travel rates as shown in the graph below. It clearly shows the difference in travel times between the peak and off peak periods.

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

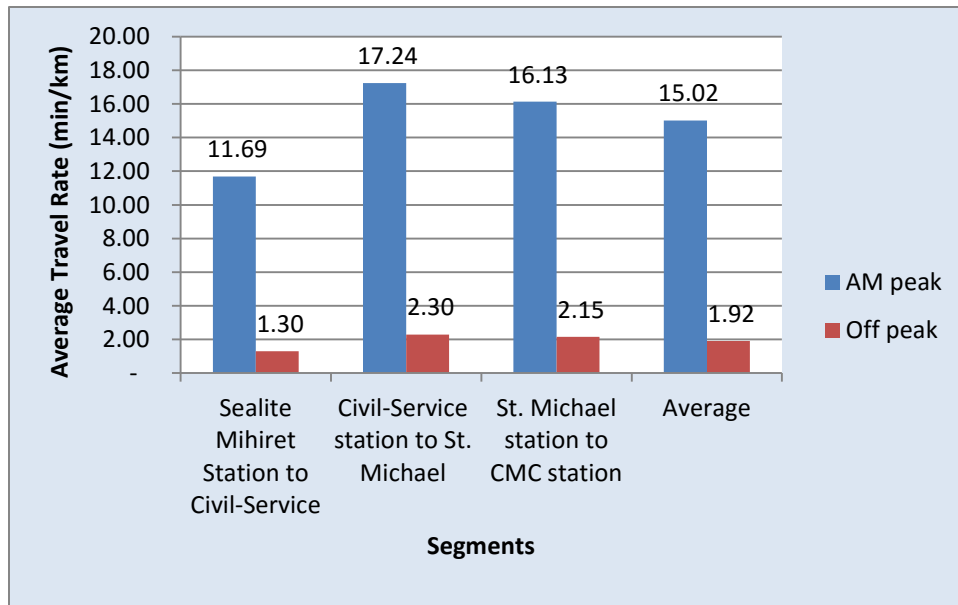


Figure 19: Average travel rate in minutes per kilometer

The delay rate result in Figure 20 indicates that, for segment 2 which is from Civil service station to St. Mikael station having the highest delay rate, extra 14.94 minutes per kilometer must be reserved by a traveler to complete the segment with the desired time. On average 13.1 minutes per kilometer extra time is needed at the AM peak period when traveling on the study corridor which is more than 100 % of the off peak travel time per kilometer.

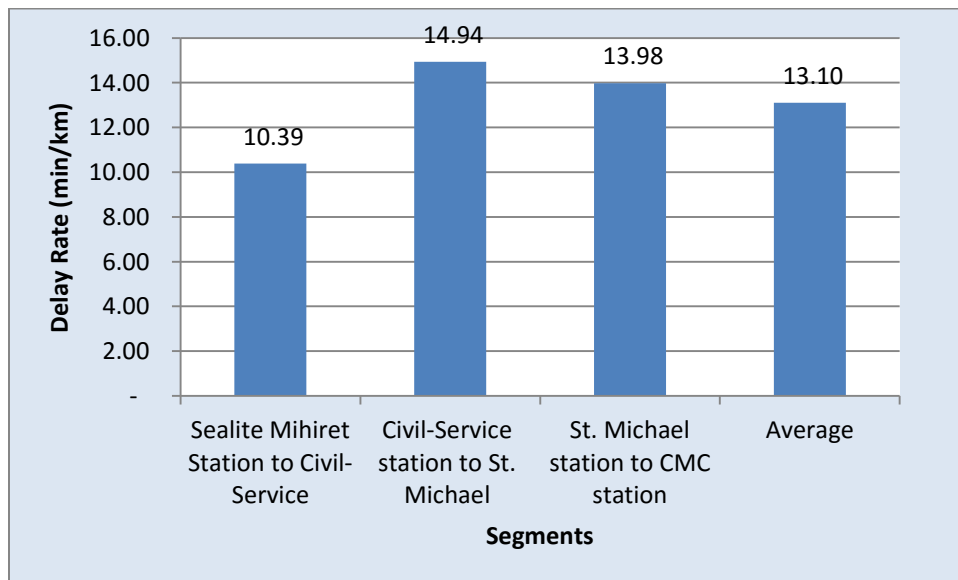


Figure 20: Delay Rate in minutes per kilometer

4.4.3. Average Travel speed

The approach which weights each link travel time and determines an average space mean speed, has been suggested as a better estimator of average corridor travel speeds. A more general form for an average space mean speed is presented in Equation 2. When a different number of travel time observations exist for numerous sequential roadway links, this equation can be used. For example, an average corridor travel speed is obtained from Equation 2 by computing the average travel time for each roadway link, then weighting each link travel time by the respective number of travel time observations (25).

$$\text{Average Space Mean Speed, } \bar{u}_L = \frac{L_T}{t_{TL}} = \frac{\sum_{i=1}^n L_i}{\sum_{i=1}^n \bar{t}_i} = \frac{1}{\sum_{i=1}^n \left[\frac{L_i}{L_T} * \frac{1}{m_i} * \sum_{j=1}^{m_i} \frac{1}{u_{ij}} \right]} \quad \text{-----(2)}$$

Where:

- u_L = average space mean (harmonic) speed for total length L
- L_T = total length of roadway for calculation of average speed
- t_{TL} = total travel time for entire length of roadway L
- L_i = length of roadway link i
- m = total number of travel time observations for each link i
- U_{ij} = travel speed for roadway link i and observation j

The average space mean speed for the study corridor has been calculated using Equation 2 found from travel time handbook and based on the results obtained the estimated average travel speed during the AM peak period is 3.92 km/hr which is a crawling speed and during the off peak period is 23.37 km/hr.

4.4.4. Total Segment Delay and Delay Ratio

Total segment delay is used to show the intensity of congestion. On Figure 21 the result indicates that on average 36,979 minute-vehicle or 616 vehicle-hr is lost during the morning peak period. This indicates that during the morning peak period, 616 vehicles will be idle for one hour every day and approximately for 2.5 days a month assuming 8 working hours per day.

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

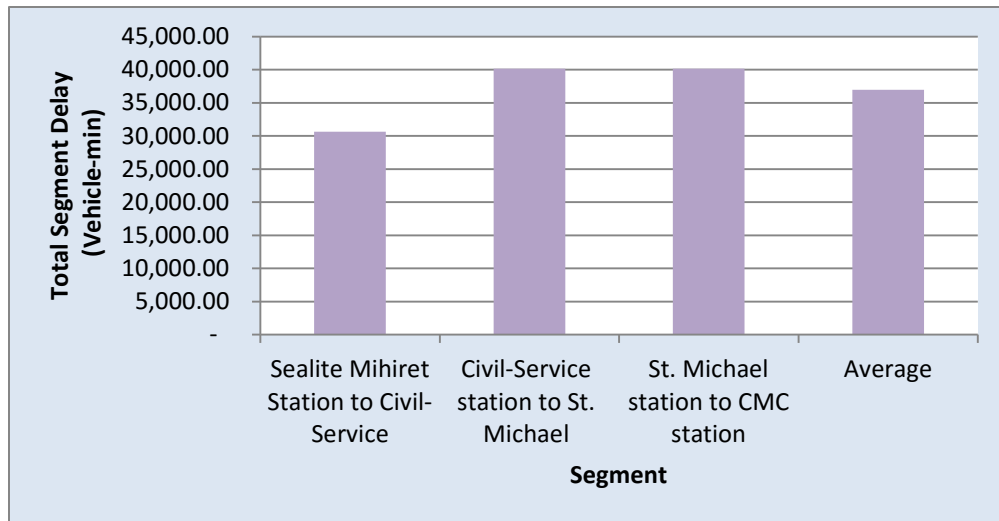


Figure 21: Total Segment Delay in Vehicle minute

Delay ratio is the ratio of delay rate to actual travel rate. The average delay ratio indicates that 88% of the actual travel time is excess and only 12% of the actual travel time is needed to traverse a segment during the off peak period.

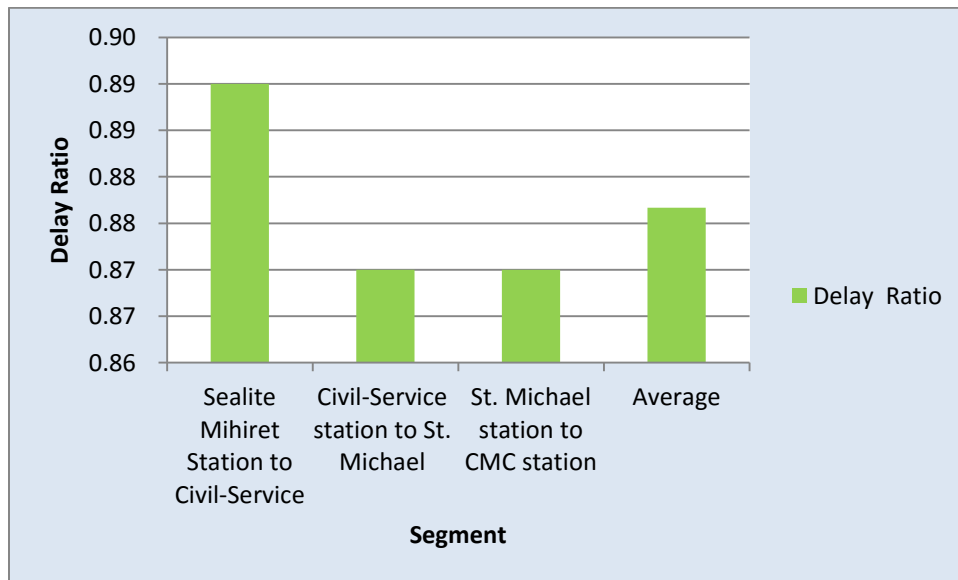


Figure 22: Delay Ratio

4.4.5. Travel Time Reliability measures

Travel time reliability refers to the consistency or dependability in travel times, as measured day-to-day or across different times of the day (15). The 95th percentile travel time, Buffer Index and planning time index are measures of travel time reliability on a segment or a corridor.

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The 95th percentile travel time is a simple and straightforward measure of travel time reliability which estimates how bad delay will be on specific routes during the heaviest traffic days. The buffer index is a time and distance-neutral measure that expresses the proportionate extra time that a traveler should budget in addition to the travel time required under average conditions to arrive on time 95% of the time. The planning time index is the ratio of the 95th percentile travel time over free flow travel time. It expresses the extra time a traveler should budget in addition to free-flow travel time to arrive on time 95% of the time (15).

The following table and figures show the three travel time reliability measures defined above; 95th percentile travel time, the buffer index and planning time index for the three segments.

Table 21: Buffer Index and Travel time index

Travel time reliability Measures	From Sealite Mihiret Station to Civil-Service station	From Civil-Service station to St. Michael station	From St. Michael station to CMC station
95th percentile Travel Time (min)	12	19	28
Buffer Index	0.33	0.27	0.87
Planning Time Index	12.00	9.50	14.00

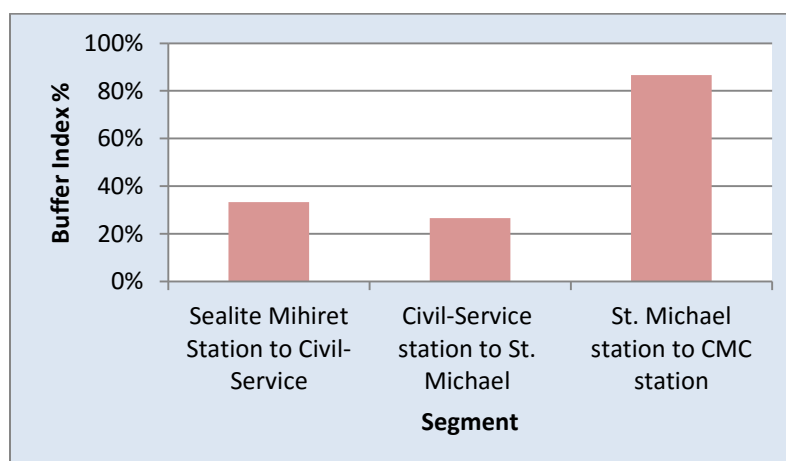


Figure 23: Buffer Index

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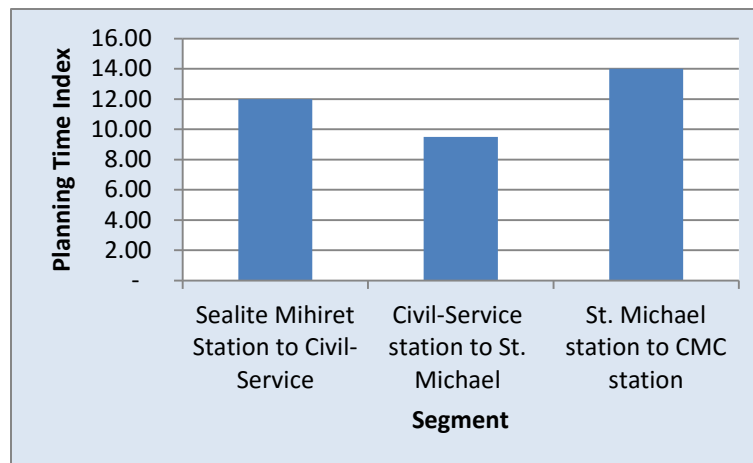


Figure 24: Planning Time Index

For a traveler who wants to traverse the corridor during the AM peak period and be on time 95% of the time, for the worst condition 14 times the off peak (light traffic travel time) should be reserved for this trip. From the average travel time 87% of the average travel time is an extra time that should be budgeted to be on time 95percent of the time (late once in a month).

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

4.5. Summary of Results and Findings

Study Objectives	Locations	Results	Findings
Roundabout performance evaluation	CMC Roundabout	Morning Peak 7:30 AM to 8:30 AM and Afternoon peak 4:00 PM to 5:00 PM	
		Highest flow rate from East (Ayat approach) in the morning peak hour and from West (Megenagna approach) in the Afternoon peak hour	Home to work trip due to concentration of residential areas at CMC and Ayat areas.
		The roundabout reaches its capacity both in the morning and afternoon peak hour.	High circulating flows contribute for low approach capacity
		The roundabout is performing with LOS F based on delay parameter both in the morning and afternoon peak hour	higher delays due to high approach demand flows
			The existence of heavy vehicles causes more than 10% increase in delay at the roundabout.
Due to the LRT crossing at grade at the roundabouts there is 187 secs closure time per hour	The effect of at grade rail crossing is more significant in the afternoon peak hour since the morning peak hour is already congested with the normal traffic		

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Study Objectives	Locations	Results	Findings
Roundabout performance evaluation	Sealite Mihiret Roundabout	Morning Peak 7:15 AM to 8:15 AM and Afternoon peak 4:00 PM to 5:00 PM	
		Highest flow rate from East (Ayat approach) in the morning peak hour and from West (Megenagna approach) in the Afternoon peak hour	Home to work trip due to concentration of residential areas at CMC and Ayat areas.
		The roundabout reaches its capacity both in the morning and afternoon peak hour.	High circulating flows contribute for low approach capacity
		The roundabout is performing with LOS F based on delay parameter both in the morning and LOS C in the afternoon peak hour	higher delays due to high approach demand flows The existence of heavy vehicle causes more than 10% increase in delay at the roundabout.
		Due to the LRT crossing at grade at the roundabouts there is 171 secs closure time per hour	The effect of at grade rail crossing is more significant in the afternoon peak hour since the morning peak hour is already congested with the existing Traffic
Quantifying Congestion using Travel Time	Three consecutive segments (Sealite Mihiret Station to Civil Service station, Civil Service station to Saint Michael station and Saint Michael station to CMC station)	From the Three segments Civil Service to St. Michael Station has the highest travel rate and delay rate	There is high number of pedestrians observed crossing on this segment which is the only non- train station crossing. The other two segments have also high number of pedestrians crossing most of them alighting from and boarding on the trains.
		The average speed of the road during the AM peak is estimated to be 3.92 Km/hr and during the off peak 23.37 km/hr	This speed is a crawling speed that indicates serious congestion.
		On should reserve 14 times the acceptable travel time to travel on this corridor in order to reach on time 95th percent of the time.	This is also an indicator of serious traffic congestion

CHAPTER FIVE: Conclusions and Recommendations

5.1. Conclusions

From the findings of the research the following conclusions are drawn.

- The two roundabouts, CMC and Sealite Mihiret, are performing over capacity both in the morning and afternoon peak hours. The unbalanced high approach flows from one or two approaches which change direction in the morning and afternoon peak periods due to the home to work trip causes the roundabouts to perform poorly.
- The high approach demand flows at the roundabouts causes delay on the roundabouts' approaches.
- The existence of heavy vehicles in the traffic composition causes a considerable amount of delay at the roundabouts that can't be ignored.
- The LRT line that crosses the roundabouts at grade causes additional delay on left movements of all approaches and through movements of minor approaches. This delay is significant in the afternoon peak hour since in the morning peak hour the roundabouts are already congested by the normal traffic.
- In addition to the high vehicular traffic flow on the road, the observed high number of pedestrians crossing at midblock sections, most of them alighting from and boarding on the trains, causes delay.
- In quantifying the traffic congestion when observing the delay numbers they are more than the tolerable values which makes the traffic congestion on the road significant.
- The average speed of the study road in the morning peak hour is determined to be 3.92 km/hr which is a crawling speed indicating a serious congestion.
- The travel time reliability results show that commuters on the study road should plan their trip 87% longer than the average travel time and the total maximum travel time that should be planned to be on time most of the time is more than 100% of the off peak light

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

traffic travel time. It can be understood from this that the peak hour congestion is very intense which needs attention.

5.2. Recommendations

- Providing other alternative routes would help in decreasing the vehicles that use this road to reach different destinations.
- Restricting heavy vehicles during peak periods would have effect in improving roundabout performances.
- By studying the effect of pedestrians crossing at mid blocks on congestion in detail and by comparing the cost of congestion and providing overpass pedestrian crossing or pedestrian lights, providing the facility would help in minimizing the travel time.
- In order to decrease the delay caused by the LRT line at the roundabouts where it crosses at grade, it is advisable to improve the warning systems. In the current situation the trains tend to slow down when they reach the roundabouts to avoid crashes, which increases the closure time. But a better warning system that restricts vehicles crossing the LRT line on train arrival well would improve this situation by decreasing the concern of train-vehicle crashes. This intern allows the trains to cross the roundabouts without decreasing their speed.

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APPENDICES

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Traffic Data

Video setup Station:	<u>On the ninth floor of a new building under construction</u>	Location:	CMC Roundabout		RT = Right Turn	TM = Through Movement										
Counter Name:	Tsedey Debebe				LT = Left Turn											
Traffic Volume (DATE 26/03/2019)																
Time	Karalo Approach				Ayat Approach				GurdShola Approach				Summit Approach			
	LT	RT	TH	Ped	LT	RT	TH	Ped	LT	RT	TH	Ped	LT	RT	TH	Ped
7:00-7:15 AM	23	141	37	12	47	9	186	72	38	74	146	250	143	12	35	98
7:15-7:30 AM	26	159	42	10	74	34	316	111	41	76	164	312	292	20	72	165
7:30-7:45 AM	20	126	32	11	128	40	510	120	23	58	96	365	210	44	52	102
7:45-8:00 AM	33	190	48	7	128	47	504	98	48	107	201	221	196	52	44	145
8:00-8:15 AM	35	216	57	15	96	36	459	141	49	51	197	196	176	68	40	123
8:15-8:30 AM	35	215	52	10	106	36	432	162	47	60	211	177	186	66	46	120
8:30-8:45 AM	25	162	39	8	108	30	454	118	51	76	202	125	132	60	32	114
8:45-9:00 AM	32	205	53	9	91	37	362	81	37	47	154	117	99	53	28	92
4.00 -4.15 PM	126	30	86	11	124	41	211	159	124	142	471	320	152	75	41	152
4.15 -4.30 PM	90	19	56	14	120	39	209	108	107	142	435	275	149	75	38	136
4.30 -4.45 PM	80	16	52	11	109	35	193	102	99	127	397	192	136	68	39	121
4.45 -5.00 PM	69	14	43	8	134	41	234	85	88	115	360	102	128	63	36	91
5.00 -5.15 PM	67	16	45	13	115	41	208	140	77	103	329	242	151	71	43	108
5.15 -5.30 PM	74	13	44	9	135	46	234	168	110	146	447	363	173	84	48	110
5.30 - 5.45 PM	92	21	62	14	95	34	165	71	122	142	478	185	135	66	35	87
5.45 - 6.00 PM	69	14	39	7	100	33	174	62	116	147	462	113	148	73	43	79

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

SIDRA INTERSECTION 8.0 Analysis Results

Roundabout Basic Parameters

Site: CMC Roundabout

Site ID: 1

Roundabout

Central Island Diam	Circ Width	Insc Diam.	Entry Radius	Entry Angle	Circ Lanes	Entry Lanes	Av.Entry Lane Width	App Dist	Prop Upstr	Queued Signal	Extra Bunching
m	m	m	m	deg			m	m			%

South: Summit											
132.0	20.5	173.0U	75.0	3.0	4	2	4.10	500		NA	0.0N

East: Ayat											
132.0	20.5	173.0U	93.0	40.0	4	4	4.20	500		NA	0.0N

North: Karalo											
132.0	20.5	173.0U	75.0	4.0	4	2	4.10	500		NA	0.0N

West: Megenagna											
132.0	20.5	173.0U	93.0	40.0	4	4	4.20	500		NA	0.0N

Roundabout Capacity Model: SIDRA Standard

U Inscribed diameter value was specified by the user.

NA Not Applicable (single Site analysis or unconnected Site in Network analysis).

N Program option resulted in zero value (single Site analysis or unconnected Site in Network analysis).

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Roundabout Gap Acceptance Parameters Site: CMC Roundabout Morning Peak

Site ID: 1
Roundabout

Dest	Turn	Lane No.	Lane Type	In-Bunch Headway sec	Prop. Bunched	Priority Sharing	HVE for Entry	Critical Gap		Follow-up Headway sec
								Headway sec	Dist m	

South: Summit

Environment Factor: 1.20

Entry/Circ. Flow Adjustment: Medium

W	L2	1	Subdominant	0.86	0.460	Y	1.09	3.01	39.1	2.73
N	T1	1	Subdominant	0.86	0.460	Y	1.08	2.98	38.8	2.71
N	T1	2	Dominant	0.86	0.460	Y	1.08	2.81	36.5	2.55
E	R2	2	Dominant	0.86	0.460	Y	1.24	3.20	41.6	2.91

East: Ayat

Environment Factor: 1.20

Entry/Circ. Flow Adjustment: Medium

S	L2	1	Subdominant	0.96	0.562	Y	1.11	2.92	37.3	2.65
W	T1	1	Subdominant	0.96	0.562	Y	1.12	2.95	37.7	2.68
W	T1	2	Subdominant	0.96	0.562	Y	1.12	2.95	37.8	2.68
W	T1	3	Subdominant	0.96	0.562	Y	1.12	2.95	37.8	2.68
W	T1	4	Dominant	0.96	0.562	Y	1.12	2.58	33.1	2.35
N	R2	4	Dominant	0.96	0.562	Y	1.12	2.59	33.1	2.35

North: Karalo

Environment Factor: 1.20

Entry/Circ. Flow Adjustment: Medium

E	L2	1	Subdominant	0.94	0.783	Y	1.08	2.73	35.4	2.48
S	T1	1	Subdominant	0.94	0.783	Y	1.10	2.79	36.2	2.53
W	R2	2	Dominant	0.94	0.783	Y	1.11	2.33	30.2	2.12

West: Megenagna

Environment Factor: 1.20

Entry/Circ. Flow Adjustment: Medium

N	L2	1	Subdominant	1.03	0.394	Y	1.16	3.21	40.3	2.92
E	T1	1	Subdominant	1.03	0.394	Y	1.18	3.24	40.7	2.95
E	T1	2	Subdominant	1.03	0.394	Y	1.18	3.25	40.8	2.95
E	T1	3	Subdominant	1.03	0.394	Y	1.18	3.25	40.8	2.95
E	T1	4	Dominant	1.03	0.394	Y	1.18	3.00	37.7	2.73
S	R2	4	Dominant	1.03	0.394	Y	1.16	2.97	37.3	2.70

Roundabout Capacity Model: SIDRA Standard

Priority sharing means Follow-up Headway plus Intra-bunch Headway is larger than the Critical Gap.

Dist (Distance): Spacing, i.e. distance between the front ends of two successive vehicles across all lanes in the circulating or exiting stream

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Lane Performance and Capacity Information Site: CMC Roundabout Morning Peak

Site ID: 1

Roundabout
LANE PERFORMANCE

Lane No.	Flow veh/h	Cap veh/h	Deg. Satn x	Aver. Delay sec	Eff. Stop Rate	Q u e u e 95% Back ----- veh m		Lane Length m
South: Summit								
1	670	604	1.109	61.6	2.41	30.7	221.5	500.0
2	702	632	1.109	61.1	2.46	31.9	234.5	500.0
East: Ayat								
1	571	450	1.269	131.2	3.03	46.5	336.1	500.0
2	563	444	1.269	131.4	3.02	46.0	334.4	500.0
3	563	444	1.269	131.4	3.02	46.0	334.4	500.0
4	687	541	1.269	129.9	3.31	54.9	400.1	500.0
North: Karalo								
1	441	300	1.468	228.3	2.71	54.3	399.1	500.0
2	626	375	1.670	313.7	3.61	90.2	669.2	500.0
West: Megenagna								
1	282	577	0.489	3.0	0.56	1.8	13.0	500.0
2	279	571	0.489	3.1	0.50	1.8	13.0	500.0
3	279	571	0.489	3.1	0.50	1.8	13.0	500.0
4	315	644	0.489	2.6	0.44	1.9	13.6	500.0

MOVEMENT PERFORMANCE Site: CMC Roundabout Morning Peak

Mov ID	Turn	Total Delay (veh-h/h)	Total Delay (pers-h/h)	Aver. Delay (sec)	Eff. Stop Rate	Total Stops	Perf. Index	Tot.Trav. Distance (veh-km/h)	Tot.Trav. Time (veh-h/h)	Aver. Speed (km/h)
South: Summit										
10	L2	7.14	12.27	61.6	2.41	1005.5	70.60	502.9	14.3	35.1
11	T1	13.35	22.13	61.0	2.44	1924.9	89.39	872.9	28.0	31.2
12	R2	2.86	6.53	61.9	2.46	409.2	59.48	176.7	5.7	30.9
East: Ayat										
1	L2	16.02	28.45	131.2	3.03	1332.6	107.38	544.6	24.0	22.7
2	T1	65.34	133.65	130.9	3.11	5581.0	206.91	1931.9	97.6	19.8
3	R2	5.35	8.71	129.9	3.31	490.6	99.12	157.7	8.0	19.8
North: Karalo										
4	L2	7.89	9.46	228.1	2.71	336.7	77.67	140.3	9.9	14.2
5	T1	20.09	24.11	228.4	2.71	856.7	96.37	357.1	26.4	13.5
6	R2	54.51	70.99	313.7	3.61	2259.4	223.43	667.8	66.0	10.1
West: Megenagna										
7	L2	0.15	0.26	3.0	0.56	98.6	7.15	214.1	3.2	66.2
8	T1	0.61	1.07	3.0	0.50	362.7	18.50	779.4	13.7	56.9
9	R2	0.19	0.36	2.6	0.44	114.1	8.41	276.4	4.8	57.4

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Roundabout Gap Acceptance Parameters Site: CMC Roundabout Afternoon Peak

Site ID: 1
Roundabout

Dest	Turn	Lane No.	Lane Type	In-Bunch Headway sec	Prop. Bunched	Priority Sharing	HVE for Entry	Critical Gap		Follow-up Headway sec
								Headway sec	Dist m	

South: Summit

Environment Factor: 1.20

Entry/Circ. Flow Adjustment: Medium

W	L2	1	Dominant	0.94	0.744	Y	1.19	2.60	33.8	2.36
N	T1	2	Subdominant	0.94	0.744	Y	1.21	3.10	40.3	2.82
E	R2	2	Subdominant	0.94	0.744	Y	1.19	3.05	39.6	2.77

East: Ayat

Environment Factor: 1.20

Entry/Circ. Flow Adjustment: Medium

S	L2	1	Dominant	0.95	0.396	Y	1.15	2.89	35.2	2.63
W	T1	2	Subdominant	0.95	0.396	Y	1.15	3.26	39.8	2.97
W	T1	3	Subdominant	0.95	0.396	Y	1.15	3.26	39.8	2.97
W	T1	4	Subdominant	0.95	0.396	Y	1.15	3.26	39.7	2.96
N	R2	4	Subdominant	0.95	0.396	Y	1.13	3.21	39.2	2.92

North: Karalo

Environment Factor: 1.20

Entry/Circ. Flow Adjustment: Medium

E	L2	1	Dominant	1.05	0.712	Y	1.13	2.62	33.1	2.38
S	T1	1	Dominant	1.05	0.712	Y	1.12	2.61	32.9	2.37
S	T1	2	Subdominant	1.05	0.712	Y	1.12	2.98	37.6	2.71
W	R2	2	Subdominant	1.05	0.712	Y	1.11	2.95	37.2	2.68

West: Megenagna

Environment Factor: 1.20

Entry/Circ. Flow Adjustment: Medium

N	L2	1	Subdominant	0.90	0.489	Y	1.09	2.89	35.6	2.63
E	T1	1	Subdominant	0.90	0.489	Y	1.10	2.93	36.1	2.67
E	T1	2	Subdominant	0.90	0.489	Y	1.10	2.94	36.2	2.67
E	T1	3	Subdominant	0.90	0.489	Y	1.10	2.94	36.2	2.67
E	T1	4	Dominant	0.90	0.489	Y	1.10	2.62	32.3	2.38
S	R2	4	Dominant	0.90	0.489	Y	1.11	2.65	32.7	2.41

Roundabout Capacity Model: SIDRA Standard

Priority sharing means Follow-up Headway plus Intra-bunch Headway is larger than the Critical Gap.

Dist (Distance): Spacing, i.e. distance between the front ends of two successive vehicles across all lanes in the circulating or exiting stream

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Lane Performance and Capacity Information Site: CMC Roundabout Afternoon Peak

Site ID: 1
Roundabout

LANE PERFORMANCE

Lane No.	Flow veh/h	Cap veh/h	Deg. Satn x	Aver. Delay sec	Eff. Stop Rate	Q u e u e		Lane Length m
						95% Back veh	m	

South: Summit								
1	509	318	1.597	280.6	3.52	68.7	516.4	500.0
2	387	246	1.576	274.3	2.99	52.6	395.5	500.0

East: Ayat								
1	446	695	0.642	3.7	0.68	3.2	23.2	500.0
2	308	584	0.527	3.6	0.58	2.2	15.7	500.0
3	308	584	0.527	3.6	0.58	2.2	15.7	500.0
4	312	591	0.527	3.6	0.56	2.2	15.6	500.0

North: Karalo								
1	409	419	0.975	34.0	1.54	11.3	82.6	500.0
2	334	342	0.975	37.4	1.50	9.9	71.4	500.0

West: Megenagna								
1	651	476	1.366	172.0	4.15	62.0	438.7	500.0
2	639	468	1.366	172.1	4.12	60.9	435.5	500.0
3	639	468	1.366	172.1	4.12	60.9	435.5	500.0
4	743	544	1.366	171.1	4.47	70.1	503.8	500.0

MOVEMENT PERFORMANCE

Site: CMC Roundabout Afternoon Peak

Mov ID	Turn	Total Delay (veh-h/h)	Total Delay (pers-h/h)	Aver. Delay (sec)	Eff. Stop Rate	Total Stops	Perf. Index	Tot.Trav. Distance (veh-km/h)	Tot.Trav. Time (veh-h/h)	Aver. Speed (km/h)
South: Summit										
10	L2	39.65	98.27	280.6	3.52	1787.7	7171.05	656.8	49.8	13.2
11	T1	10.49	24.39	274.4	2.99	412.1	99.90	146.7	13.0	11.3
12	R2	19.00	46.39	274.2	2.99	746.9	112.26	265.8	23.6	11.3

East: Ayat										
1	L2	0.46	0.68	3.7	0.68	301.8	16.87	576.2	9.3	61.9
2	T1	0.78	1.10	3.6	0.57	447.2	20.55	829.0	14.5	57.1
3	R2	0.14	0.17	3.5	0.56	82.8	5.82	156.8	2.7	57.3

North: Karalo										
4	L2	3.69	5.20	34.0	1.54	603.4	33.58	501.8	11.1	45.1
5	T1	2.64	3.16	37.2	1.50	382.0	21.40	274.9	7.1	38.5
6	R2	0.99	1.19	37.3	1.50	143.2	15.43	101.9	2.6	38.5

West: Megenagna										
7	L2	20.82	29.63	172.0	4.15	1809.0	114.51	530.3	28.5	18.6
8	T1	81.75	124.38	172.0	4.17	7138.1	252.42	1851.3	112.8	16.4
9	R2	24.94	42.24	171.1	4.47	2347.8	160.11	559.3	34.2	16.4

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Roundabout Basic Parameters Site: Sealite Mihiret RA morning peak

Site ID: 1
Roundabout

Central Island Diam m	Circ Width m	Insc Diam. m	Entry Radius m	Entry Angle deg	Circ Lanes	Entry Lanes	Av.Entry Lane Width m	App Dist m	Prop Upstr	Queued Signal	Extra Bunching %

East: CMC											
100.0	14.0	128.0U	27.0	24.0	4	4	5.50	500		NA	0.0N

NorthEast: Wossen											
60.2	14.0	88.2U	64.5	1.6	4	3	5.20	500		NA	0.0N

West: Megenagna											
100.0	14.0	128.0U	23.2	24.0	4	4	5.50	500		NA	0.0N

SouthWest: Jacros											
60.2	14.0	88.2U	69.5	1.6	4	3	5.50	500		NA	0.0N

Roundabout Capacity Model: SIDRA Standard

Some roundabout geometry parameters shown in this table have been adjusted according to the Sensitivity analysis results.

U Inscribed diameter value was specified by the user.

NA Not Applicable (single Site analysis or unconnected Site in Network analysis).

N Program option resulted in zero value (single Site analysis or unconnected Site in Network analysis).

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Roundabout Gap Acceptance Parameters Site: Sealite Mihret RA morning peak

Site ID: 1
Roundabout

Dest	Turn	Lane No.	Lane Type	In-Bunch Headway sec	Prop. Bunched	Priority Sharing	HVE for Entry	Critical Gap		Follow-up Headway sec
								Headway sec	Dist m	

East: CMC										
Environment Factor: 1.20										
Entry/Circ. Flow Adjustment: Medium										
SW	L1	1	Subdominant	0.83	0.569	Y	1.14	2.66	31.5	2.42
W	T1	1	Subdominant	0.83	0.569	Y	1.12	2.61	30.9	2.37
W	T1	2	Subdominant	0.83	0.569	Y	1.12	2.61	30.9	2.38
W	T1	3	Subdominant	0.83	0.569	Y	1.12	2.61	30.9	2.38
W	T1	4	Dominant	0.83	0.569	Y	1.12	2.05	24.3	1.86
NE	R3	4	Dominant	0.83	0.569	Y	1.08	2.00*	23.7	1.80

NorthEast: Wossen										
Environment Factor: 1.20										
Entry/Circ. Flow Adjustment: Medium										
E	L3	1	Subdominant	0.93	0.844	Y	1.09	2.25	27.9	2.04
SW	T1	1	Subdominant	0.93	0.844	Y	1.12	2.31	28.8	2.10
SW	T1	2	Subdominant	0.93	0.844	Y	1.12	2.31	28.8	2.10
SW	T1	3	Dominant	0.93	0.844	Y	1.12	2.00*	24.9	1.32
W	R1	3	Dominant	0.93	0.844	Y	1.10	2.00*	24.9	1.30

West: Megenagna										
Environment Factor: 1.20										
Entry/Circ. Flow Adjustment: Medium										
NE	L1	1	Subdominant	0.99	0.486	Y	1.25	3.11	35.0	2.83
E	T1	1	Subdominant	0.99	0.486	Y	1.25	3.11	35.0	2.83
E	T1	2	Subdominant	0.99	0.486	Y	1.25	3.11	35.0	2.83
E	T1	3	Subdominant	0.99	0.486	Y	1.25	3.11	35.0	2.83
E	T1	4	Dominant	0.99	0.486	Y	1.25	2.58	29.0	2.35
SW	R3	4	Dominant	0.99	0.486	Y	1.30	2.68	30.2	2.44

SouthWest: Jacros										
Environment Factor: 1.20										
Entry/Circ. Flow Adjustment: Medium										
W	L3	1	Subdominant	0.83	0.522	Y	1.17	2.73	34.4	2.48
NE	T1	1	Subdominant	0.83	0.522	Y	1.16	2.71	34.2	2.46
NE	T1	2	Subdominant	0.83	0.522	Y	1.16	2.71	34.2	2.46
NE	T1	3	Dominant	0.83	0.522	Y	1.16	2.13	26.8	1.94
E	R1	3	Dominant	0.83	0.522	Y	1.21	2.22	27.9	2.01

Roundabout Capacity Model: SIDRA Standard

Priority sharing means Follow-up Headway plus Intra-bunch Headway is larger than the Critical Gap.

* Critical gap or follow-up headway set to MINIMUM value

Dist (Distance): Spacing, i.e. distance between the front ends of two successive vehicles across all lanes in the circulating or exiting stream

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Lane Performance and Capacity Information Site: Sealite Mihiret RA morning peak

Site ID: 1
Roundabout

LANE PERFORMANCE

Lane No.	Flow veh/h	Cap veh/h	Deg. Satn x	Aver. Delay sec	Eff. Stop Rate	Q u e u e		Lane Length m
						95% Back veh	m	
East: CMC								
1	948	487	1.947	438.2	5.85	154.3	1083.5	500.0
2	974	500	1.947	432.9	5.99	158.4	1144.2	500.0
3	974	500	1.947	432.9	5.99	158.4	1144.2	500.0
4	1408	724	1.947	431.4	7.45	225.8	1617.1	500.0
NorthEast: Wossen								
1	218	2628	0.083	17.0	1.00	4.7	33.0	500.0
2	218	2625	0.083	14.7	1.00	4.8	33.2	500.0
3	226	2727	0.083	12.1	1.00	4.1	28.7	500.0
West: Megenagna								
1	269	460	0.586	11.9	0.90	2.2	15.8	500.0
2	269	460	0.586	7.3	0.80	2.2	16.2	500.0
3	269	460	0.586	7.3	0.80	2.2	16.2	500.0
4	348	594	0.586	6.0	0.69	2.4	17.5	500.0
SouthWest: Jacros								
1	415	560	0.740	17.5	1.06	4.4	30.9	500.0
2	418	565	0.740	9.3	1.00	4.4	31.0	500.0
3	579	783	0.740	7.3	0.84	5.0	35.3	500.0

MOVEMENT PERFORMANCE Site: Sealite Mihiret RA morning peak

Mov ID	Turn	Total Delay (veh-h/h)	Total Delay (pers-h/h)	Aver. Delay (sec)	Eff. Stop Rate	Total Stops	Perf. Index	Tot.Trav. Distance (veh-km/h)	Tot.Trav. Time (veh-h/h)	Aver. Speed (km/h)
East: CMC										
4a	L1	107.06	159.74	438.6	5.85	5144.34	1.01	1009.5	122.4	8.2
2	T1	370.57	658.45	432.4	6.49	20036.28	29.88	3339.9	424.0	7.9
6b	R3	40.78	60.40	431.2	7.45	2537.64	24.43	364.7	47.0	7.8
NorthEast: Wossen										
24b	L3	0.39	0.47	22.7	1.00	62.3	5.72	69.8	1.3	54.7
25	T1	1.82	2.66	14.3	1.00	457.6	20.48	502.1	9.8	51.3
26a	R1	0.47	0.56	12.1	1.00	140.9	8.85	151.9	2.9	52.6
West: Megenagna										
10a	L1	0.79	2.29	12.9	0.90	198.9	9.66	251.9	4.5	56.5
8	T1	1.67	4.81	6.9	0.77	673.8	24.92	955.2	16.6	57.4
12b	R3	0.10	0.33	6.1	0.69	39.0	5.19	60.9	1.1	53.5
SouthWest: Jacros										
30b	L3	1.96	4.39	17.9	1.06	418.9	19.53	472.4	8.7	54.2
31	T1	1.81	3.87	8.5	0.93	721.3	27.77	838.3	15.1	55.5
32a	R1	0.50	1.23	7.3	0.84	206.5	14.18	264.9	4.8	55.5

Roundabout Gap Acceptance Parameters

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Site: Sealite Mihiret RA Afternoon peak

Site ID: 1
Roundabout

Dest	Turn	Lane No.	Lane Type	In-Bunch Headway sec	Prop. Bunched	Priority Sharing	HVE for Entry	Critical Gap		Follow-up Headway sec
								Headway sec	Dist m	
East: CMC										
Environment Factor: 1.20										
Entry/Circ. Flow Adjustment: Medium										
SW	L1	1	Dominant	0.91	0.403	Y	1.10	2.37	26.9	2.16
W	T1	2	Subdominant	0.91	0.403	Y	1.11	2.94	33.3	2.67
W	T1	3	Subdominant	0.91	0.403	Y	1.11	2.94	33.3	2.67
W	T1	4	Subdominant	0.91	0.403	Y	1.11	2.94	33.3	2.67
NE	R3	4	Subdominant	0.91	0.403	Y	1.12	2.98	33.8	2.71

NorthEast: Wossen										
Environment Factor: 1.20										
Entry/Circ. Flow Adjustment: Medium										
E	L3	1	Subdominant	1.02	0.723	Y	1.13	2.47	29.4	2.25
SW	T1	1	Subdominant	1.02	0.723	Y	1.13	2.47	29.4	2.25
SW	T1	2	Subdominant	1.02	0.723	Y	1.13	2.47	29.4	2.25
SW	T1	3	Dominant	1.02	0.723	Y	1.13	2.00*	23.8	1.68
W	R1	3	Dominant	1.02	0.723	Y	1.13	2.00*	23.8	1.69

West: Megenagna										
Environment Factor: 1.20										
Entry/Circ. Flow Adjustment: Medium										
NE	L1	1	Subdominant	1.07	0.579	Y	1.14	2.81	31.3	2.55
E	T1	1	Subdominant	1.07	0.579	Y	1.12	2.77	30.8	2.52
E	T1	2	Subdominant	1.07	0.579	Y	1.12	2.76	30.8	2.51
E	T1	3	Subdominant	1.07	0.579	Y	1.12	2.76	30.8	2.51
E	T1	4	Dominant	1.07	0.579	Y	1.12	2.27	25.3	2.07
SW	R3	4	Dominant	1.07	0.579	Y	1.13	2.29	25.6	2.09

SouthWest: Jacros										
Environment Factor: 1.20										
Entry/Circ. Flow Adjustment: Medium										
W	L3	1	Subdominant	0.84	0.707	Y	1.08	2.22	27.8	2.01
NE	T1	1	Subdominant	0.84	0.707	Y	1.12	2.32	29.1	2.11
NE	T1	2	Subdominant	0.84	0.707	Y	1.12	2.30	28.9	2.09
E	R1	3	Dominant	0.84	0.707	Y	1.23	2.00*	25.1	1.69

Roundabout Capacity Model: SIDRA Standard

Priority sharing means Follow-up Headway plus Intra-bunch Headway is larger than the Critical Gap.

* Critical gap or follow-up headway set to MINIMUM value

Dist (Distance): Spacing, i.e. distance between the front ends of two successive vehicles across all lanes in the circulating or exiting stream

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Lane Performance and Capacity Information Site: Sealite Mihiret RA Afternoon peak

Site ID: 1
Roundabout

LANE PERFORMANCE

Lane No.	Flow veh/h	Cap veh/h	Deg. Satn x	Aver. Delay sec	Eff. Stop Rate	Q u e u e		Lane Length m
						95% Back veh	m	

East: CMC								
1	663	919	0.722	11.5	0.88	4.4	30.5	500.0
2	344	691	0.498	5.5	0.58	2.1	15.9	500.0
3	344	691	0.498	5.5	0.58	2.1	15.9	500.0
4	342	687	0.498	5.4	0.63	2.1	15.4	500.0

NorthEast: Wossen								
1	232	433	0.537	16.2	1.01	2.9	20.1	500.0
2	232	433	0.537	10.9	0.96	2.9	19.5	500.0
3	336	626	0.537	8.9	0.99	3.5	24.2	500.0

West: Megenagna								
1	549	528	1.039	46.7	1.94	18.1	127.8	500.0
2	558	537	1.039	42.6	1.95	18.3	132.2	500.0
3	558	537	1.039	42.6	1.95	18.3	132.2	500.0
4	727	700	1.039	39.1	2.06	22.2	156.1	500.0

SouthWest: Jacros								
1	233	352	0.663	18.7	1.05	3.6	25.7	500.0
2	225	340	0.663	13.6	1.03	3.6	25.4	500.0
3	385	447	0.862	19.6	1.20	6.9	49.6	500.0

MOVEMENT PERFORMANCE Site: Sealite Mihiret RA Afternoon peak

Mov ID	Turn	Total Delay (veh-h/h)	Total Delay (pers-h/h)	Aver. Delay (sec)	Eff. Stop Rate	Total Stops	Perf. Index	Tot. Trav. Distance (veh-km/h)	Tot. Trav. Time (veh-h/h)	Aver. Speed (km/h)

East: CMC										
4a	L1	2.11	2.94	11.5	0.88	583.4	25.77	765.2	13.8	55.5
2	T1	1.43	4.89	5.5	0.59	558.7	24.86	1017.1	17.5	58.0
6b	R3	0.13	0.16	5.4	0.63	56.4	4.66	95.9	1.8	53.8

NorthEast: Wossen										
24b	L3	0.77	1.63	19.4	1.01	144.2	7.78	165.6	3.0	55.3
25	T1	1.07	1.57	10.8	0.98	348.5	14.62	393.5	7.4	52.9
26a	R1	0.74	0.97	8.9	0.99	297.0	13.45	323.8	5.8	55.6

West: Megenagna										
10a	L1	5.14	8.78	48.4	1.94	739.6	45.72	432.7	11.4	38.1
8	T1	17.86	30.59	42.0	1.96	3006.8	92.67	1660.6	43.8	37.9
12b	R3	5.20	9.04	39.1	2.06	989.0	55.26	501.8	13.7	36.8

SouthWest: Jacros										
30b	L3	0.88	1.26	21.7	1.05	152.0	8.91	168.0	3.1	53.8
31	T1	1.18	2.35	13.6	1.03	323.2	14.67	346.7	6.7	51.7
32a	R1	2.10	4.62	19.6	1.20	461.0	22.81	414.0	8.6	48.2

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Travel Time Data

Title	Travel Time		
Time	Off Peak (10:00 AM - 11:00 AM)		
Date	Thursday		
Data Collectors	Location		
DataCollector 1	Civil Service Station		
DataCollector 2	Sealite Mihiret Station	Length (KM)	0.77

Sample Vehicle No.	Data Collector 2	Data Collector 1	Travel Time
1	4:16	4:15	0:01
2	4:48	4:46	0:02
3	4:25	4:24	0:01
4	4:39	4:38	0:01
5	4:25	4:24	0:01
6	4:47	4:45	0:02
7	4:46	4:44	0:02
8	4:47	4:45	0:02
9	4:20	4:19	0:01
10	4:18	4:17	0:01
11	4:34	4:33	0:01
12	4:22	4:21	0:01
13	4:24	4:23	0:01
14	4:51	4:48	0:03
15	4:18	4:18	0:00
16	4:17	4:16	0:01
17	4:46	4:44	0:02
18	4:47	4:45	0:02
19	4:51	4:47	0:04
20	4:49	4:47	0:02
21	4:22	4:21	0:01
22	4:49	4:43	0:06
23	4:50	4:48	0:02
24	4:30	4:29	0:01
25	4:17	4:17	0:00
26	4:50	4:48	0:02
27	4:48	4:46	0:02
28	4:35	4:34	0:01
29	4:39	4:38	0:01
30	4:45	4:43	0:02
31	4:37	4:36	0:01
32	4:38	4:37	0:01
33	4:49	4:47	0:02
34	4:48	4:46	0:02

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Title	Travel Time		
Time	Morning Peak (7 AM - 9 AM)		
Date	Thursday		
Data Collectors	Location		
DataCollector 1	Civil Service Station		
DataCollector 3	Sealite Mihiret	Length (KM)	0.77

Sample Vehicle No.	Data Collector 1	Data Collector 3	Travel Time
1	2:32	2:43	0:11
2	1:47	1:52	0:05
3	1:51	1:56	0:05
4	2:28	2:40	0:12
5	1:50	1:55	0:05
6	2:30	2:42	0:12
7	2:24	2:36	0:12
8	1:50	1:54	0:04
9	1:53	1:58	0:05
10	1:51	1:57	0:06
11	2:28	2:38	0:10
12	1:56	2:02	0:06
13	1:55	2:01	0:06
14	1:53	1:59	0:06
15	2:25	2:36	0:11
16	2:33	2:43	0:10
17	2:32	2:42	0:10
18	2:28	2:40	0:12
19	2:18	2:30	0:12
20	2:25	2:37	0:12
21	1:56	2:02	0:06
22	1:54	1:59	0:05
23	1:55	2:00	0:05
24	1:56	2:02	0:06
25	2:33	2:44	0:11
26	1:52	2:36	0:44
27	1:46	1:50	0:04
28	2:23	2:35	0:12
29	1:48	1:52	0:04
30	1:51	1:56	0:05
31	2:27	2:39	0:12
32	1:48	1:53	0:05
33	2:28	2:39	0:11
34	1:53	1:59	0:06

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Title	Travel Time		
Time	Off Peak (from 1:00 PM to 3:00 PM)		
Date	Thursday		
Data Collectors	Location		
Data Collector 3	Civil Service Station		
Data Collector 2	St. Michael Station	Length (KM)	0.87

Sample Vehicle No.	Data Collector 2	Data Collector 3	Travel Time
1	2:43	2:45	0:02
2	2:28	2:30	0:02
3	2:07	2:09	0:02
4	2:35	2:37	0:02
5	2:30	2:32	0:02
6	2:09	2:11	0:02
7	2:08	2:11	0:03
8	2:40	2:42	0:02
9	2:10	2:12	0:02
10	2:30	2:33	0:03
11	2:45	2:47	0:02
12	2:42	2:44	0:02
13	2:35	2:38	0:03
14	2:43	2:44	0:01
15	2:21	2:26	0:05
16	2:10	2:18	0:08
17	2:41	2:43	0:02
18	2:10	2:13	0:03
19	2:13	2:15	0:02
20	2:15	2:17	0:02
21	2:27	2:29	0:02
22	2:22	2:24	0:02
23	2:40	2:42	0:02
24	2:17	2:20	0:03
25	2:22	2:26	0:04
26	2:42	2:43	0:01
27	2:39	2:42	0:03
28	2:15	2:18	0:03
29	2:15	2:22	0:07
30	2:36	2:38	0:02
31	2:46	2:47	0:01
32	2:39	2:42	0:03
33	2:21	2:24	0:03
34	2:08	2:11	0:03

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Title	Travel Time		
Time	Morning Peak (7 AM - 9 AM)		
Date	Thursday		
Data Collectors	Location		
DataCollector 2	Civil Service Station		
DataCollector 3	St. Michael Station	Length (KM)	0.87
Sample Vehicle No.	Data Collector 2	Data Collector 3	Travel Time
1	8:38	8:51	0:13
2	8:44	9:00	0:16
3	8:45	8:59	0:14
4	8:39	8:54	0:15
5	8:11	8:28	0:17
6	8:12	8:30	0:18
7	8:05	8:23	0:18
8	8:29	8:44	0:15
9	8:39	8:54	0:15
10	8:43	8:59	0:16
11	8:38	8:53	0:15
12	8:00	8:20	0:20
13	8:18	8:35	0:17
14	8:21	8:38	0:17
15	8:44	8:59	0:15
16	8:45	9:00	0:15
17	8:29	8:43	0:14
18	8:02	8:18	0:16
19	8:46	9:00	0:14
20	8:09	8:31	0:22
21	8:40	8:55	0:15
22	8:27	8:44	0:17
23	8:10	8:26	0:16
24	8:37	8:49	0:12
25	8:40	8:55	0:15
26	8:36	8:49	0:13
27	8:44	8:57	0:13
28	8:41	8:56	0:15
29	8:10	8:29	0:19
30	8:36	8:49	0:13
31	8:41	8:56	0:15
32	8:39	8:53	0:14
33	8:41	8:56	0:15
34	8:23	8:23	0:00

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Title	Travel Time		
Time	Off Peak (from 1:00 PM to 3:00 PM)		
Date	Thursday		
Data Collectors	Location		
DataCollector 1	CMC		
DataCollector 2	St. Michael Station	Length (KM)	0.93

Sample Vehicle No.	Data Collector 1	Data Collector 2	Travel Time
1	2:11	2:13	0:02
2	2:28	2:30	0:02
3	2:27	2:29	0:02
4	2:35	2:35	0:00
5	2:21	2:21	0:00
6	2:09	2:11	0:02
7	2:29	2:30	0:01
8	2:29	2:35	0:06
9	2:08	2:10	0:02
10	2:14	2:14	0:00
11	2:23	2:24	0:01
12	2:08	2:10	0:02
13	2:05	2:07	0:02
14	2:15	2:16	0:01
15	2:19	2:20	0:01
16	2:25	2:26	0:01
17	2:06	2:08	0:02
18	2:19	2:20	0:01
19	2:15	2:16	0:01
20	2:21	2:22	0:01
21	2:20	2:21	0:01
22	2:18	2:26	0:08
23	2:13	2:14	0:01
24	2:35	2:36	0:01
25	2:06	2:07	0:01
26	2:07	2:10	0:03
27	2:15	2:16	0:01
28	2:14	2:14	0:00
29	2:23	2:23	0:00
30	2:06	2:08	0:02
31	2:10	2:31	0:21
32	2:21	2:22	0:01
33	2:22	2:22	0:00
34	2:07	2:09	0:02

Assessment of Congestion and Performance Evaluation of Roundabouts on CMC-Megenagna road

Title	Travel Time		
Time	Morning Peak (7 AM - 9 AM)		
Date	Thursday		
Data Collectors	Location		
DataCollector 1	CMC		
DataCollector 2	St. Mikael	Length (KM)	0.93

Sample Vehicle No.	Data Collector 1	Data Collector 2	Travel Time
1	7:57	8:20	0:23
2	7:57	8:04	0:07
3	7:56	8:06	0:10
4	7:55	8:03	0:08
5	7:55	8:05	0:10
6	7:56	8:09	0:13
7	8:08	8:22	0:14
8	8:22	8:38	0:16
9	7:57	8:05	0:08
10	8:29	8:43	0:14
11	7:59	8:08	0:09
12	8:07	8:21	0:14
13	8:08	8:23	0:15
14	8:11	8:27	0:16
15	7:58	8:40	0:42
16	8:25	8:39	0:14
17	8:09	8:23	0:14
18	7:58	8:06	0:08
19	8:07	8:22	0:15
20	8:06	8:19	0:13
21	8:20	8:35	0:15
22	8:10	8:25	0:15
23	8:08	8:21	0:13
24	8:03	8:10	0:07
25	8:26	8:40	0:14
26	8:07	8:21	0:14
27	8:22	8:38	0:16
28	8:01	8:36	0:35
29	8:24	8:46	0:22
30	8:12	8:37	0:25
31	7:59	8:07	0:08
32	8:27	8:42	0:15
33	8:12	8:29	0:17
34	8:07	8:22	0:15