JIMMA UNIVERSITY

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JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

CIVIL ENGINEERING DEPARTMENT

HIGHWAY ENGINEERING STREAM

COMPARATIVE STUDY OF OPERATIONAL PERFORMANCE BETWEEN ROUNDABOUT AND SIGNALIZED INTERSECTION IN ADDIS ABABA CITY: A CASE STUDY AT AYER-TENA AND GERGI-IMPERIAL INTERSECTIONS

A Final Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Highway Engineering

By

Habtamu Mebratu

October, 2017
Jimma, Ethiopia

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Main advisor: Prof. Emer T. Quezon

Co-advisor: Engr. Markos Tsegaye, MSc.

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BY:

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Declaration

I, the undersigned, declare that this thesis entitled ""Comparative Study of Operational Performance between the Roundabout and Signalized Intersection in Addis Ababa City"." is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for theses have been duly acknowledged.

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As Master's Thesis Advisors, we hereby certify that we have read and evaluated this MSc Thesis prepared under our guidance, by HABTAMU MEBRATU entitled: "Comparative Study of Operational Performance between the Roundabout and Signalized Intersection in Addis Ababa City"."

We recommend that it can be submitted as fulfilling the MSc Thesis requirements.

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ACKNOWLEDGEMENT

Firstly, I would like to thank almighty God for the blessings and being with me in every step I pass through.

Secondly, I would like to express my sincere and deepest gratitude to my advisor Prof. Emer T. Quezon and my co-advisor Engr. Markos Tsegaye, MSc, for all their limitless efforts in guiding me through my work and for providing me useful reference materials.

Thirdly, my deep hearted gratitude to Ethiopian Road Authority (ERA) and Jimma University by giving me the opportunity to avail the scholarship program in pursuing my master's degree in civil engineering.

Last but not the least, my particular thanks go to my parents, brothers, and sisters who are always there in times of difficulties and giving me moral support to complete this research work.

ABSTRACT

Intersection plays a significant role in the road network, where traffic flowing in different directions crosses each other. Traffic signals and roundabouts controls are commonly used in several at-grade junctions in urban areas for maximizing traffic efficiency and safety by separating traffic movements in time. The intersection performance measures (capacity, a degree of saturation, delay, queue length, fuel consumption, operating costs and emission, etc.) used to compare the intersection performance.

In Addis Ababa, most of the intersections are congested and excessive delay during peak hours in the morning and afternoon experienced by the travelers. The objective of this research was to assess and provide a comparative study of operational performance between a roundabout and signalized intersection at the selected intersections. In pursuing the objective of the research study, it focused on two areas Gergi-Imperial Signalized intersection and Ayer-Tena Roundabout. The traffic data on all approach of the intersections were collected by video camera during the most congested days of the week (i.e. Monday, Wednesday and Friday). The traffic volume obtained in different classes of a vehicle has been converted to uniform vehicle fleet by the passenger car equivalency factor. While, the geometric data's for the selected intersections were measured. Data analysis and processing were performed using SIDRA (Signalized and Unsignalized intersection Design and Research Aid) intersection software to know the traffic flow condition at the intersection. The performance measures used to compare the intersections where the Average delay, Degree of saturation and Level of service at each intersection were interpreted.

Based on the findings of the research, the performance of signalized intersection compared with that of roundabouts. The capacities of the signalized intersection were found to be higher than the capacities of roundabout while the Average delay and Degree of saturation for the roundabout was considered to be greater than that of signalized intersections. However, both roundabout and signalized intersection were found to be operating at the same level of service. There was a 13.68% and 31.49 % decrease in the Average delay and Degree of saturation respectively and capacity value increased with 11.18%, after the installation of the proposed signalized intersection at Ayer-Tena intersection. And also, Gergi-Imperial intersection there was a 22.28% and 36.09% decrease in the Average delay and Degree of saturation respectively and capacity value increased with 3.00%, after the installation of the signalized intersection. Therefore, Ayer-Tena and Gergi-Imperial signalized intersections were better than the roundabout in terms of the degree of operational performance. Lastly, Capacity improvement methods such as improving the capacity of roads, improving public transport and avoid effect of pedestrian conflict with vehicles are the major recommendations forwarded.

Keywords: Average delay, Capacity, Degree of Saturation, Conflicting traffic movement, Level of Service (LOS).

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ACRONYMS

AACRA	Addis Ababa City Roads Authority
FHWA	Federal Highway Administration
HCM	Highway Capacity Manual
HV	Heavy Vehicle
JIT	Jimma institute of Technology
LT	Left Turning
LOS	level of service
NCHRP	National Cooperative Highway Research Program
PCU	Passenger Car Unit
PHF	Peak-hour factor
RT	Right Turning
SIDRA	Signalized (un-Signalized) Intersection Design and Research Aid
Std	Standard
TH	Through Traffic
TRB	Transportation Research Board
veh	Vehicle
vph	Vehicle per hour
4WD	Four Wheel Drive

CHAPTER ONE

INTRODUCTION

1.1 Background

Traffic congestion is one of the leading societal and economic problems in urban areas related to transportation industries, both in developed and developing countries [1]. Traffic congestion is mainly observed around intersections. Particularly, it becomes severe during peak hours. Intersection plays a major role in the road network, where traffic flowing in different directions crosses each other. Hence, level of service at the intersection significantly affects the overall level of service of the road. The critical aspect of increasing capacity of any road lies in increasing the capacity of the intersection. Traffic signals and roundabouts controls are commonly used in several at-grade junctions in urban areas for maximizing traffic efficiency and safety by separating traffic movements in time. And Intersection performance measures (capacity, a degree of saturation, delay, queue length, fuel consumption, operating costs and emission, etc.) used to compare the intersection performance [5].

A junction always has a common space shared by several traffic streams. The conflicts between the traffic streams are the major sources of traffic accidents. To prevent traffic accidents, the conflicting traffic streams should be separated in time. The roundabout is a junction with a central island where the conflicting traffic streams are separated in time by the priority rules, i.e., the entry vehicles should give way to circulating vehicles. Signalized junction is a junction with traffic lights where the conflicts are separated in time by the traffic lights [23].

In Addis Ababa, most of the intersections are congested, and their capacities are not well identified. Road traffic congestion and excessive delay during peak hours in the morning and afternoon at the intersection in Addis Ababa have increased over the years.

The purpose of this research is to assess and provide a comparative study of operational performance between roundabout and a signalized intersection at identified intersections with a final recommendation at each intersection location. A comparison between a roundabout and signalized intersection regarding performance has been analyzed.

The study is also important for urban planners, traffic engineers and other concerned bodies who aim to mitigate the problems.

1.2 Statement of the problem

Traffic congestion is one of the main societal and economic problems in urban areas related to transportation industries, both in developed and developing countries [1]. Prevalently, Ethiopia is one of the countries that are in rapid economic development. This influences the travel pattern of the community from their origin to any destination. Road traffic congestion and excessive delay during peak hours in the morning and afternoon at junction in Addis Ababa have increased over the year.

This traffic congestion, long queues and excessive delay during peak hours in the morning and afternoon at junction have major problems in the city. However; little research was available to compare the study of operational performance between roundabout and signalized intersection.

This problem will continue and it may more difficult in the future due to the rapid growth of population and vehicle numbers in Addis Ababa. Therefore, it is essential to evaluate

and compare study of operational performance between roundabout and signalized intersection.

1.3 Research Questions

The research questions that this study will attempt to clarify; are as follows:

1. What is the performance of Roundabout and 4-Leg Signalized intersection?
2. What is the existing average control delay of Roundabout and 4-Leg Signalized intersection?
3. What is the effect of pedestrians and heavy vehicle in the performance of intersections?
4. What is the current capacity of Roundabout and 4-Leg Signalized intersection?

1.4 Objective

1.4.1 General objective

The general objective of this research was to compare the operational performance between Roundabout and Signalized Intersection in Addis Ababa City.

1.4.2 Specific objectives

Specific objectives of this study are:

- ✓ To determine the performance of roundabout and 4-Leg signalized intersection.
- ✓ To determine the average control delay of the roundabout and 4-Leg signalized intersection.
- ✓ To study the effect of pedestrians and heavy vehicles in the performance of intersections.
- ✓ To evaluate and compare the current capacity of the roundabout and 4-Leg signalized intersection.

1.5 Significance of the study

Now a day's traffic congestion has a serious effect on once country development so, without doubt, the researches on traffic capacity evaluation and comparison have a broad range of significance for both the researcher and city administer. The researcher will have a better understanding regarding the determination of operational performance and capacity of intersections. For the city administration, the research will help them to designing and improving the performance of the intersections in the future for the city. And also it will be important for design, operations and planning purposes in traffic management in the city.

1.6 Scope

As the topic of operational performance of intersection touches lots of areas and wide, it is necessary to define the scope of the study so that the untreated topics could be left for other researchers. Accordingly, the scope of the research is to evaluate and compare study of operational performance between the roundabout and signalized intersection in Addis Ababa a case study at Ayer-Tena roundabout, and Gerg-Imperial signalized intersection.

CHAPTER TWO

LITERATURE REVIEW

2.1 Intersection Traffic Control

The intersection is an area shared by two or more roads. This area is designated for the vehicles to turn to different directions to reach their desired destinations. Its main function is to guide vehicles to their respective directions. Traffic intersections are complex locations on any highway. This is because vehicles moving in different direction want to occupy same space at the same time. Also, the pedestrians also seek same space for crossing. Both from accident and capacity perspective, the study of intersection are very important especially in the case of urban scenario [2].

Types of intersection traffic control include: Basic rules of the road, give way control, two-way stop control, and all-way stop control, channelization islands, roundabouts, signalized intersection, Grade separation [2].

2.1.1 Roundabout

2.1.1.1 General

A roundabout is a channelized intersection at which all traffic moves anticlockwise around a central traffic island [3]. All traffic-through, as well as turning, enters this one-way flow. Although usually circular, the central island of a roundabout can be oval or irregularly shaped. Roundabouts can be appropriate design alternative to both stop-controlled and signal-controlled intersections, as they have fewer conflict points than traditional intersections (eight versus 32, respectively) [4].

2.1.1.2 Geometric features of modern Roundabouts

Geometric elements of roundabouts play an important part in the efficiency of roundabouts operational performance. The good geometric design will improve not only capacity but also safety, which is a major concern for road design [5]. Basic elements for design consideration of roundabouts are:

2.1.1.3 Description of Basic Elements of Roundabouts

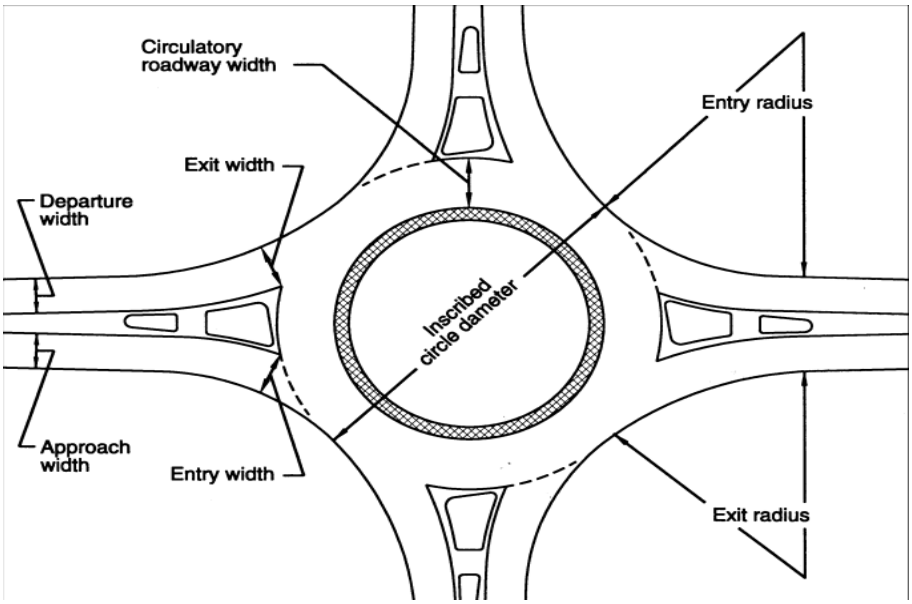


Figure 2.1: Major Geometric Features of Modern Roundabout [5].

Inscribed circle diameter inscribed circle diameter is the basic parameter used to define the size of a roundabout. It is measured between the outer edges of the circulatory roadway.

Circulatory roadway width the circulatory roadway width defines the road width for vehicle circulation around the central island. It is measured as the width between the outer edge of this road and the central island. It does not include the width of any mountable apron, which is defined to be part of the central island.

Approach width the approach width is the width of the roadway used by approaching traffic upstream of any changes in width associated with the roundabout. The approach width is typically no more than half of the total width of the roadway.

The departure width is the width of the roadway used by departing traffic downstream of any changes in width associated with the roundabout. The departure width is typically less than or equal to half of the total width of the roadway.

Entry width the entry width defines the width of the entry where it meets the inscribed circle. It is measured perpendicularly from the right edge of the entry to the intersection point of the left edge line and the inscribed circle.

Exit width the exit width defines the width of the exit where it meets the inscribed circle. It is measured perpendicularly from the right edge of the exit to the intersection point of the left edge line and the inscribed circle.

Entry radius the entry radius is the minimum radius of curvature of the outside curb at the entry.

Exit radius the exit radius is the minimum radius of curvature of the outside curb at the exit [5].

2.1.1.4 Roundabout Categories

For this guide, roundabouts have been categorized according to size and environment to facilitate discussion of specific performance or design issues. There are six basic categories base d on environment, number of lanes, and size: [5].

• Mini-roundabouts

• Urban compact roundabouts

• Urban single-lane roundabouts

• Urban double-lane roundabouts

• Rural single-lane roundabouts and Rural double-lane roundabouts

Table 2.1: Basic design characteristics for each of the six roundabout categories [5]

Design element	Mini-roundabout	Urban compact	Urban Single-Lane	Urban Single-Lane	Rural Single-Lane	Rural Single-Lane
Recommended maximum entry design speed	25 km/h (15 mph)	25 km/h (15 mph)	35 km/h (20 mph)	40 km/h (25 mph)	40 km/h (25 mph)	50 km/h (30 mph)
Maximum number of entering lanes per approach	1	1	1	2	1	2
Typical inscribed circle diameter	13 m to 25 m (45 ft to 80 ft)	25 m to 30 m (80 ft to 100 ft)	30 m to 40 m (100 ft to 130 ft)	45 m to 55 m (150 ft to 180 ft)	35 m to 40 m (115 ft to 130 ft)	55 m to 60 m (180 ft to 200 ft)
Splitter island treatment	Raised if possible, crosswalk Cut if raised	Raised, with crosswalk Cut	Raised, with crosswalk Cut	Raised, with crosswalk Cut	Raised and extended, with crosswalk Cut	Raised and extended, with crosswalk Cut
Typical daily service volumes on 4-leg roundabout (veh/day)	10,000	15,000	20,000	40,000 to 50,000	20,000	40,000 to 50,000

2.1.1.5 Advantages and Disadvantages

Table 2.2: Advantages and Disadvantages of Roundabouts vs. Other Alternatives

Category	**Advantages**	**Disadvantages**
Safety	Reduced number of conflict points compared to other non-circular intersections. Left-turn conflicts are removed. Elimination of high angles of conflict and high operational speeds; fewer and less severe accidents. Reduction in conflicting speeds passing through the intersection.	Crashes may temporarily increase due to improper driver education. During emergencies, signalized intersections can preempt control. Multilane roundabouts present more difficulties for pedestrians with blindness or low vision due to challenges in detecting gaps and determining that vehicles have yielded at crosswalks.

	Reduced decision-making at the point of entry. Long splitter islands and other geometric features provide good advanced warning of the intersection. Raised level of consciousness for drivers. Facilitate U-turns that can substitute for more difficult midblock left turns.	May reduce the number of available gaps for midblock unsignalized intersections and driveways
Operations	Traffic yields, nonstop, continuous traffic flow. Higher capacities experienced. Can reduce the number of lanes required between intersections, including bridges between interchange ramp terminals. During off-peak hours, signal timing can create the undue delay at signalized intersections.	Coordinated signal systems can increase the capacity of the network. As queues develop, drivers accept smaller gaps, which may increase crashes. Equal priority for all approaches can reduce the progression for high volume approaches. Cannot provide explicit priority to specific users (e.g., trains, emergency vehicles, transit, pedestrians) unless supplemental traffic control devices are provided.
Cost	No maintenance of signals (heads, loop detectors, controllers). Lower accident rate and severity; reduced accident costs.	Central island landscaping maintenance. Illumination cost. May have significant real estate impacts
Pedestrians & Bicyclists	Splitter islands provide pedestrian refuge and shorter one-directional traffic crossing. Pedestrians only need to consider one the direction of traffic at a time. Low-speed conditions improve bicycle and pedestrian safety. Depending on their skills and level of comfort, bicyclists have the option to	Pedestrians, especially children, elderly, and handicapped may experience increased delay and reduced safety in securing acceptable gaps to cross. Pedestrians with vision impairments may have the most trouble establishing safe Opportunities to cross. Longer travel path. Bicycle ramps could be confused for

	take a lane to negotiate through a roundabout.	pedestrian ramps.
Environmental	Reduced starts and stops; reduced air pollution.	Possible impacts to natural and cultural resources due to potentially greater spatial requirements at the intersection.
OSOW Truck Route (OSOW TR)	Reduction of potential obstacles at intersections (traffic signals, signing, median islands).	The geometric design may be challenging to allow the navigation of OSOW vehicles. Additional right-of-way and paved areas may be needed to accommodate OSOW vehicles.

2.1.1.6 Methods for Estimating the capacity of Roundabouts

Capacity is the maximum sustainable flow rate that can be achieved during a specific period under the prevailing road, traffic and control conditions. The prevailing condition is important since capacity is not a constant value, but varies as a function of traffic flow levels. Capacity represents the service rate (queue clearance rate) in the performance (delay, Queue length, stop rate) functions, and therefore is relevant to both under saturated and over saturated conditions [6].

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

1. Empirical models
2. Analytical models

1. Empirical models

Empirical models on field data to develop relationships between geometric design features and performance measures such as capacity and delay. Empirical models are

better but require some congested roundabouts for calibration and may have poor transferability to other countries [7].

2. Analytical models

Analytical models are based on the concept of gap acceptance theory. The choice of an analysis approach depends on the calibration data available. The capacity at a roundabout can be estimated using gap acceptance techniques with the basic parameters of a critical gap and follow-up time [7]. The gap is the headway between two consecutive vehicles on the circulating flow; so, the "critical gap" is the minimum headway accepted by a driver in the entering stream. If the gap accepted is larger than minimum, them more than one driver can enter the roundabout; the headway between two consecutive vehicles in the entering flow, which utilizes the same gap, is defined as "follow-up time" .so, the analytical model calculates the roundabout capacity as a function of the critical gap, follow-up time and the circulating flow.

2.1.1.7 Capacity Models Developed in Different countries

1.Australia

Troutbeck (1993) conducted studies for the Australian Road Research Board and developed an analytical equation based on gap acceptance characteristics observed and measured at roundabouts operating below capacity. Critical gap and follow-up times are related to roundabout geometry and capacity are then determined using the following equation.

$$Qe = \frac{\propto Qce - \lambda(tc - tm)}{1 - e - \lambda tf} \qquad (2\text{-}1)$$

Where

Qe; entry capacity, vph;

Qc ; circulating flow, vph;

α ; a proportion of non-bunched (free) vehicles in the circulating streams;

λ ; model parameter;

tc; critical gap, s;

tf; minimum headway in circulating streams, s; and

tm; follow-up time, s.

2. United States U.S

The Highway Capacity Manual 2010 (HCM) presents a methodology for estimating roundabout capacity based on gap acceptance. The capacity model is applicable only to single-lane roundabouts if the circulating volume is less than 1,200 vph. Insufficient experience in the U.S. precludes the HCM from containing guidelines for multiple-lane roundabouts. The HCM assumes that the gap acceptance characteristic of drivers entering a roundabout to be similar to those of drivers making right turns the following model was developed in the U.S.

$$Ca = \frac{vc * e^{-\frac{vc * tc}{3600}}}{1 - e^{-\frac{vc * tt}{3600}}} \qquad (2\text{-}2)$$

Where

ca; approach capacity, vph;

vc; conflicting circulating traffic, vph;

tc; critical gap, s; and

tt; follow-up time, s.

2.1.2 Signalized Intersections

Control using traffic signal is based on time sharing approach. At a given time, with the help of appropriate signals, certain traffic movements are restricted whereas certain other movements are permitted to pass through the intersection. Two or more phases may be provided depending upon the traffic conditions of the intersection. The signals can operate in several modes. Most common are fixed time signals and vehicle actuated signals [2].

Type of signal control

1. **Pre-Timed controls**

The Pre-Timed control, which has fixed cycle lengths and preset phase intervals, operates according to a predetermined schedule. The Pre-timed controllers are best suited for locations with predictable volumes and traffic patterns such as downtown areas. Timing plans are usually selected on a time-of-day-of-week basis using time clocks. Although Pre-Timed controllers have a degree of flexibility in different timing plan, they can cause excessive delay to vehicles where there exists a high degree of variability in the traffic flows because the pre-timed control does not recognize or accommodate short-term fluctuations in traffic demand and uses timing plans determined from historical demands. Pre-Timed signals assign the right of way to different traffic streams by a preset timing plan. The Webster method is used to determine the optimum cycle lengths. Since the actuated signals act as a fixed signal when all approaches are saturated, this method can be used to compute the cycle lengths and the green times for actuated traffic signals when the actuated controller operates as a Pre-timed signal [8].

2. Actuated controls

An actuated signal operates with variable vehicular timing and phasing intervals that depend on traffic volumes. The signals are actuated by vehicular detectors placed on the roadways. The cycle lengths and green times of actuated control may vary from cycle to cycle in response to demands. Actuated controllers include semi-actuated, fully actuated, and density controllers [8].

2.1.2.1 Geometric features of Signalized Intersections

The capacity of the urban street is related primarily to the signal timing and the geometric characteristics of the facility as well as to the composition of the traffic on the facility. Geometrics is a fixed characteristic of the facility. Thus, while traffic composition may vary somewhat over time, the capacity of a facility is a stable value that can be significantly improved only by initiating geometric improvements [7].

At the signalized intersection, the additional element of time allocation is introduced into the concept of capacity. A traffic signal primarily allocation is introduced into the concept of capacity. A traffic signal essentially allocates time among conflicting traffic movements that seek to use the same space. The way in which time is allocated significantly affects the operation and the capacity of the intersection and its approaches [7].

A preference for traffic signals can be because of them:

- Allow all traffic movements to get a turn in a signal cycle. This results in the form of control that is more predictable to us, often reducing stress on the user.
- Give pedestrians particular priority.
- Allow specific priority to public transport vehicles.

- Allow the use of longer delays for particular movements to discourage these specific changes [9].

2.1.2.2 Traffic Operations Elements

Signalized intersection operations are a function of three elements described in the following sections along with a discussion on their effect on operations.

- Traffic volume characteristics.
- Roadway geometry.
- Signal timing.

2.1.2.2.1 Traffic Volume Characteristics

Vehicle volume is a number of vehicles traversing the segment that is associated the travel time. Person volume is the number of pedestrian traversing the segment being studied. The person volume can be collected for each travel mode or estimated using average vehicle occupancy rates for the type of vehicle [10].

The traffic characteristics used in an analysis can play a critical role in determining intersection treatments. Over conservative judgment may result in economic inefficiencies due to the construction of unnecessary treatments, while the failure to account for certain conditions (such as a peak recreational season) may result in facilities that are inadequate and experience failing conditions during certain periods of the year.

An essential element of developing an appropriate traffic profile is distinguishing between traffic demand and traffic volume. For an intersection, traffic demand represents the arrival pattern of vehicles, while traffic volume is measured based on vehicles' departure rate [11].

2.1.2.2.2 Intersection Geometry

The geometric features of an intersection influence the service volume or amount of traffic an intersection can process. A key measure used to establish the supply of an intersection is saturation flow, which is similar to capacity in that it represents the number of vehicles that traverse a point per hour; however, saturation flow is reported assuming the traffic signal is green the entire hour. By knowing the saturation flow and signal timing for an intersection, one can calculate the capacity (capacity = saturation flow times the ratio of green time to cycle length).

Saturation headway is determined by measuring the average time headway between vehicles that discharge from a standing queue at the start of green, beginning with the fourth vehicle. Saturation headway is expressed in time (seconds) per vehicle [11].

2.1.2.2.3 Signal Timing

Signal timing is very important in the efficient and safe movement of traffic. If justified and properly timed, signals increase the traffic handling capacity of an intersection, and when installed under certain conditions, reduce certain type of accidents, interrupt extremely heavy flows to permit the crossing of minor movements that could not otherwise move safely through an intersection and improve the safety and efficiency of both pedestrian and vehicular traffic. If signal timing and installation is not justified, they increase the overall travel times, queuing and delays by adding stops to the through traffic [11].The signal timing of an intersection also plays an important role in its operational performance. Key factors include:

- **Effective green time**. Effective green time represents the amount of usable time available to serve vehicular movements during a phase of a cycle. It is equal to the

displayed green time minus startup loss time plus end gain. The effective green time for each phase is determined based on the proportion of volume in the critical lane for that phase relative to the total critical volume of the intersection.

- **Clearance interval.** The clearance interval represents the amount of time needed for vehicles to safely clear the intersection and includes the yellow change and red clearance intervals. The capacity effect of the clearance interval is dependent upon the loss time.
- **Loss time.** Loss time represents the unused portion of a vehicle phase. Loss time occurs twice during a phase: at the beginning when vehicles are accelerating from a stopped position and at the end when vehicles decelerate in anticipation of the red indication. Longer loss times reduce the amount of effective green time available and thus lessen the capacity of the intersection.
- **Cycle length**. Cycle length determines how frequently during the hour each movement is served. It is either a direct input, in the case of pre-timed or coordinated signal systems running a typical cycle length, or an output of vehicle actuation, minimum, and maximum green settings, and clearance intervals.
- **Progression**. Progression is the movement of vehicle platoons from one signalized intersection to the next. A well-progressed or well-coordinated system moves platoons of vehicles so that they arrive during the green phase of the downstream intersection. When this occurs, fewer vehicles arrive on red, and vehicle delay and queues are minimized [11].

2.1.3 Standard Operational Measures

Standard operational measures of intersection performance are compute for the locations operating under roundabout (before) and the compared with values estimated for the same

intersection operating with signalized control (after). These operational measures included average vehicle delay, capacity, and degree of saturation and queue length.

2.1.3.1 Queue length

Queue length reflects how far traffic backs up as a result of traffic control (e.g., a queue from a traffic signal) or a vehicle stopped in the travel lane while waiting to make a turn. Queuing is both an important operational measure and design consideration-queues that are longer than the available storage length can create several types of operational problems. A through-lane queue that extends past the entrance to a turn lane blocks access to the turn lane, keeping it from beginning used effectively. Similarly, a turn-lane queue overflow into a through lane interferes with the movement of through vehicles. Queues that extend upstream from an intersection can block access into and out of driveways and –in a worst case-can spill back into and block upstream intersections, causing side streets to begin to queue back [8].

SIDRA gives a percentile queue length in the output. This is defined as: "A percentile queue length is a value below which the specified percentage of the average queue values observed for individual cycles fall." [12]. The SIDRA software uses the 95^{th} percentile value as a default value for queues, and initially, the analysis was performed using this 95^{th} percentile value.

2.1.3.2 Capacity and Degree of saturation

Capacity is the maximum sustainable flow rate that can be archived during a specified period under given (prevailing) road, traffic and control conditions [5]. The proviso "prevailing conditions" is important since capacity is not a constant value, but varies as a function of traffic flow levels. Capacity represents the service rate (queue clearance rate) in the performance (delay, queue length, stop rate) functions, and therefore is relevant to

both undersaturated and oversaturated conditions. Conceptually, this is different from the maximum volume that the intersection can handle which is the practical capacity (based on the target degree of saturation) under increased demand volumes, not the capacity under prevailing condition [6].

The degree of saturation is the ratio of the demand for the intersection entry to the capacity of the entry. A v/c ration less than 0.85 indicate that adequate capacity is available and vehicles are not expected to experience significant queues and delays. As the v/c ratio approaches 1.0, traffic flow may become unstable, and delay and queuing conditions may occur. Once the demand exceeds the capacity (a v/c ratio greater than 1.0), traffic flow is the unstable and excessive delay and queuing is expected [5].

2.1.3.3 Delay

Delay is the additional travel time experienced by a vehicle or pedestrian concerning a base travel time (e.g., free-flow travel time). The delay to a vehicle which decelerates from the approach cruise speed to a full stop (due to a reason such as a red signal, a queue ahead, or lack of an acceptable gap),waits and then accelerates to the exit cruise speed is considered to include the delay due to a deceleration from the approach cruise speed down to an approach negotiation speed and then due to zero speed, idling time, acceleration to an exit negotiation speed along the negotiation distance, travelling the rest of the negotiation distance(if any) at the constant exit negotiation speed, and the acceleration to the exit cruise speed. This delay is the intersection control delay (overall delay with geometric delay) [12].

2.1.3.3.1 Types of delay at signalized intersection

In analytical models for predicting delay, there are three distinct components of delay. These are uniform, random and overflow delays.

1. **Uniform delay**

Uniform delay is the delay based on an assumption of uniform arrivals and stable flow with no individual cycle failures. No signal cycle fails here, i.e., no vehicles are forced to wait for more than one green phase to be discharged. During every green phase, the departure function catches up with the arrival service. Total aggregate delay during this period is the total of all the triangular areas between the arrival and departure curves. This type of delay is known as uniform delay [13].

2. **Random delay**

Random delay is the additional delay, above and beyond uniform delay, because flow is randomly distributed rather than uniform at isolated intersections.at the end of the second and third green intervals, some vehicles are not served (i.e., they must wait for a second green interval to depart the intersection).by the time the entire period ends, however, the departure function has caught up with the arrival service, and there is no residual queue left unserved. This case represents a situation in which the overall period of analysis is stable (i.e., total demand does not exceed total capacity) [13].

3. **Overflow delay**

Overflow delay is the additional delay that occurs when the capacity of an individual phase or series of phases is less than the demand or arrival flow rate. The worst possible case, every green interval fails for a significant period of time, and the residual, unserved, queue of vehicles continues to grow throughout the analysis period [13].

2.1.3.3.2 Delay model

1. HCM delay model for signalized intersection

The delay model incorporated into the HCM 2000 includes the uniform delay model, aversion of Akcelik's overflow delay model

$$d=d_1*(PF)+d_2+d_3 \quad (2\text{-}3)$$

$$PF=((1-P)*f_{pa})/(1-(g/C)) \quad (2\text{-}4)$$

$$d_1=(0.5C(1-(g/C))^2)/(1-\min(1, X)(g/C)) \quad (2\text{-}5)$$

$$d_2=900T[(X-1)+((X-1)^2+8klX/cT)^{1/2}] \quad (2\text{-}6)$$

$$d3=(1800Q_b(1+u)t/(cT) \quad (2\text{-}7)$$

Where, d=control delay, s/veh

d_1=uniform delay components, s/veh

PF=progression adjustment factor

d_2=overflow delay component, s/veh

d_3= delay due to pre-existing queue, s/veh

T= analysis period, h

X=v/c ratio

C=cycle length, sec

U=delay parameter

c= lane group capacity (vehicle per hour (vph))

g= duration of green interval (seconds)

$Q_{b=}$ initial queue at the start of period T (veh)

K=incremental delay factor for actuated controller settings; 0.50 for all pre-timed controllers

L=upstream filtering/ metering adjustment factor; 1.0 for all individual intersection analyses

2. HCM delay models for roundabout

For roundabouts, delays can be predicted in the manner similar to that for stop-controlled and signal-controlled intersections. Equation (2-8) shown that should be used to estimate control delay for each lane of an approach to a roundabout.

$$d= 3600/c + 900\ T[X-1 + ((X-1)^2 + ((3600/c)\ X)/450T)\ 1/2] \quad (2\text{-}8)$$

Where:

d= control delay, sec/veh:

X=v/c ratio

C=capacity of subject lane, veh/h; and

T=time period, h (T=1 for 1-hr analysis, T=0.25 for 15-min analysis).

The HCM delay models do not include geometric delay although HCM qualifies delay equations control delay. SIDRA INTERSECTION standard delay models include geometric delay as an explicit additional term. SIDRA INTERSECTION output includes geometric delay estimated using the SIDRA standard methods for all types of the intersection even when the HCM Delay formula Option is selected. These geometric delays are not added to delay values obtained using the HCM delay equations when the delay formula option is used [12].

2.1.4 Level of Service (LOS)

In highway capacity manual (HCM) 2010, level of service (LOS) is defined as "a quality measure describing operational conditions within a traffic stream, generally regarding such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience."

The level of service at any intersection on a highway has a significant effect on the overall operating performance of that highway. Thus, improvement of the level of service

at each intersection usually results in an improvement of the overall operating performance of the highway. An analysis procedure that provides for the determination of capacity or level of service at intersections is, therefore, an important tool for designers, operation personnel, and policy makers. Factors that affect the level of service at intersections include the flow and distribution of traffic, the geometric characteristics, and the signalization system. A major difference between considerations of level of service on highway segments and level of service at intersections is that only through flows are used in computing the levels of service at highway segments, whereas turning flows are significant when computing the levels of service at signalized intersections [3]**.**

There are six levels of service, level A to level F based on the mentioned measure of effectiveness. Level of service A represents the zone of free flow. Here the traffic volume will be less; traffic will be experiencing free flow. Level of service B represents the zone of reasonably free-flow; free-flow speeds are still maintained at this level of service. The driver's freedom to choose their desired speed is only slightly restricted. At a level of service C, the presence of other vehicles begins to restrict the maneuverability within the traffic stream. At a level of service D, the average speeds begin to decline with increasing flows. Freedom to maneuver within the traffic stream is noticeably restricted. Level of service E defines operation at capacity. At this level, the stream reaches its maximum density limit. Finally, Level of service F describes conditions in a queue that has formed behind a point of breakdown or disruption [7].

Table 2.3: Typical intersection Level of Service (LOS) rating (Source: HCM 2010)

Level of Service (LOS)	Delay at signalized intersection	Delay at un-signalized intersection	Level of Service For v/c>1.0
A	<= 10 sec	<= 10 sec	F
B	10-20 sec	10-15sec	F
C	20-35 sec	15-25 sec	F
D	35-55 sec	25-35 sec	F
E	55-80 sec	35-50 sec	F
F	>= 80 sec	>= 50 sec	F

2.1.5 Traffic composition

Traffic composition needs to be considered when determining capacities for both roundabout and signalized intersections. The increase of heavy vehicles will reduce the capacities of the intersection due to their slow follow-up headways and increased size. Passenger car equivalents allow heavy vehicles to resemble a standard passenger vehicle to better represent the capacity of an intersection [14].

The transport Research Board HCM suggests that the conversion factors for passenger car equivalents shown in Table 2.4 be used.

Table 2.4: Conversion factors for passenger car equivalents (Pce) [7]

Vehicle type	Car and taxi	4WD	Minibus	Medium bus	Standard bus	Medium truck	Large truck
PCU factor	1	1	1.5	1.5	3	3	3

Car and taxi, 4WD, Minibus and Medium bus are considered as light vehicles and Standard bus, Medium truck and large truck are grouped under heavy vehicles in applying SIDRA INTERSECTION software. The volume of light vehicles and heavy vehicles is entered separately in volume dialogue box.

CHAPTER THREE

RESEARCH METHODOLOGY

The methods employed for a research work was the critical aspect for ensuring the proper result which aligns with the objective of the research. Hence, this part of the thesis discusses the methodology followed and the reason for the selection of the methods to address the research problem stated earlier.

3.1 Description of Study Area

The study area selected for this research was Addis Ababa city which is the capital City of Ethiopia, which is located in the horn of Africa with geographical coordinates of $9^{o}1'48''$ North and $38^{o}44'24''$ East and with an average elevation of 2355m above sea level. The City has a total area of about 530.14 square kilometers and a population of 2,738, 248 according to 2007 census. The City is divided into ten administrative sub cities and 99 Kebeles, and it is the most important business and commercial center of the country, it is the highly populated town in the country [15].

As it lies in the central part of the country, in addition to serving as a capital, there is a higher concentration of human and vehicle populations leading to road traffic congestion. Most of the economic and social developments in the country manifested at this capital city and hence all the benefits and aftermath of such economic and population growth affect Addis Ababa. One of the undesirable effects of such growth in the city is traffic congestion. To study traffic congestion in Ethiopia, there is no a best place like Addis Ababa due to many factors.

To compare the operational performance of Roundabout and Signalized intersections in Addis Ababa, Gergi-Imperial intersection, but in 2017 the intersection is converted to a

signalized intersection (it will be analyzed before and after), and Ayer-Tena intersection is selected.

Table 3.1: Selected study Junctions

No.	Intersection Name	No. of approaches	Location
1	Gergi-Imperial	4	On Eastern Ring road
2	Ayer-Tena	4	Along South-West of Addis Ababa

3.1.1 Description of the Roundabout

Ayer-Tena Roundabout is one of most congested roundabout found on the major highway. It is Roundabout with four legs namely, Torhailoch approach in the East, Jomo approach in the South, Alembank approach in the North and Alemgena approach in the West approach and having a central island diameter of 55m. The geometric features of the roundabout junction are summarized as shown in Table 3.5. Plan view of the Roundabout is shown in Figure 3.1.

Figure 3.1: Satellite image of Ayer-Tena Roundabout

3.1.2 Description of the Signalized Intersection

The Imperial roundabout was converted to Signalized intersection in 2017. It is signalized intersection with four legs namely, Megenagna approach in the North, Bola approach in the South, Hayahulet approach in the West and Gerji approach in the East. This junction is the link between ring road and a collector road; mostly these heavy vehicles travel along the ring road. Plan view of the before is shown in Figure 3.2.

Figure 3.2: Satellite image of Imperial Roundabout (Before improvement)

3.2 Research design

To answer the specific objective of investigation quantitative data and analysis using SIDRA INTERSECTION software version 5.1 model has been applied in the study. The Software can be divided into two types: Macroscopic and Microscopic Models. The Macroscopic Models use traffic volume flows to model intersections as isolated locations. On the other hand, the Microscopic Models simulate the movement of individual vehicles thereby allowing a network-wide analyzes. For this study, one of the macroscopic models

(SIDRA) software program was applied to analyze traffic operations at roundabouts and signalized intersections. The level of service (LOS) and performance of roundabout and signalized intersection have been compared by using Sidra intersection software.

To compare the operational performance of Ayer-Tena intersection after the introduction of new signalized intersection (hypothetical) with the existing Roundabout. Additionally, compares the four-leg intersection of Gergi-Imperial that was converted in 2017 to a signalized intersection to its previous status as a Roundabout. Primary data collected at two selected junctions with the existing intersection. Traffic data was collected, and geometric elements of the study junctions were measured and also obtained from AACRA.

The primary measure of effectiveness used to measure the performance of introducing signalized intersection into existing Roundabout in this research is the average vehicular delay associated with the Level of Service using SIDRA INTERSECTION software version 5.1. One intersection from converted into signalized and one intersection from existing roundabout are selected. These are Imperial signalized and Ayer-Tena Roundabout intersection.

The capacity of each was analyzed as "before" and "after" the introduction of signalized intersection under the same geometric condition and present traffic volume in the intersection. Ayer-Tena intersection "after" is by converting the roundabout with a hypothetical alternative signalized intersection. The research design is as described in the diagram below:

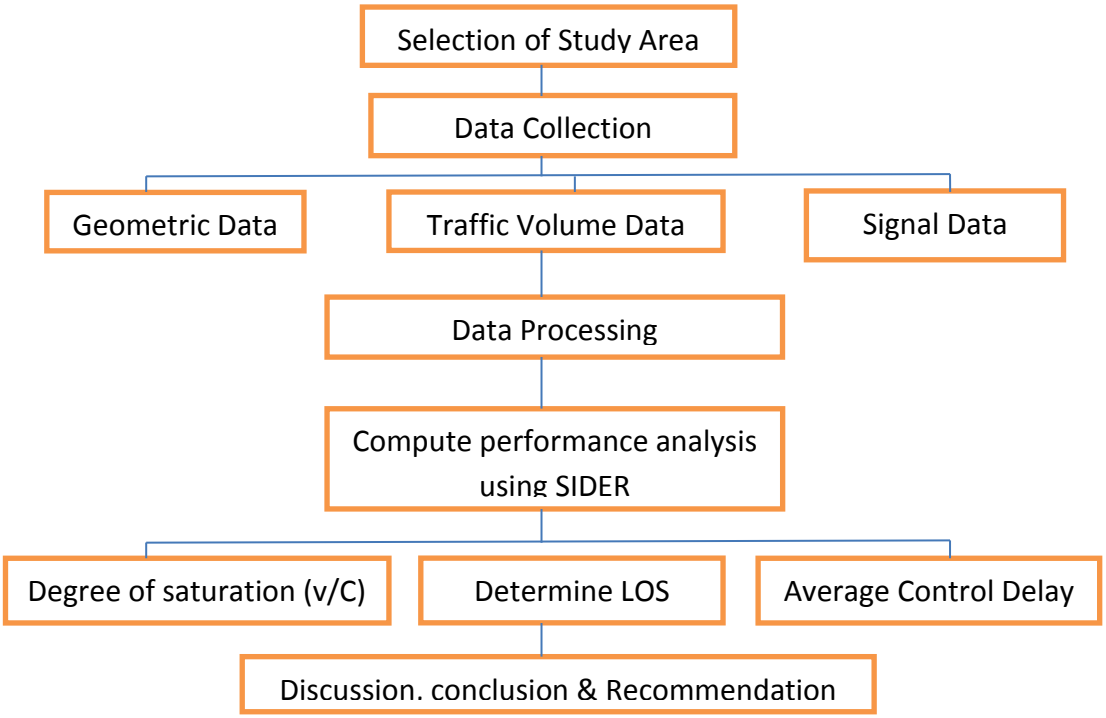


Figure 3.3: Flow chart showing general outline of the study

3.3 Study Variables

3.3.1 Dependent Variable

- Comparison of Operational Performance of Roundabout and Signalized intersection

3.3.2 Independent Variables

- Directional traffic volume
- Types of vehicles
- Number of lanes
- Layout of road
- Grades of each approach
- Signal data

3.4 Data collection

To achieve the objectives of the research, this section of the study discusses how data was sampled, collected and extracted from the data source and also presented the gathered primary and secondary data by systematically organizing and summarizing using standard formats.

3.4.1 Traffic Volume Data

Volume counts for this research are used video recording with manual transcription at the selected intersections.

The data collected was done only for three days. Those days have been selected by the researcher observation of traffic flow of days of the week and information collected from traffic police that working on Ayer-Tena Roundabout and Gergi-Imperial Signalized Intersection.

According to observation and information from traffic policies Monday, Wednesday, and Friday have the highest volume of traffic. Therefore the researcher chose those days for the road traffic volume data collection. After collecting the data traffic volume count was done and the Friday daily traffic volume was found to be higher volume than Monday and Wednesday daily traffic volume. Therefore, the researcher took Friday traffic volume count for the analysis purpose.

Hence, acquiring a traffic volume data for before convert of the Imperial Intersection daily traffic volume data was available at the Addis Ababa City Transport Program Management Office which was collected for their purpose.

The traffic volume count was made for 12 hours starting the morning 7:00 AM to the evening 7:00 PM at 15 minutes interval. The vehicles were counted in a category as cars

and taxi, 4WD, minibus taxi, Mid-bus and standard Bus, Medium and Heavy truck vehicles. The total daily traffic volume for each approach is summarized in the Table 3.2 for Monday, Wednesday, and Friday traffic volume count. The raw data of traffic volume for each approach is summarized in Appendix-A.

The vehicle volume count should be converted to passenger's equivalent unit to conduct an analysis. Therefore, the passenger's equivalent factor was used to convert the number of heavy vehicles to passenger car equivalent as indicated in Table 2.4.

Table 3.2: Total daily Traffic Volume count for all approaches

Gergi-Imperial Signalized Intersection(after)					
	Date	Bole Approach	Megenagna Approach	Gergi Approach	Hayahulet Approach
Total	Monday (17/07/2017)	13,353	14,879	7,078	6,720
	Wednesday (19/07/2017)	12,584	14,381	7,161	6,473
	Friday (21/07/2017)	15,402	17,055	8,027	7,701
Gergi-Imperial Roundabout (before) Source :(Addis Ababa City Transport Program Management Office)					
	Date	Bole Approach	Megenagna Approach	Gergi Approach	Hayahulet Approach
Total	Wednesday (25/01/2017)	14,364	18,564	8,439	7,051
Ayer-Tena Roundabout					
	Date	Alemgena Approach	Alembank Approach	Torhailoch Approach	Jomo Approach
Total	Monday (05/06/2017)	10,151	8,903	10,173	5,395
	Wednesday (07/06/2017)	9,612	8,518	9,640	5,082
	Friday (09/06/2017)	11,210	10,468	11,921	6,036

Table 3.3: Vehicles and pedestrians volume at intersections at peak hour

No	Junction Name	Heavy Vehicles			Light Vehicles	Total No. of Vehicles	Total Traffic (PCU)	% of Heavy Vehicles	Number of pedestrians
		Bus and Medium Truck	Long Truck	Total					
1	Imparial (before)	292	8	300	4451	4751	5351	6.72	1811

2	Imparial (after)	268	15	283	4491	4774	5322	5.955	2647
3	Ayer-Tena	345	13	358	4313	4671	5387	7.66	6450

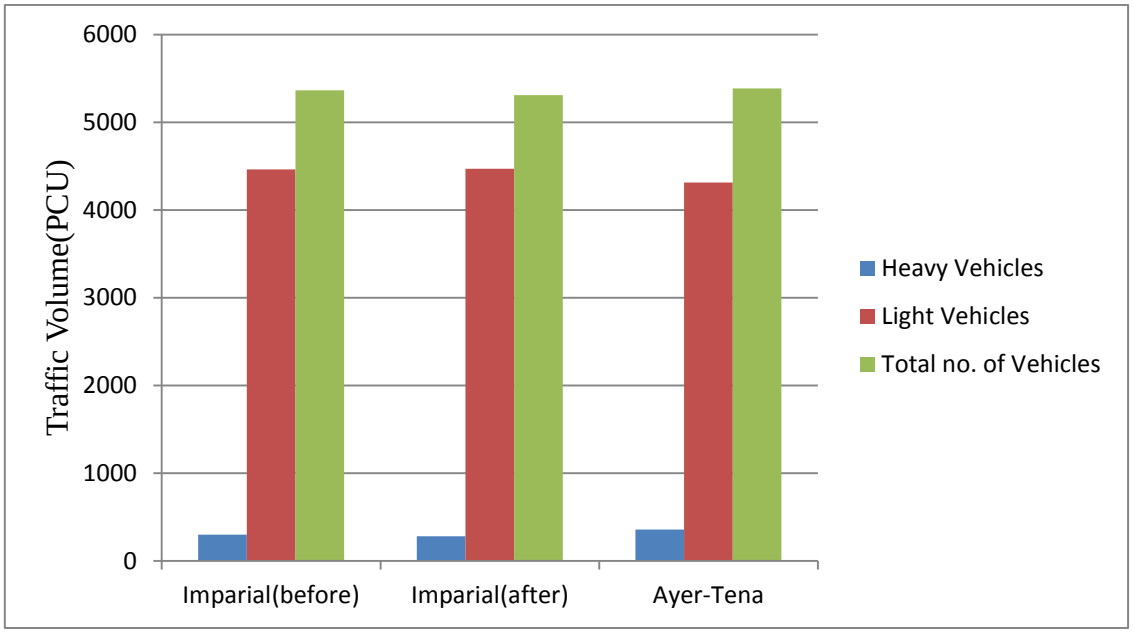


Figure 3.4: Maximum Peak Hour Vehicle Volumes Distribution at Intersections

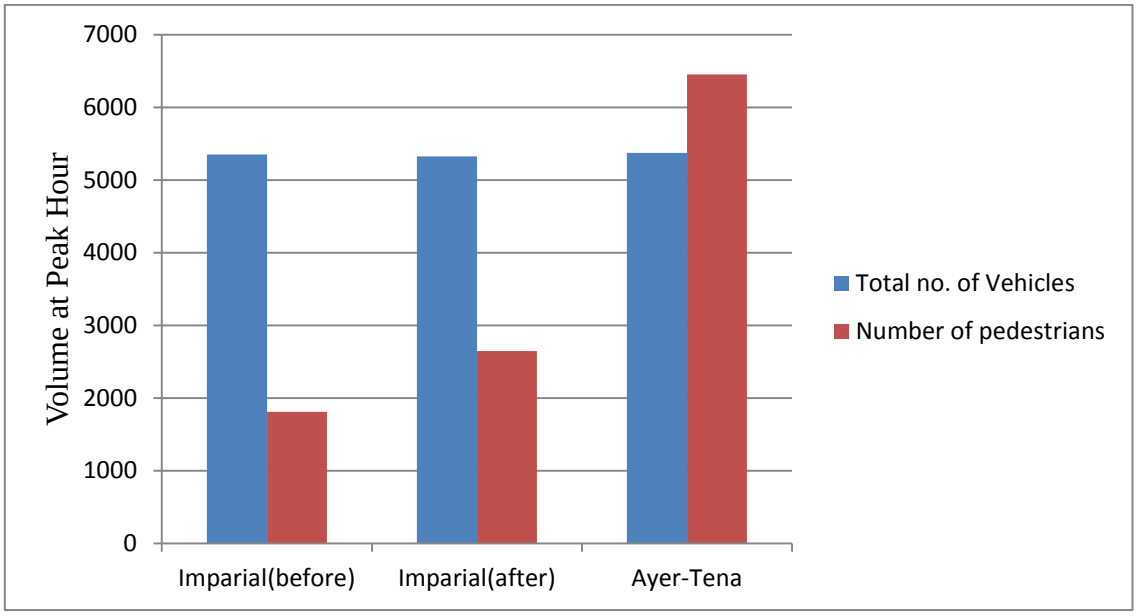


Figure 3.5: Maximum Peak Hour Vehicle Volumes vs. Pedestrian Numbers at Junctions

Figure 3.4 and Figure 3.5 show that highest and lowest numbers of vehicle and pedestrian traffic at the junction. The maximum number of vehicles and pedestrians traffic exists at Ayer-Tena that is located at the major road corridor and residential part of Addis Ababa.

The percentages of heavy vehicles at imperial roundabout (before), imperial signalized (after) and Ayer-Tena roundabouts have 6.72%, 5.95% and 7.66% of heavy vehicles respectively, out of the total number of vehicles counted at those junctions. These junctions are a link between ring road and a collector road; mostly, heavy vehicles travel along the ring road.

Table 3.4: Entry Peak Hour Traffic Flow and Percentage Share on Each Leg

No	Junction Name	Approach Leg	Entry Traffic on Leg(PCU) (veh/hr)	% of Traffic-share
1	Imperial(before)	Bole	1524	28.47
		Megenagna	2255	42.13
		Gergi	956	17.86
		Hayahulet	617	11.53
2	Imperial(after)	Bole	1719	32.32
		Megenagna	2027	38.12
		Gergi	966	18.16
		Hayahulet	606	11.39
3	Ayer-Tena	Alemgena	1822	33.83
		Alembank	1710	31.75
		Torhailoch	1275	26.67
		Jomo	579	10.75

From Table 3.4, it is observed that there is unbalanced traffic flow at approaches at Gergi-Imperial and Ayer-Tena roundabouts.

3.4.2 Geometric Data

As per the requirement of the SIDRA Intersection Version 5.1, the collected geometric data include; island diameter, circulatory width, number of circulatory lanes, entry lane number and average lane width at entry for roundabout junction; and number of lanes, lane width, configurations of lanes, width of median for signalized junction. These data are measured with a tape meter and also obtained from AACRA. The collected geometric data are summarized as shown in Table 3.5. The geometry features of considered junctions are also shown in Appendix-B

Table 3.5: Summary of Roundabouts Geometry Data

No.	Junction Name	Approach Leg	Entry Lane	Number of Circulatory lane	Island Diameter(m)	Average lane width(m)	Circulatory Road width(m)
1	Imperial (before converted)	Bole	3	2	21	3.7	12
		Megenagna	3	2	21	3.7	12
		Gergi	2	2	21	3.8	12
		Hayahulet	2	2	21	3.8	12
2	Ayer-Tena (before)	Alemgena	2	3	55	3.8	13
		Alembank	2	3	55	3.8	13
		Jomo	3	3	55	3.5	13
		Torhailoch	3	3	55	3.5	13

From the summarized geometric data Table 3.5 we can see that the island diameter of the roundabouts was 21m and 55m. When we add their circulatory width, the range becomes 45m to 91m, which can be categorized from mini–roundabouts to urban multilane urban Double-lane roundabouts [8]. As shown in Table 3.6 the geometric data for the Ayer-Tena signalized intersection to use the existing layout.

Table 3.6: Summary of Signalized Intersection Geometry Data

No	Junction Name	Approach name	No. of Entry Lane	No. of Exit Lane	Average Lane Width(m)	Median width(m)
1	Imperial(after converted)	Bole	3	3	3.7	0.68
		Megenagna	3	3	3.7	0.68
		Gergi	2	2	3.8	NA
		Hayahulet	3	3	3.5	1.2
2	Ayer-Tena (after)	Alemgena	2	2	3.8	NA
		Alembank	2	3	3.8	10
		Jomo	3	3	3.5	0.68
		Torhailoch	3	3	3.5	0.68

3.5 Analysis Software

The software used for data analysis is SIDRA Intersection Version 5.1. The Australian Road Research Board (ARRB), Transport Research Ltd., developed the SIDRA package as an aid for design and evaluation of intersections such as signalized intersections, roundabouts, two-way stop control, and yield-sign control intersections.

The input data for the analysis of the level of service using SIDRA intersection software are as follows: field measures like a number of lane, lane width, circulating lane, circulating width, island diameter has been measured. Directional hourly traffic flow data, heavy vehicle percentage, number of pedestrians were also collected. The SIDRA software analyzed the data, and the output provides measures of effectiveness from which the performance of the roadway can be determined.

Measures of effectiveness given by SIDRA output only four measures of effectiveness used in this study to evaluate performance are:

- Average Delay
- Degree of saturation
- Capacity
- Level of service

To analyze the LOS using the software, input data was made with options right-hand driving rule and HCM 2010 Metric version which represents the driving rule of Ethiopia.

The software program was applied to analyze and design traffic operations at Roundabouts and Signalized intersections. In fact, AACRA also recommends SIDER Intersection software for capacity analysis.

However, default values like environmental factor 1.2 and lane utilization factors 100 have been used as input data for the analysis.

The environmental factor can be seen as a collection factor that includes everything from the junction environment regarding design type, visibility, Size of the light and heavy vehicles, operating speeds, pedestrians, heavy vehicle activity and parking near the junction.

Lane Utilization factor is a saturation flow adjustment factor for modeling unequal lane utilization at entry.

According to Addis Ababa City Roads Geometric Manual (2003), the design approaching speed limit for arterial roads is between 40 and 60 km/hr. For this study intersection approach and exit cruise speed of 30 km/hr is therefore taken for the purpose of analysis.

3.5.1 Approach and Exit grades

Elevation data has been collected and fixing the length of the segment at each approach to determine the approach and exit grades. The raw data of Elevation for each approach is summarized in Appendix-C.

$$\text{Grade} = \frac{\Delta V}{\Delta H} * 100\% \qquad (3\text{-}1)$$

Where: ΔV= Change in elevation

ΔH= Change in distance

Table 3.7: Approach and Exit grades values for Gergi-Imperial and Ayer-Tena Intersection

Name of Intersection	Name of Approaches	Approaches grades values (%)	Exit grades values (%)
Gergi-Imperial	Bole	+2.74	-2.74
	Megenagna	+1.52	-1.52
	Gergi	-4.57	+4.42
	Hayahulet	+2.13	-2.24
Ayer-Tena	Alemgena	+1.22	-1.22
	Alembank	-2.44	+2.33
	Torhailoch	+0.61	-0.91
	Jomo	+4.27	-4.37

3.5.2 Basic Saturation Flow Rate

Saturation flow rate could be defined as the flow rate per lane at which vehicles can pass through a signalized intersection. A saturation flow rate at intersection and recommendable values ranges in between 1500 and 2000 pc/h/lane with the corresponding headway of 2.4 and 1.9 seconds. The research work used the following saturation flow rate equation [21].

The equation used for the estimation of saturation flow rate at the study area is:

$SFR = 990 + 288TL + 8.5SL - 26.8G$ (3-2) [16]

Where:

SFR = Saturation flow rate,

TL= Number of through lanes,

SL =Speed limit,

G = Gradient in percent

The saturation flow rate and the corresponding saturation headway are tabulated in the following table 3.8 for each approach by taking 30km/h of speed limit.

Table 3.8: Saturation flow rate for Gergi-Imperial and Ayer-Tena Intersection

Name of Intersection	Name of Approaches	Gradient (%)	Number of exclusive through lanes	Speed limit (Km/h)	Saturation flow rate (pc/h/ln)	Headway(sec.) H=3600/SFR
Gergi-Imperial	Bole	+2.74	1	30	1460	2.46
	Megenagna	+1.52	1	30	1493	2.41
	Gergi	-4.57	0	30	1368	2.63
	Hayahulet	+2.13	1	30	1476	2.44
Ayer-Tena	Alemgena	+1.22	0	30	1213	2.97
	Alembank	-2.44	0	30	1311	2.74
	Torhailoch	+0.61	1	30	1517	2.37
	Jomo	+4.27	1	30	1419	2.54

CHAPTER FOUR

RESULTS AND DISCUSSION

Different types of data were collected which is relevant in comparing of the intersection, and the results are presented in the following sections with the brief explanation.

4.1 Traffic volume and Flow Pattern Analysis

4.1.1 Traffic Volume at Gergi-Imperial Intersection (before improvement)

Traffic volume data before the improvement of the Imperial Intersection traffic volume data was available at the Addis Ababa City Transport Program Management Office. The traffic count was done for 12hr starting from 7:00 AM up to 7:00 PM on each approach. Accordingly, Megenagna and Bole approaches have a high number of traffic volumes in the morning and evening period but the evening period volume is relatively less than the morning period. When we see Gerji and Hayahulat approach, it has almost uniform traffic volume distribution and low volume of traffic throughout the day. The result is summarized in Figure 4.1.

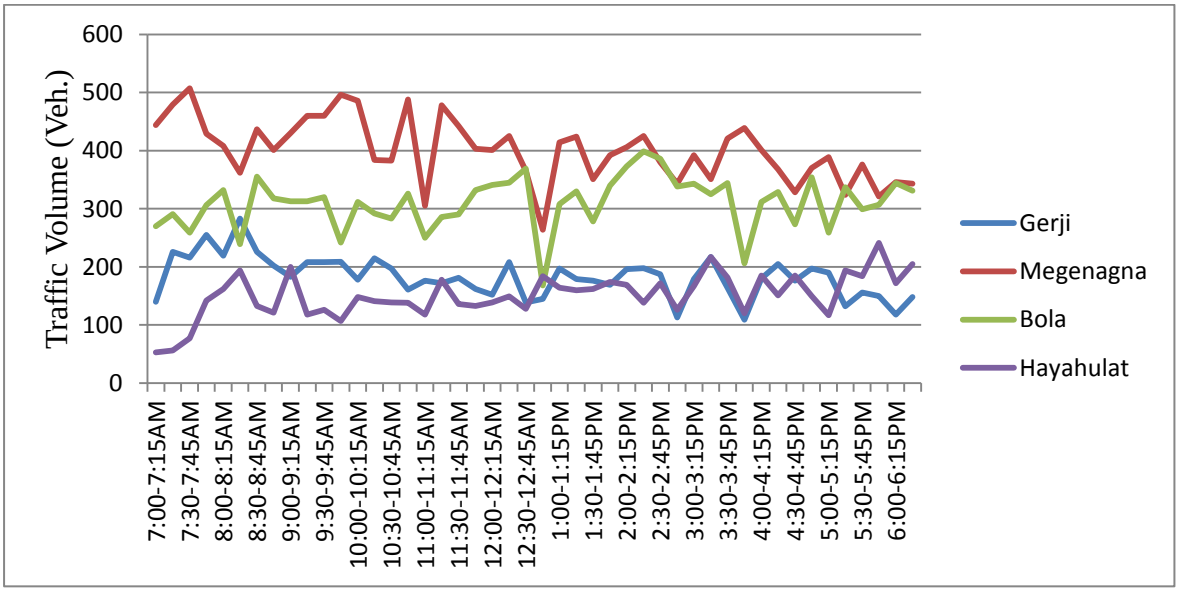


Figure 4.1: Total traffic volume distribution at Gergi-Imperial (before) Intersection

From Figure 4.1, it is observed that there is unbalanced traffic flow at approaches at Gergi-Imperial roundabout. However, it is not recommended to build roundabouts as traffic control devices when there is unbalanced traffic on the approaches [5].

4.1.1.1 Traffic Volume by Vehicle Type

When we see the total traffic volume distribution by vehicle type from the total traffic 36,256 or 74.88% is the only car, 4WD, and taxi. Minibuses and Modern truck have moderately high but commercial vehicle like std. Bus and large trucks have very low volume according to Figure 4.2.

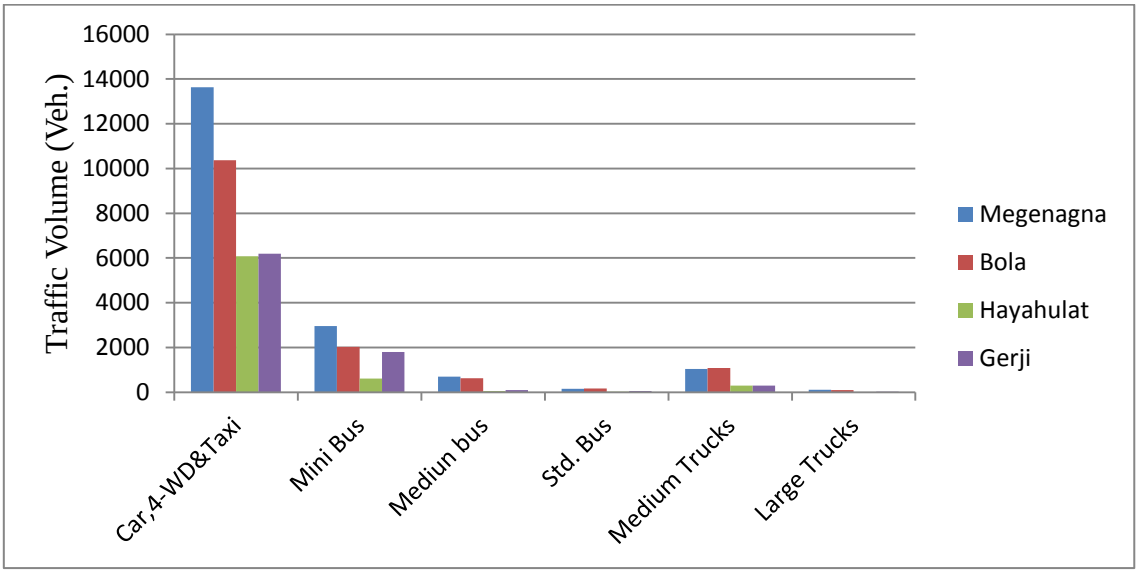


Figure 4.2: Traffic volume Distribution by Vehicle Type at Gergi-Imperial (before) Intersection

4.1.2 Traffic Volume at Gergi-Imperial Intersection (after improvement)

The traffic count was done for 12hr starting from 7:00 AM up to 7:00 PM on each approach considering all the turning movement independently.

As shown in Figure 4.3 below Megenagna approaches has high number of traffic volume in the morning and evening period but the night period volume is relatively less than the morning period. Next, to this approach, Bole approach has highest traffic volume and has

morning and evening peak period. The rest namely Hayahulat and Gerji approach have almost uniform traffic volume distribution and low volume of traffic throughout the day.

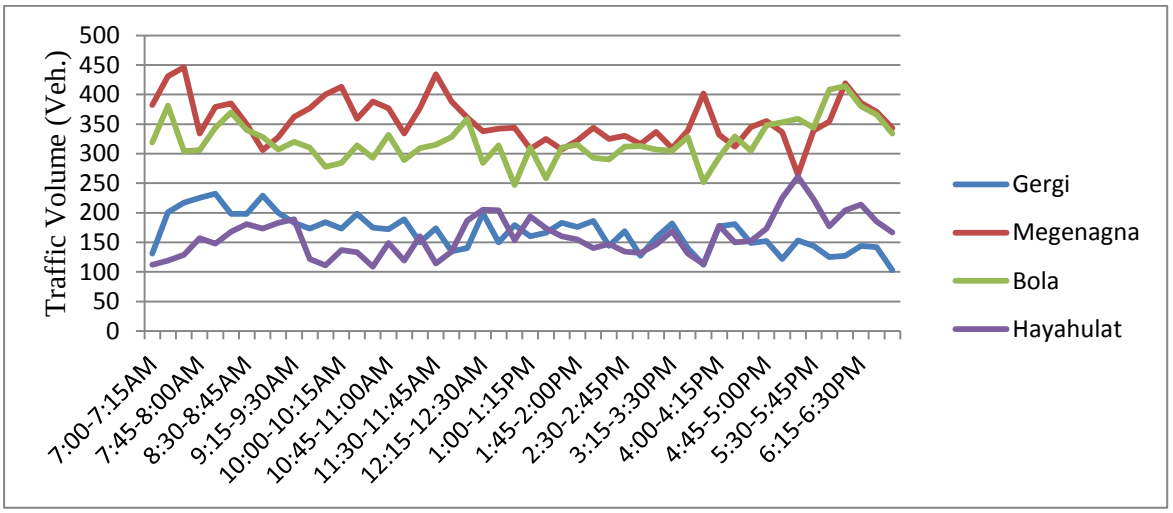


Figure 4.3: Total traffic volume distribution at Gergi-Imperial (Signalized) Intersection

4.1.1.1 Traffic Volume by Vehicle Type

When we see the total traffic volume distribution by vehicle type from the total traffic 34,948 or 72.53% is the car, 4WD, and taxi. Minibuses and Modern truck have moderately high but commercial vehicle like std. Bus and large trucks have very low volume.

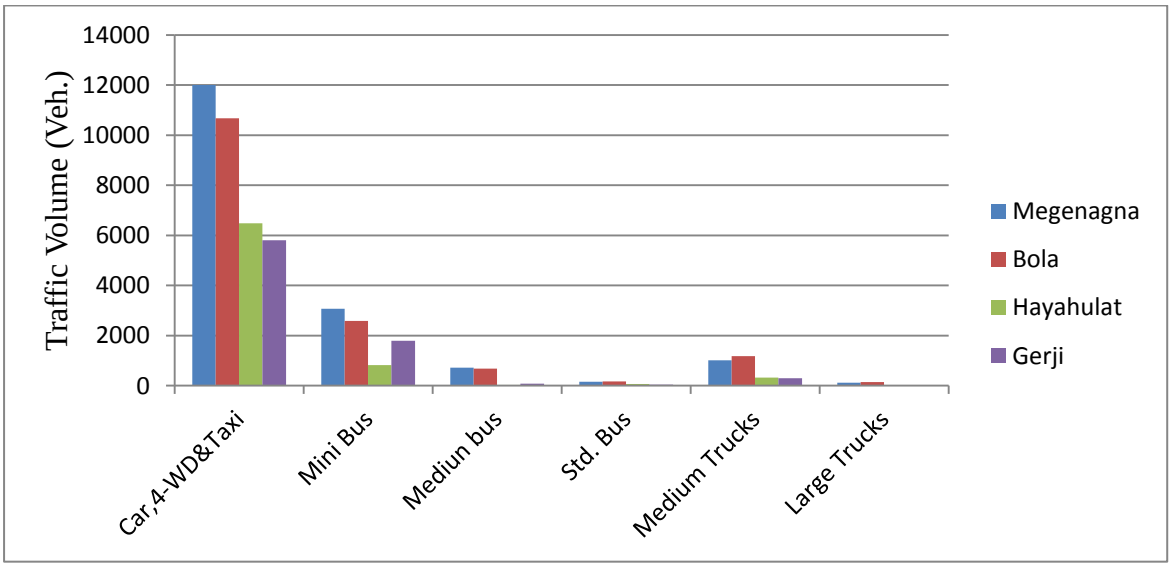


Figure 4.4: Traffic volume Distribution by Vehicle Type at Gergi-Imperial (Signalized) Intersection

4.1.3 Traffic Volume at Ayer-Tena Intersection

Ayer-Tena intersection is a roundabout intersection link between ring road and a collector road. The traffic count was performed on the four approaches for 12hr considering all the turning movement independently.

As shown in the figure below Alemgena and Alembank approach has the highest traffic volume with both morning and evening peak period. Also, the morning peak period traffic volume is found to be higher than the evening peak period due to the road section carries many commuters from residential areas of the city (Sebeta, Kenteriy, Alembank) to the commercial body district of Merkato and Mexico.

Similarly, Torhyloch approach has relatively highest traffic volume, and it has similar characteristics with Alemgena approach, but it's peak period During the evening peak hour because the commuters will back to home.

Finally, Jamo approach has low traffic volume with uniform distribution and little variation of traffic throughout the day as shown in Figure 4.5.

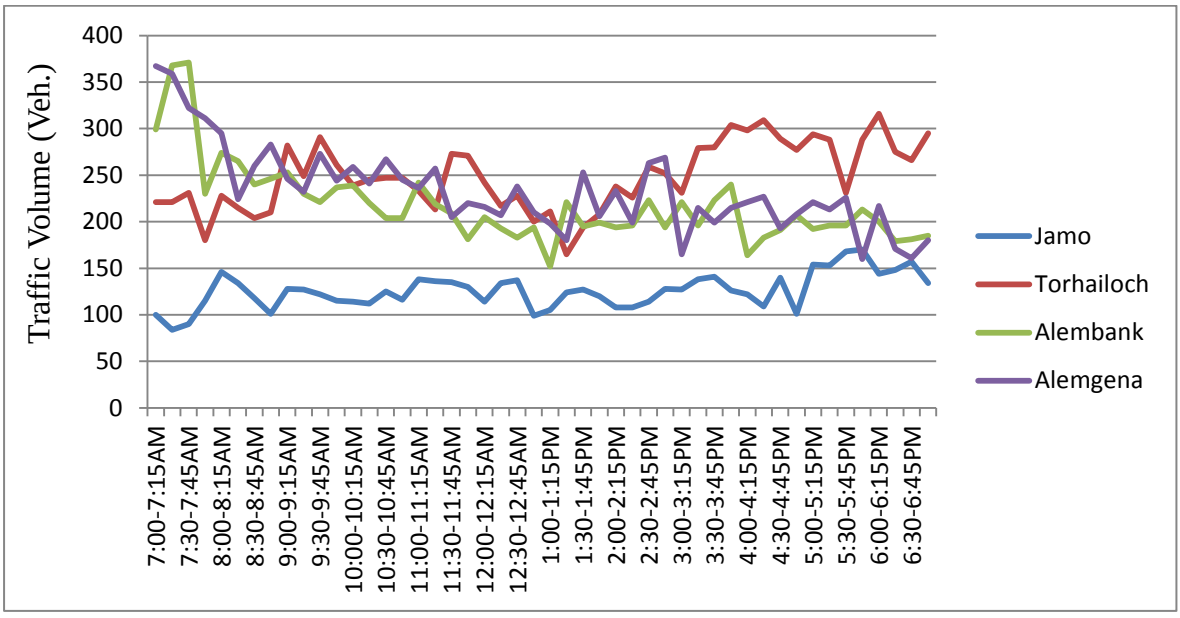


Figure 4.5: Total traffic volume distribution at Ayer-Tena Intersection

When we see the traffic composition from the total traffic of 39,635 vehicles on the four approaches out of this 14,124 vehicles, or 35.63% and 6132 vehicles or 15.47% of the total are composed of minibus and car & taxi respectively.

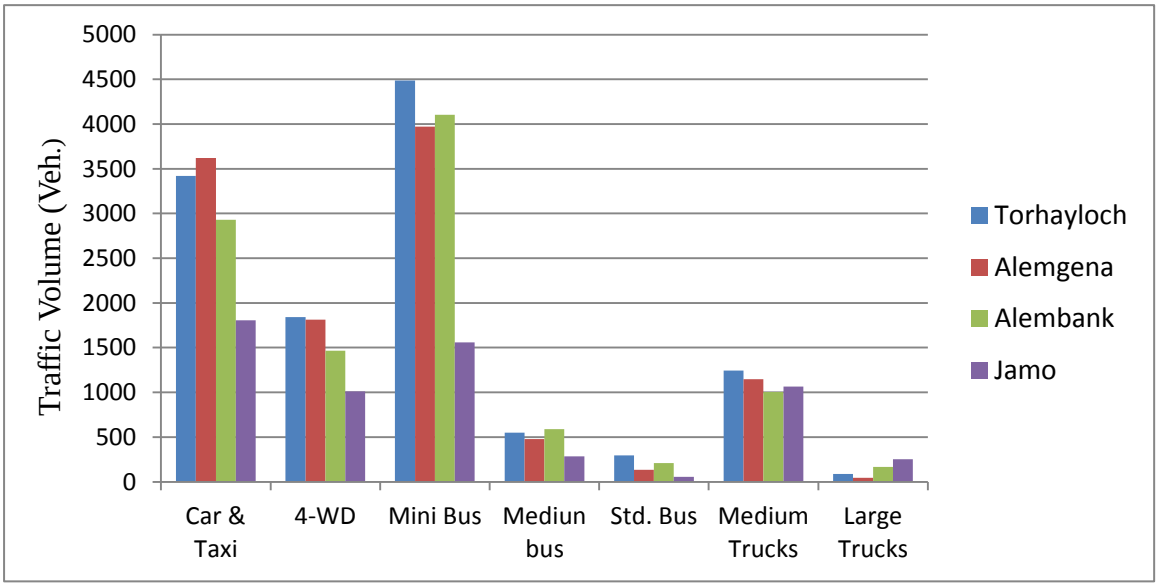


Figure 4.6: Traffic volume Distribution by Vehicle Type at Ayer-Tena Intersection

Based on the results presented in section 4.1 Traffic volume and flow pattern analysis the following points can be identified.

The traffic count was done for 12hrs starting from 7:00 AM up to 7:00 PM on each approach for all intersection considering the turning movement principle. Intersection found on the link between ring road and a collector road, mostly these heavy vehicles travel along the ring road namely Ayer-Tena and Gergi-Imperial intersection, the traffic volume distribution as per Figure 4.3 and Figure 4.5 all the approaches have morning and evening peak period except Gergi approach on Gergi-Imperial intersection and Jamo approach on Ayer-Tena intersection which shown uniform distribution with little variation throughout the day and the total number of vehicle volume at Gergi-Imperial (before), Gergi-Imperial (after) and Ayer-Tena intersection almost 75%,72% & 46% of vehicle volume is occupied by private vehicles respectively.

4.2 Intersection performance Analysis

4.2.1 Gergi-Imperial junction

4.2.1.1 Gergi-Imperial Roundabout (Before Improvement)

Input Data's for SIDRA Intersection software for the Analysis of performance

Geometric Data

1- Number of approaches or legs -4

2- Number of circulating lane – 2

3- Inscribed circle Diameter – 45m

4- Central island diameter – 21m

Table 4.1: Geometric data for Gergi-Imperial Roundabout (before improvement)

	Bole Approach	Megenagna Approach	Gergi Approach	Hayahulet Approach
Number of entry lane	3	3	2	2
Average Lane width(m)	3.7	3.7	3.8	3.8

Table 4.2: Traffic data for Gergi-Imperial Roundabout (before improvement)

Junction Name	Approach leg	Total Traffic volume(Veh/hr)			Peak Hour Factor (%)			Heavy Vehicle Factor (%)		
		TH	LT	RT	TH	LT	RT	TH	LT	RT
Imperial (before)	Bole	1405	120	217	93.2	92.1	93.5	9.65	7.65	7.97
	Megenagna	1767	419	206	92.8	93.6	94.8	7.93	3.72	4.89
	Gergi	344	443	287	96.1	94.5	96.7	3.26	5.8	3.37
	Hayahulet	283	407	202	94.5	90.3	87.1	3.71	4.44	3.31

Accordingly, the analysis and the results of the study are summarized in Figures show on 4.7, 4.8, 4.9 and 4.10 below, and the outputs of the analysis for each intersection are attached in Annex B.

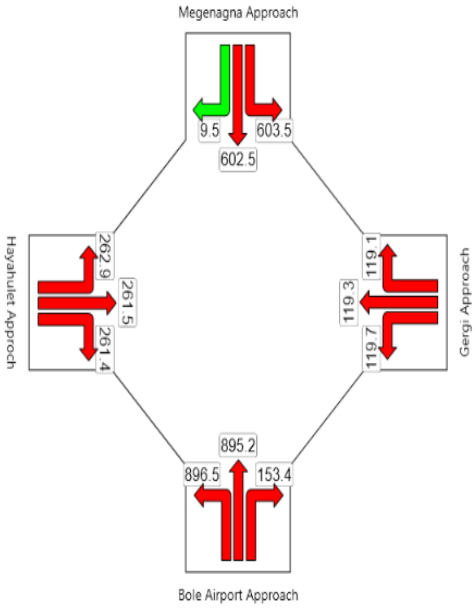


Figure 4. 7: Delay in Second at Gergi-Imperial Roundabout

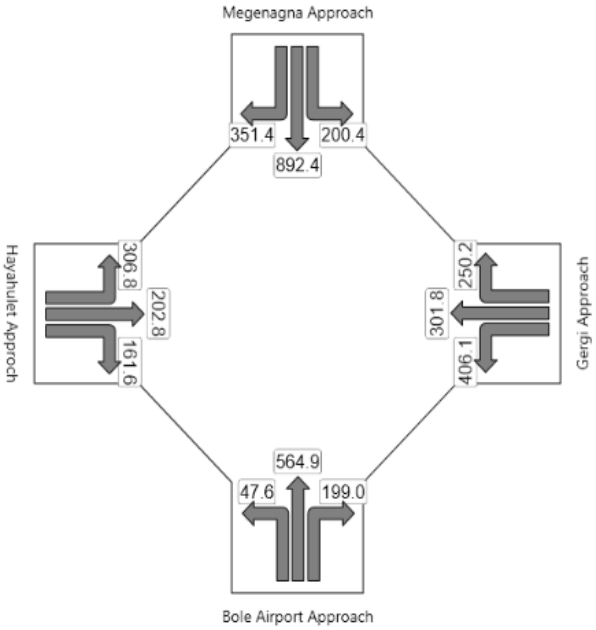


Figure 4. 8: Capacity at Gergi- Imperial Roundabout

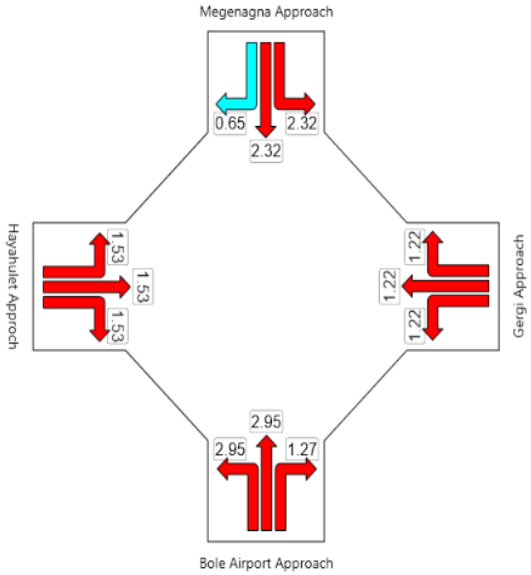


Figure 4. 9: Degree of Saturation at Gergi-Roundabout

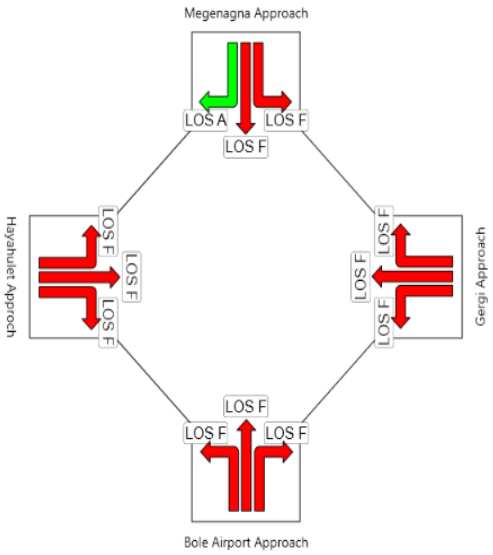
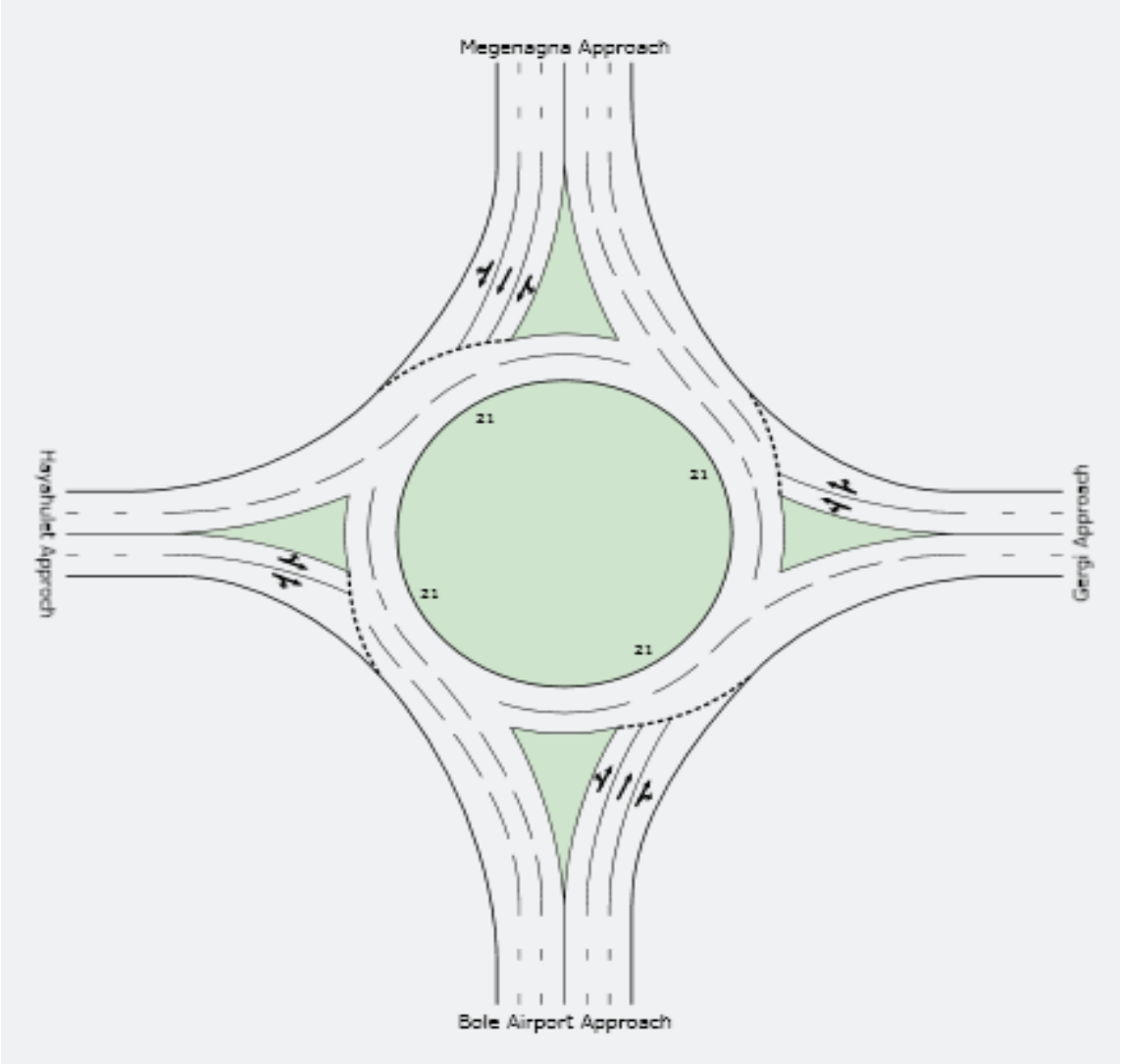


Figure 4. 10: Level of service Gergi-Imperial Roundabout



	South	East	North	West	Intersection
LOS	F	F	F	F	F

Figure 4.11: Level of Service (LOS) at Gerji-Imperial Roundabout (before)

Capacity, degree of saturation, delay, queue length, and level of service are the primary performance measures of intersections. Analysis results of Gerji-Imperial Roundabout intersection show high values of the degree of saturation, delay, queue length and low

values of capacity for the all approaches of the intersection and in effect level of service of all the four approaches are F.

4.2.1.2 Gergi-Imperial signalized intersection (After Improvement)

Input Data's for SIDRA Intersection software for the Analysis of LOS and Average Delay

Table 4.3: Geometric data for Gergi-Imperial signalized intersection (after improvement)

Junction Name	Approach name	No. of Entry Lane	No. of Exit Lane	Lane Width(m)	Median width
Imperial	Bole	3	3	3.7	0.68
	Megenagna	3	3	3.7	0.68
	Gergi	2	2	3.8	NA
	Hayahulet	2	2	3.8	1.2

Table 4.4: Traffic data for Gergi-Imperial signalized intersection (after improvement)

Junction Name	Approach leg	Total Traffic volume(Veh/hr)			Peak Hour Factor (%)			Heavy Vehicle Factor (%)		
		TH	LT	RT	TH	LT	RT	TH	LT	RT
Imperial (after)	Bole	1414	158	235	97.62	96.15	92.33	10.1	7.09	7.81
	Megenagna	1474	312	230	95.11	96.63	97.19	8.78	3.80	4.57
	Gergi	318	456	239	91.67	93.24	95.98	2.92	6.03	3.51
	Hayahulet	304	280	378	94.15	90.46	94.65	3.87	5.82	5.31

Table 4.5: Signal Time Data for Gergi-Imperial Signalized Intersection

Phase	A	B	C	D	E
Movement					
Green Time (sec)	30 30	20 20	48 48	30 30	50 50
Yellow Time (sec)	3 3	3 3	3 3	3 3	3 3
All-Red Time (sec)	2 2	2 2	2 2	2 2	2 2
Phase Time (sec)	35	25	53	35	55
Phase Split	17%	13%	26%	17%	27%
Cycle-Time	203 Seconds				

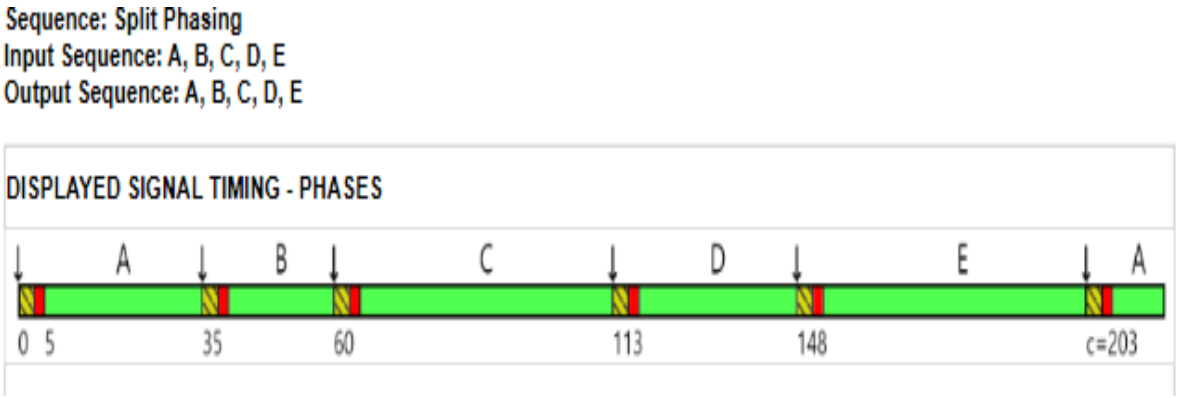


Figure 4. 12: Diagram of signal phasing of the Gergi-Imperial intersection

The number shows the timing of the actual existing signals for each phase, for example;

35 seconds=yellow time for phase A + all-red time for Phase A + green time of phase A.

Accordingly, the analysis and the results of the study are summarized in Figures show on 4.13, 4.14, 4.15 and 4.16 below, and the outputs of the analysis for each intersection are attached in Annex B.

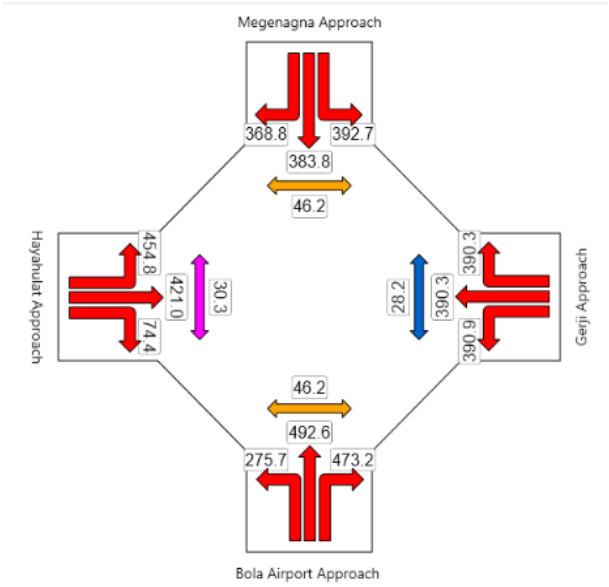


Figure 4. 13: Delay in Second at Gergi-Imperial signalized intersection

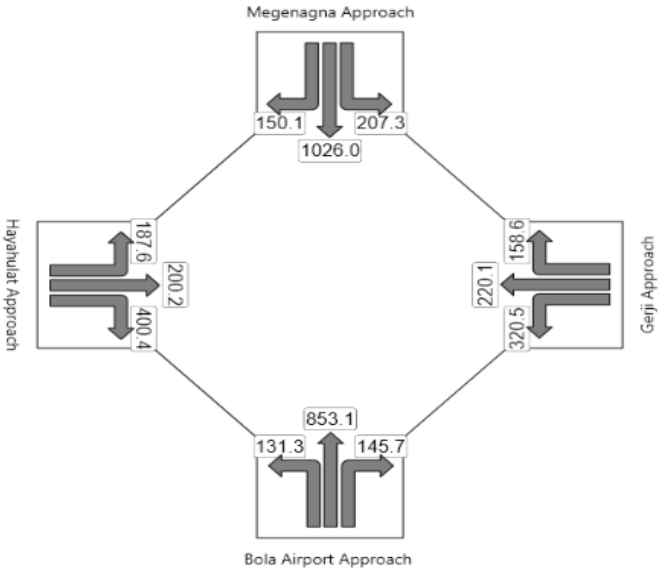


Figure 4. 14: Degree of Saturation Gergi-Imperial signalized intersection

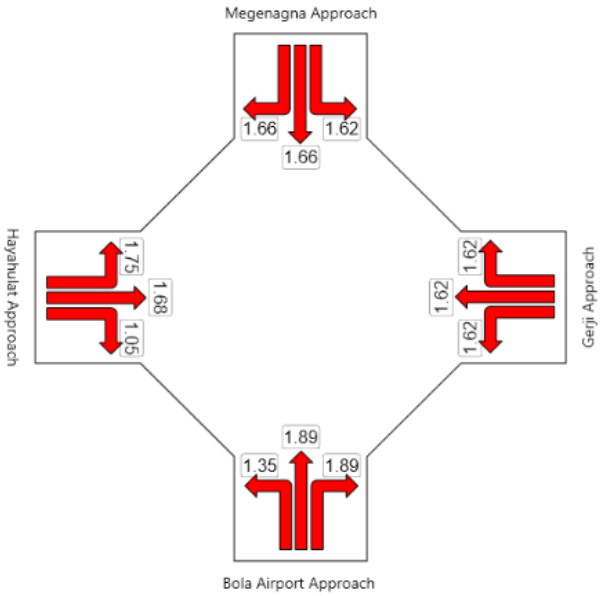


Figure 4. 15: Degree of Saturation at Gergi-Imperial signalized intersection

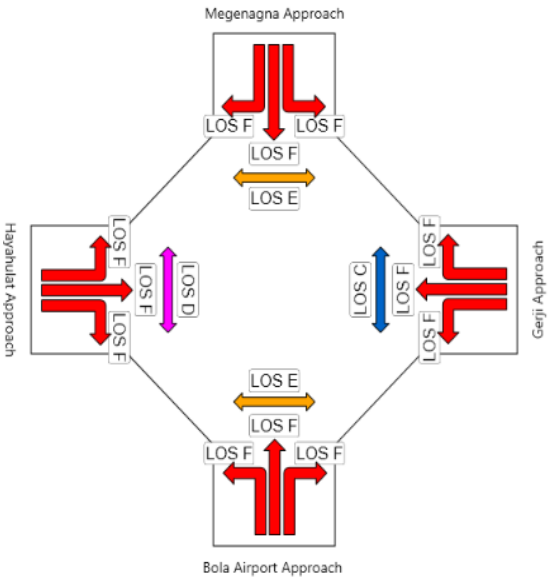
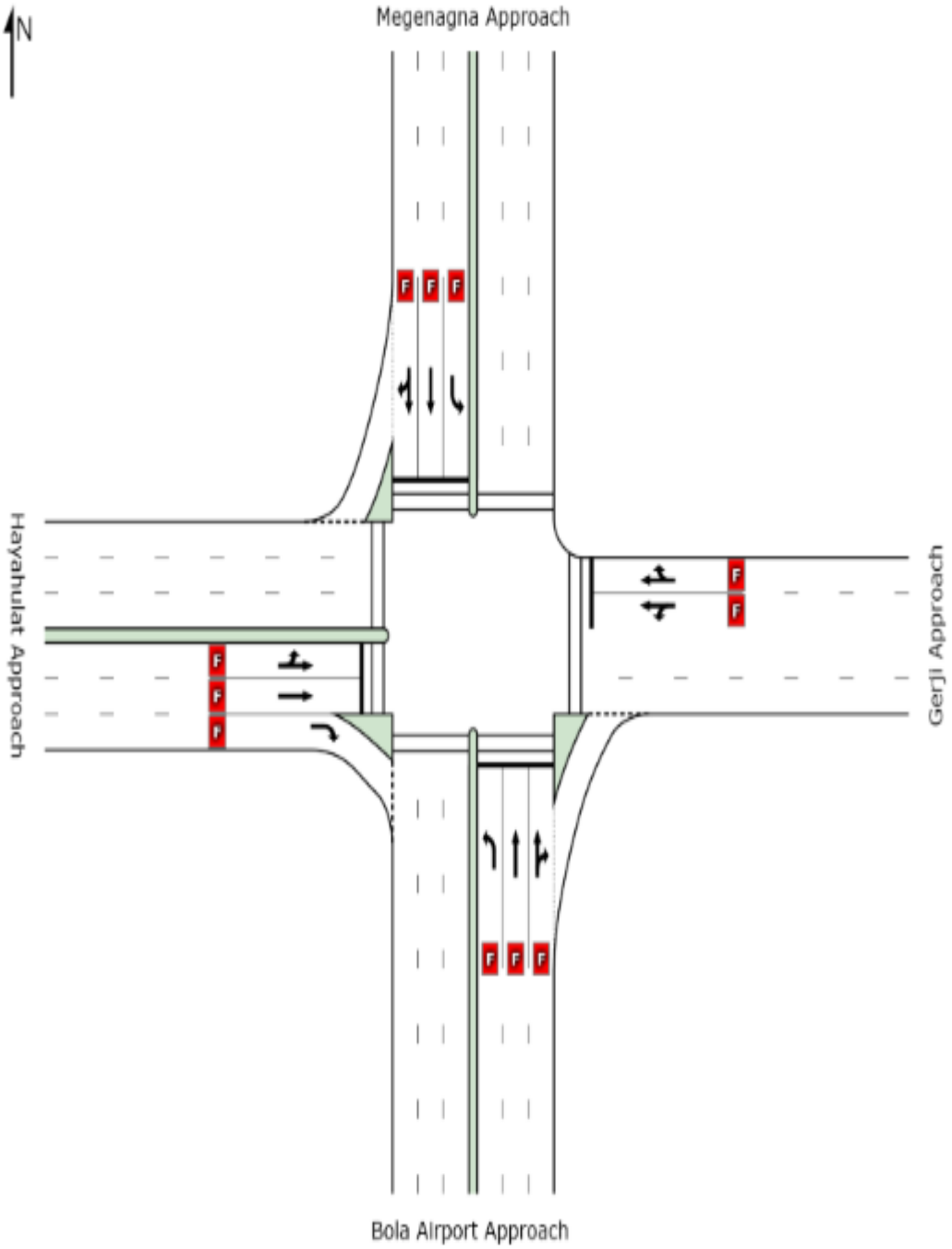


Figure 4. 16: Level of service Gergi-Imperial signalized intersection



	South	East	North	West	Intersection
LOS	F	F	F	F	F

Figure 4.17: Level of Service (LOS) at Gerji-Imparial Intersection (after)

Summary of Gergi–Imperial junction

4.2.2 Comparison of Performance Measures for roundabout (before) with signalized intersection (after)

Compare the four-approach of Girgi-Imperial that was converted in 2017 to a signalized intersection to its previous status as a roundabout.

Gergi -Imperial Roundabout (before converted)

Table 4.6: Summarized Result of Analyses for Gergi-Imperial Roundabout (before improvement)

Junction Name	Approach leg	Capacity (veh/h)	Degree of Saturation(V/C)	Average Delay(sec)	Level of Service
Gergi– Imperial (before)	Bole	812	2.954	804.7	F
	Megenagna	1443	2.320	553.7	F
	Gergi	958	1.224	119.4	F
	Hayahulet	671	1.535	252.1	F

Gergi -Imperial signalized (after converted)

Table 4.7: Summarized Result of Analyses for Gergi-Imperial Intersection (after improvement)

Junction Name	Approach leg	Capacity (veh/h)	Degree of Saturation(V/C)	Average Delay(sec)	Level of Service
Gergi– Imperial (after)	Bole	1130	1.888	471.4	F
	Megenagna	1383	1.655	383.5	F
	Gergi	699	1.623	390.6	F
	Hayahulet	788	1.750	296.7	F

4.2.2.1 Average Delay

Comparing between the roundabout and signalized intersection, existing roundabout converted into signalized intersection, it is observed that the Average Delay values at each Approach, Bole Approach, decreased about 41.42%, at Megenagna Approach decreased about 30.74%, at Gergi Approach increased about 69.43% and at Hayahulet Approach increased about 15.03%. Also, it is observed that the Average Delay values of all intersection decreased about 22.28%.

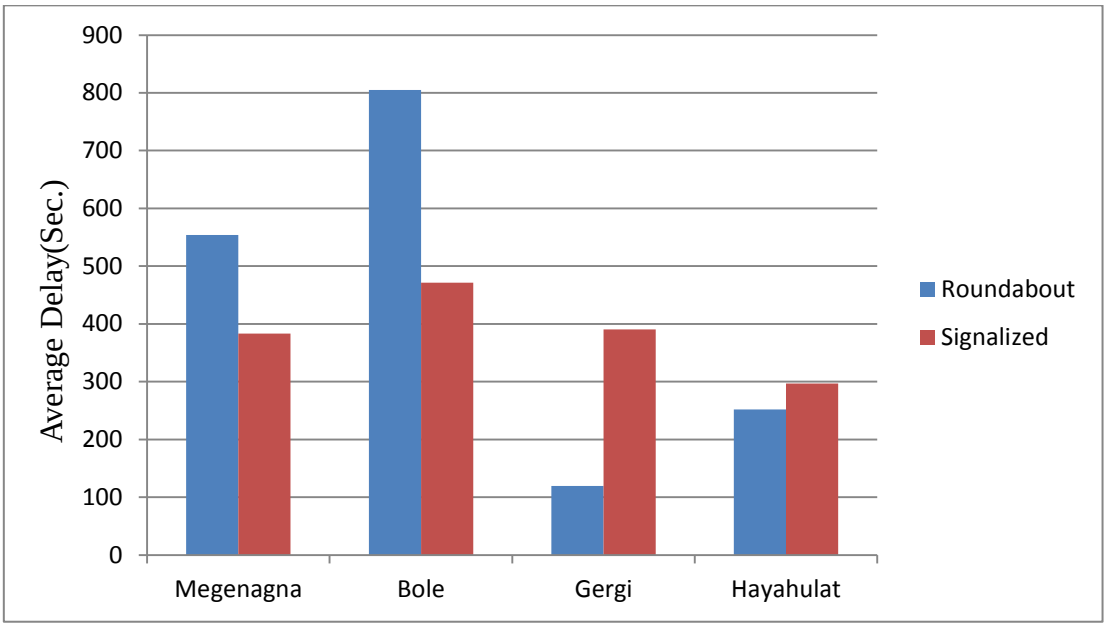


Figure 4.18: Average Delay Comparison at Gergi –Imperial Junction for roundabout and signalized

4.2.2.2 Effective Capacity

Table 4.6 and Table 4.7 show the comparison between an Effective capacity of a roundabout and Effective capacity of the signalized intersection of Gergi –Imperial intersection. It indicates that Gergi –Imperial roundabout capacity is 3884 veh/h while the signalized intersection capacity is 4000 veh/hr. It means the signalized intersection capacity is 3% more than roundabout capacity of Gergi –Imperial intersection.

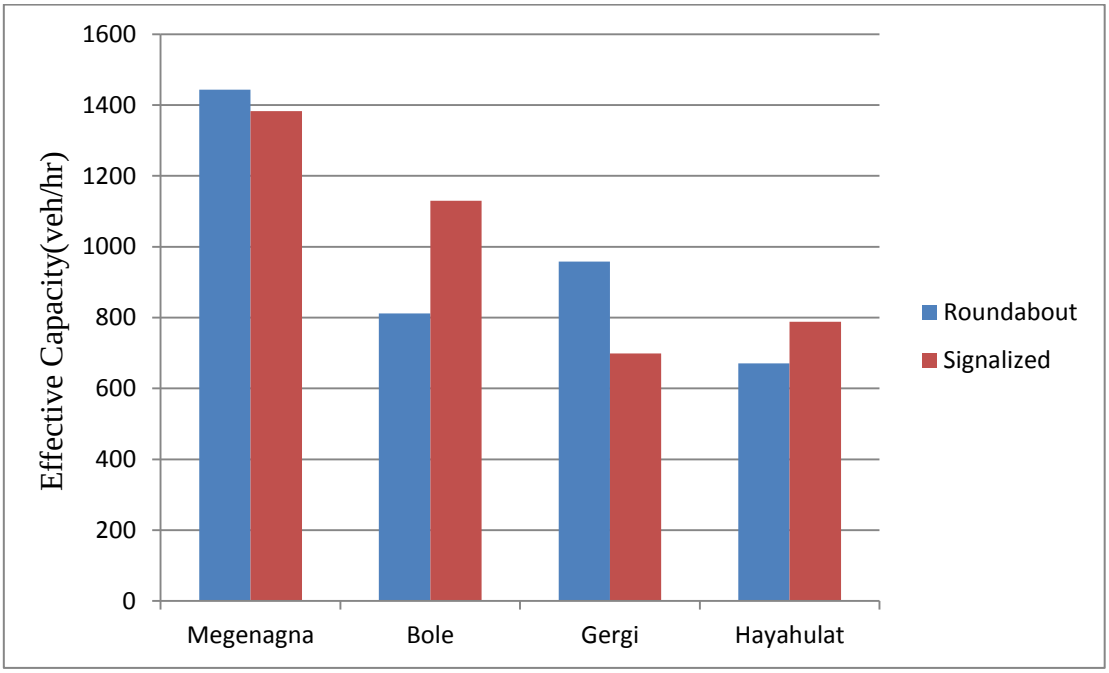


Figure 4.19: Effective Capacity Comparison at Gergi –Imperial Junction for roundabout and signalized

4.2.2.3 Degree of Saturation

The degree of saturation is a measurement of traffic flow quality that compares the number of vehicles using a given road with the number of vehicles the facility is designed to accommodate. The degree of saturation values is above 1.0, as shown in Table 4.6 and Table 4.7. These results show that the arrival flow is greater than the flow capacity ($x=q/Q > 1$). Where, x= degree of saturation, q= arrival flow and Q= flow capacity

Comparing between the roundabout and signalized intersection, roundabout converted into signalized intersection it is observed that the degree of saturation values at each Approach, at Bole Approach, decreased about 36.09%, at Megenagna Approach decreased about 28.66%, at Gergi Approach increased about 24.58% and at Hayahulet Approach increased about 12.28%. Also, it is observed that the degree of saturation values of all intersection decreased about 36.09%.

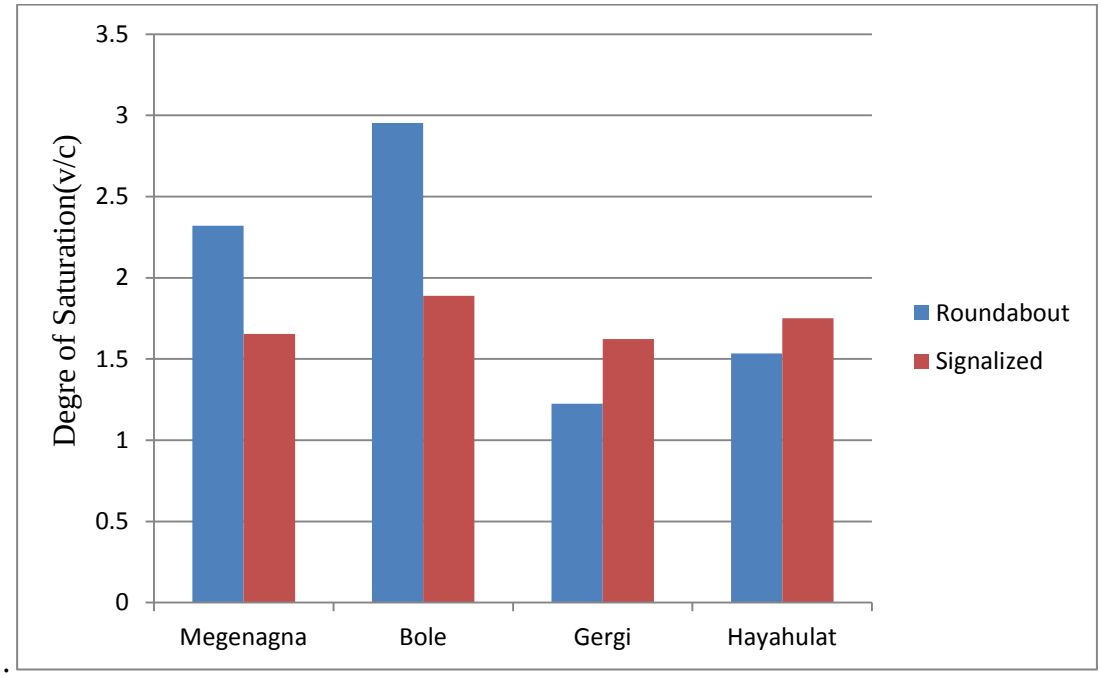


Figure 4.20: Degree of Saturation Comparison at Gergi –Imperial Junction for roundabout and signalized

4.2.2.4 Level of Service

Table 4.8 shows that level of service values do not differ for the roundabout and signalized intersection, but it also shows that there is an improvement regarding degree of saturation, delay and capacity values with the signalized intersection.

Table 4.8: LOS Comparison at Gergi –Imperial Junction for Before and After

Approach Name	Level of Service (Before)	Level of Service (After)	Remarks
Bole	F	F	Same
Megenagna	F	F	Same
Gergi	F	F	Same
Hayahulet	F	F	Same

4.2.3 Ayer-Tena Junction

4.2.3.1 Ayer-Tena Roundabout (Existing)

Input Data's for SIDRA Intersection software for the Analysis of intersection performance

Geometric Data

1- Number of approaches or legs -4

2- Number of circulating lane – 3

3- Inscribed circle Diameter – 81m

4- Central island diameter – 55m

Table 4.9: Geometric data for Ayer-Tena Roundabout (Existing)

	Alemgena Approach	Alembank Approach	Torhailoch Approach	Jomo Approach
Number of entry lane	2	2	3	3
Average Lane width(m)	3.8	3.8	3.5	3.5

Traffic Data

Table 4.10: Traffic data for Ayer-Tena Roundabout (Existing)

Junction Name	Approach leg	Total Traffic volume(Veh/hr)			Peak Hour Factor (%)			Heavy Vehicle Factor (%)		
		TH	RT	LT	TH	RT	LT	TH	RT	LT
Ayer-Tena (before)	Alemgena	1442	280	239	95.58	93.67	93.16	9.16	20.5	2.21
	Alembank	658	434	671	98.56	94.04	96.72	21.16	9.77	8.15
	Torhailoch	901	776	223	94.92	95.4	96.34	18.34	7.48	20.76
	Jomo	702	161	140	98.60	94.71	93.33	23.43	18.5	24.9

Accordingly, the analysis and the results of the study are summarized in the Figures show on 4.21, 4.22, 4.23 and 4.24 below, and the outputs of the analysis for each intersection are attached in Annex B.

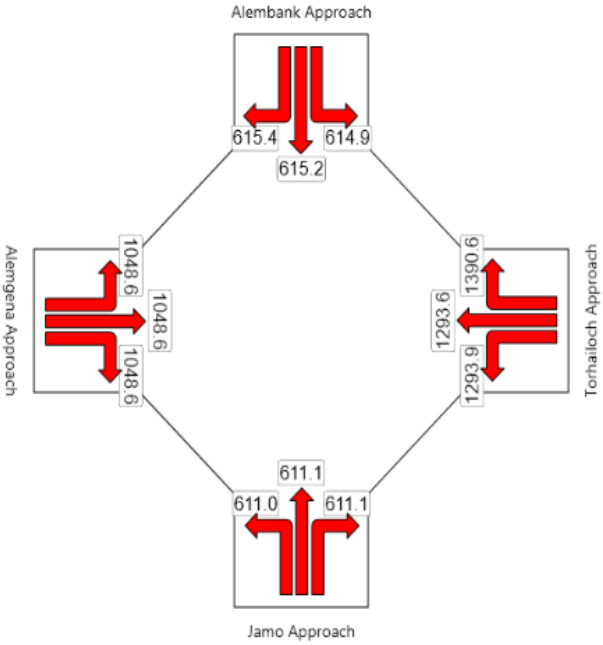


Figure 4. 21: Delay in Second at Ayer-Tena Roundabout

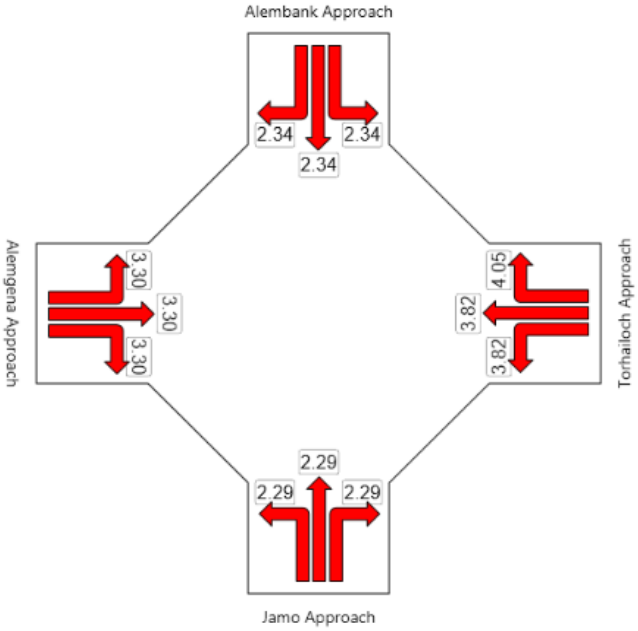


Figure 4. 22: Degree of Saturation at Ayer-Tena Roundabout

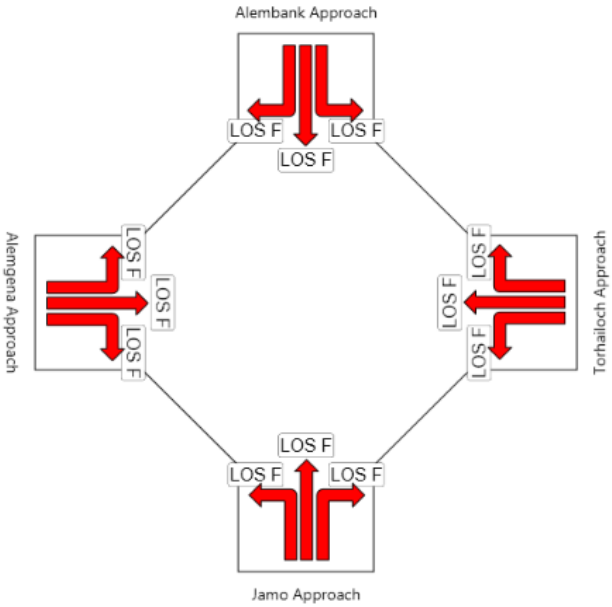


Figure 4. 23: Level of service at Ayer-Tena Roundabout

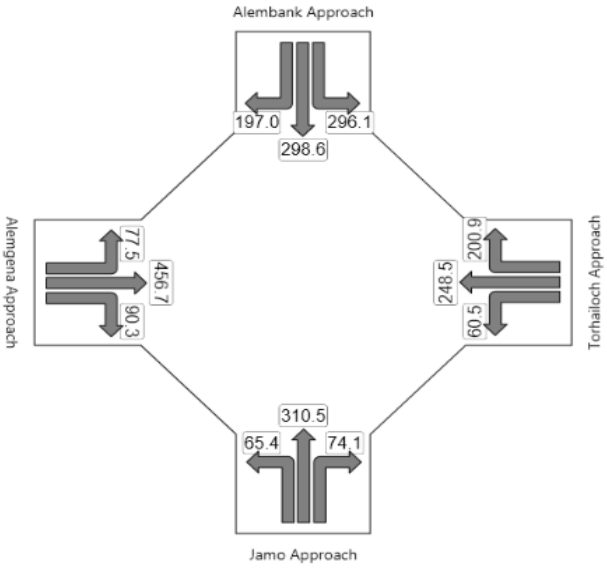
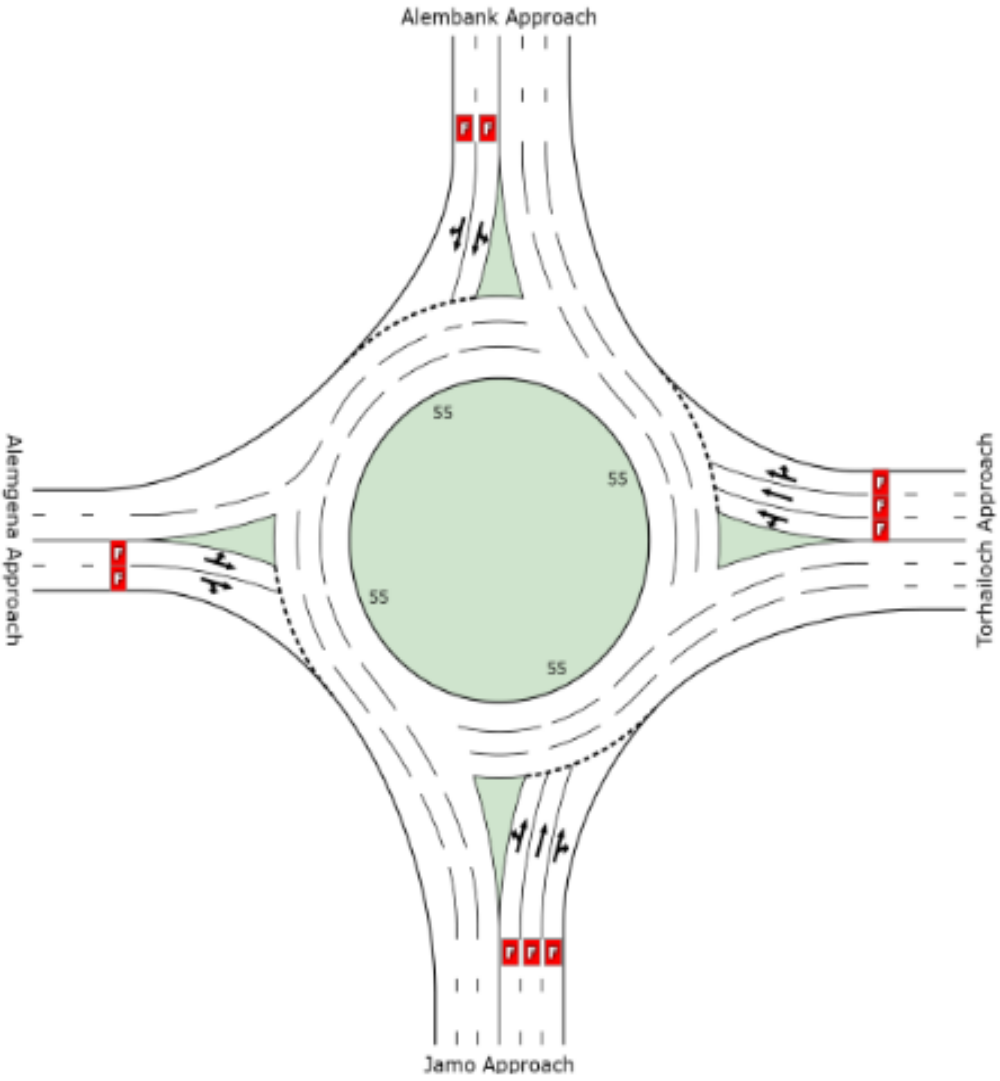


Figure 4. 24: Capacity at Ayer-Tena Roundabout



	South	East	North	West	Intersection
LOS	F	F	F	F	F

Figure 4.25: Level of Service (LOS) at Ayer-Tena Roundabout (before)

Capacity, degree of a saturation, delay, queue length, and level of service are the main performance measures of intersections. Analysis results of Ayer-Tena Roundabout intersection show high values of the degree of saturation, delay, queue length and low values of capacity for the all approaches of the intersection and in effect level of service of all the four approaches are F.

4.2.3.2 Ayer-Tena (New signalized)

Traffic Signal Design

Ayer-Tena intersection is a roundabout intersection link between ring road and a collector road (Jomo and Torhayloch ring road approach, Alembank and Alemgena a collector road approach).Introduction of signalized intersection under the same geometric condition and present traffic volume in the intersection. The "New" is created by converted the roundabout to signalized intersection to represent the actual intersection.

Data obtained from intersection are required to traffic signal Design with the help of Sidra Intersection 5.1 software. These data can be grouped as geometric and traffic volumes as shown in Table 4.11 and table 4.12 respectively;

Table 4.11: Geometric data for Ayer-Tena Signalized Intersection

	Alemgena Approach	Alembank Approach	Torhailoch Approach	Jomo Approach
Number of entry lane	2	2	3	3
Average Lane width(m)	3.8	3.8	3.5	3.5

Traffic Data

Table 4.12: Traffic data for Ayer-Tena Signalized Intersection

Junction Name	Approach leg	Total Traffic volume(Veh/hr)			Peak Hour Factor (%)			Heavy Vehicle Factor (%)		
		TH	RT	LT	TH	RT	LT	TH	RT	LT
Ayer-Tena (after)	Alemgena	1442	280	239	95.58	93.67	93.16	9.16	20.5	2.21
	Alembank	658	434	671	98.56	94.04	96.72	21.16	9.77	8.15
	Torhailoch	901	776	223	94.92	95.4	96.34	18.34	7.48	20.76
	Jomo	702	161	140	98.60	94.71	93.33	23.43	18.5	24.9

Data obtained from intersections has been entered in Sidra Intersection 5.1. Then the software has been calculated optimum cycle times by using different phase plans. In this way, cycle times have been found to minimize delays and to maximize capacities. This calculation entails entering maximum/minimum cycle times and a reference interval in the software to determine optimum cycle times. The upper limit is set to 150 seconds, as this low value minimized delays.

Ayer-Tena intersection phase plan was entered into the program as a four-phase system. So, signalization calculation was made by using different phase plan and cycle times were proposed by the methods. Table 4.13 provides a summary of the signal time data included in the design of the hypothetical signalized intersection.

Table 4.13: Output Signal Time Data for Ayer-Tena signalized intersection

Phase	A	B	C	D
Green Time (sec)	14	37	31	48
Yellow Time (sec)	3	3	3	3
All-Red Time (sec)	2	2	2	2
Phase Time (sec)	19	42	36	53
Phase Split	13%	28%	24%	35%
Cycle-Time	150 seconds			

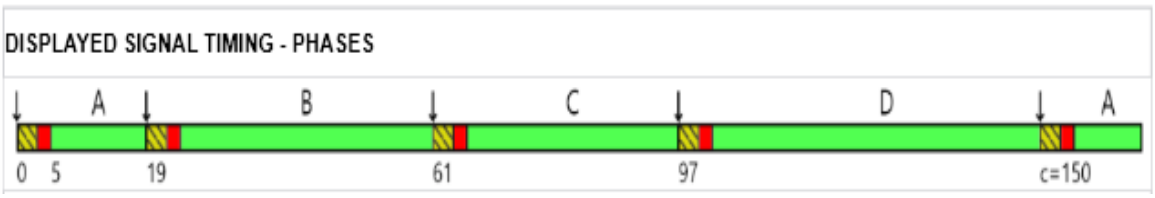


Figure 4. 26: Diagram of signal phasing of the Ayer=Tena signalized intersection

Accordingly, the analysis and the results of the study are summarized in the Figures show on 4.27, 4.28, 4.29 and 4.30 below, and the outputs of the analysis for each intersection are attached in Annex B.

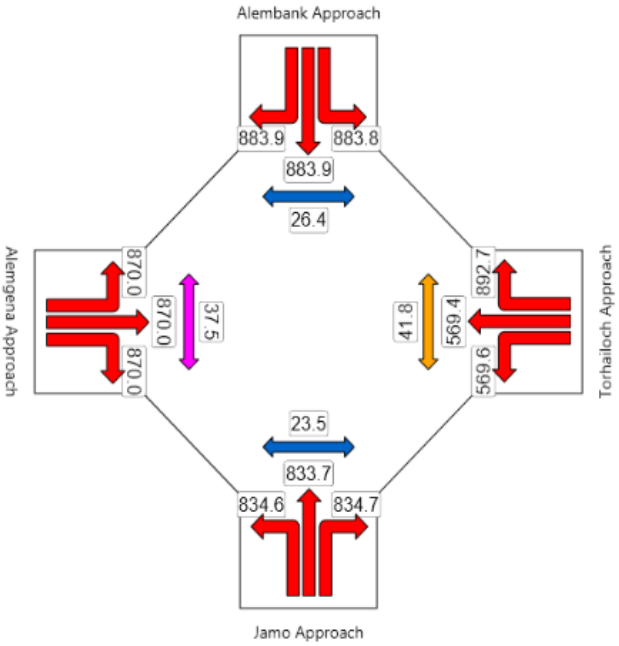


Figure 4. 27: Delay in Second at Ayer-Tena signalized intersection

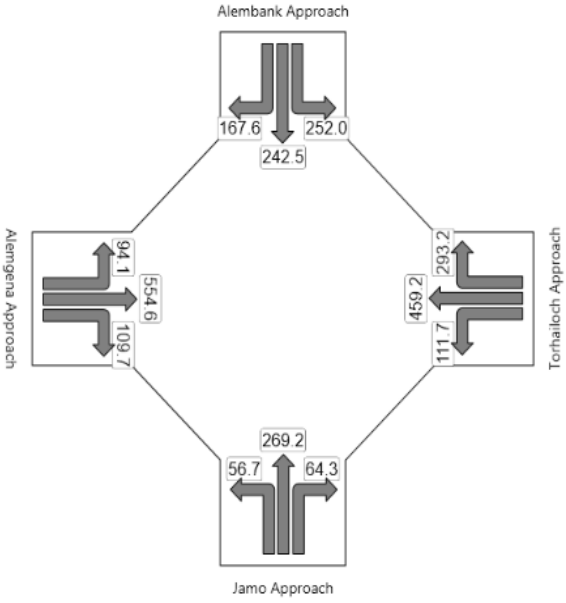


Figure 4. 28: Capacity at Ayer- Tena signalized intersection

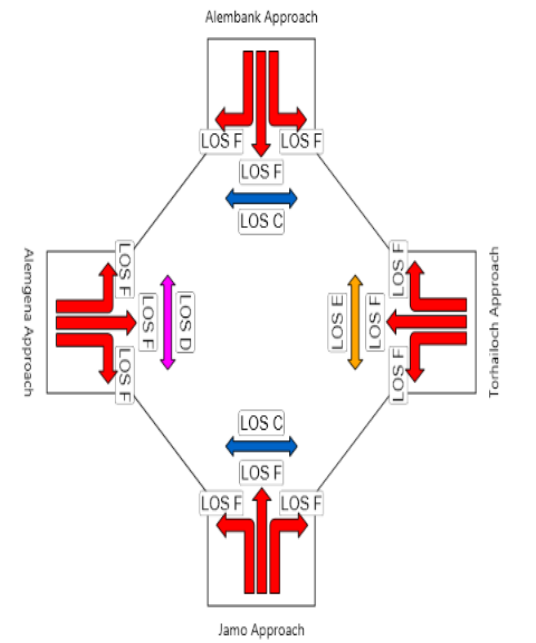


Figure 4. 29: Level of service at Ayer-Tena signalized intersection

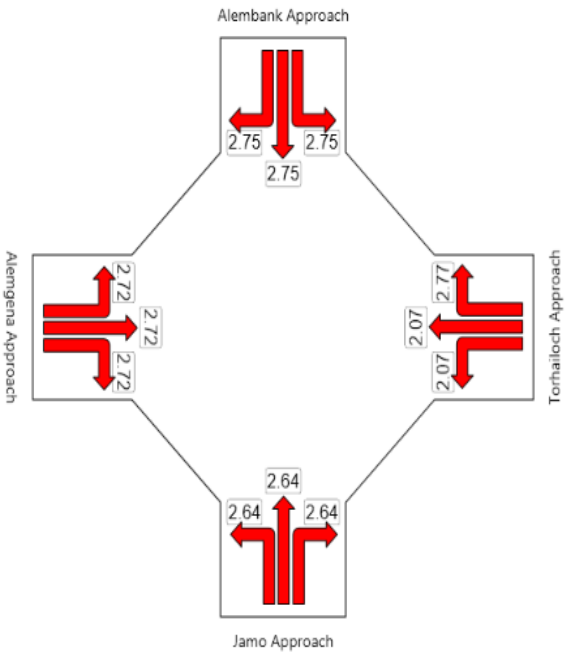
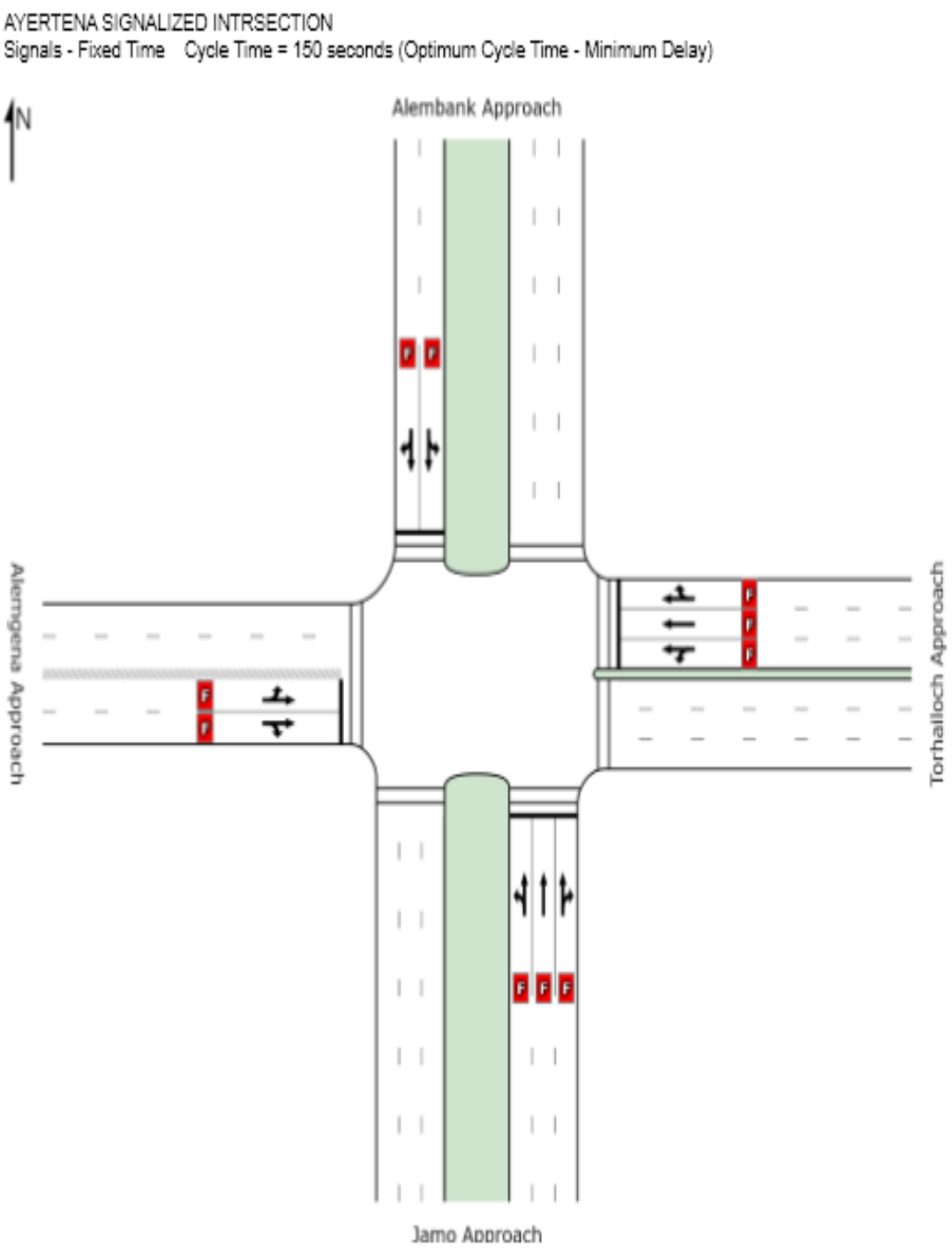


Figure 4. 30: Degree of Saturation at Ayer-Tena signalized intersection



	South	East	North	West	Intersection
LOS	F	F	F	F	F

Figure 4.31: Level of Service (LOS) at Ayer-Tena Signalized Intersection (New)

Summary of Ayer-Tena Junction

4.2.4 Comparison of Performance Measures for roundabout with signalized intersection

The study analyzed a hypothetical signalized intersection to the Ayer-Tena intersection. Using SIDRA, the researcher converted the roundabout to the signalized intersection. Compare the four-approach of Ayer-Tena intersection converted the roundabout to a signalized intersection.

Ayer-Tena Roundabout

Table 4.14: Summarized Result of Analyses for Ayer-Tena Roundabout

Junction Name	Approach leg	Capacity (veh/h)	Degree of Saturation(V/C)	Average Delay(sec)	Level of Service
Ayer-Tena (Roundabout)	Alemgena	624	3.303	1048.6	F
	Torhailoch	510	4.049	1333.2	F
	Jomo	450	2.293	611.0	F
	Alembank	792	2.343	615.1	F

Ayer-Tena signalized (after)

Table 4.15: Summarized Result of Analyses for Ayer-Tena signalized intersection

Junction Name	Approach leg	Capacity (veh/h)	Degree of Saturation(V/C)	Average Delay(sec)	Level of Service
Ayer-Tena (Signalized)	Alemgena	759	2.720	870.0	F
	Torhailoch	864	2.774	701.3	F
	Jomo	390	2.644	834.0	F
	Alembank	662	2.753	883.8	F

4.2.4.1 Average Delay

Comparing between a roundabout and signalized intersection, existing roundabout converted into hypothetical signalized intersection it is observed that the Average Delay values at each Approach, at Alemgena Approach, decreased about 17.03%, at Torhayloch Approach decreased about 47.40%, at Jamo Approach increased about 26.74% and at Alembank Approach increased about 30.40%. Also, it is observed that the Average Delay values of all intersection decreased about 13.68%.

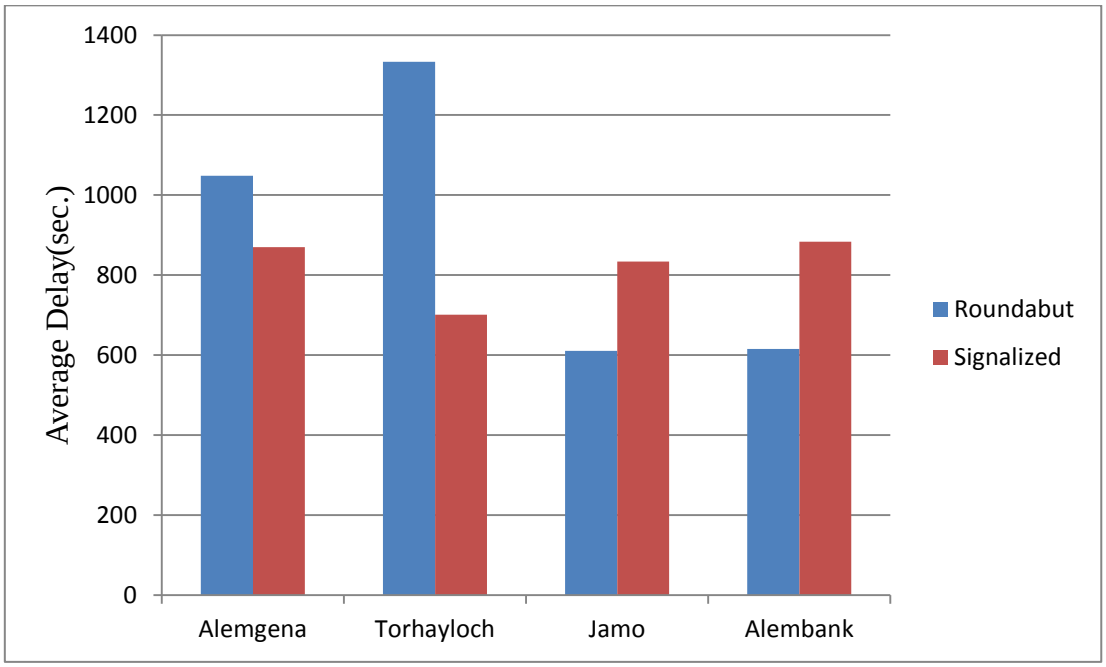


Figure 4.32: Average Delay Comparison at Ayer-Tena Junction for roundabout and signalized

4.2.4.2 Effective Capacity

Table 4.14 and Table 4.15 show the comparison between an Effective capacity of the roundabout and effective capacity of the signalized intersection of Ayer-Tena intersection. It indicates that Ayer-Tena roundabout capacity is 2376veh/h while the signalized intersection capacity is 2675veh/hr. It means the signalized intersection capacity is 11.18% more than roundabout capacity of Ayer-Tena intersection.

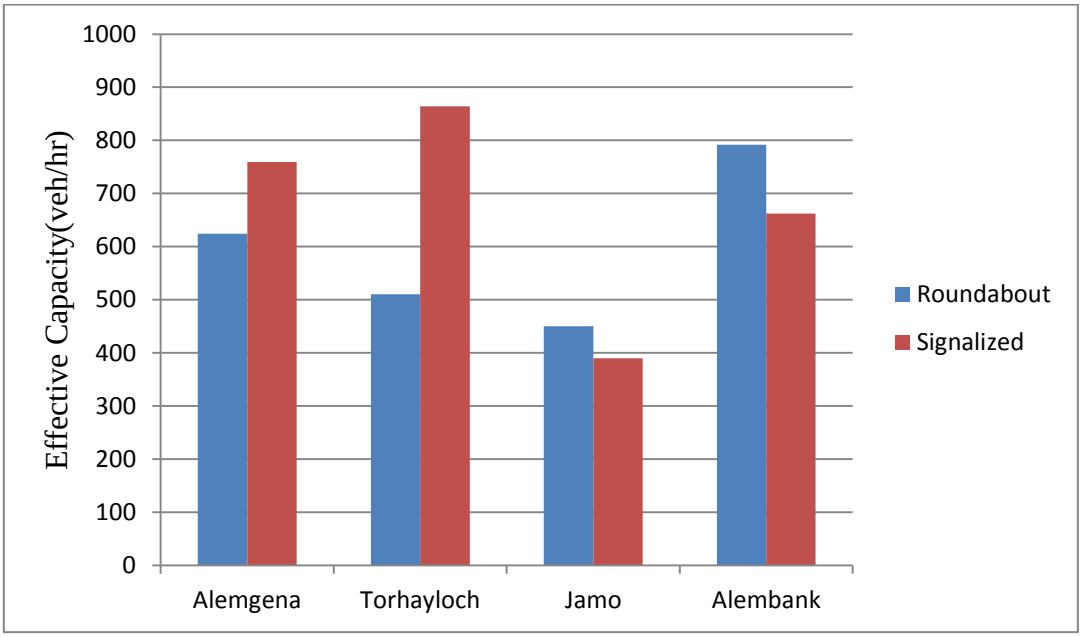


Figure 4.33: Effective Capacity Comparison at Ayer-Tena Junction for roundabout and signalized

4.2.4.3 Degree of Saturation

The degree of saturation is a measurement of traffic flow quality that compares the number of vehicles using a given road with the number of vehicles the facility is designed to accommodate. The degree of saturation values is above 1.0, as shown in Table 4.14 and Table 4.15. These results show that the arrival flow is greater than the flow capacity ($x=q/Q > 1$). Where, x= degree of saturation, q= arrival flow and Q= flow capacity

Comparing between the roundabout and signalized intersection, existing roundabout converted into hypothetical signalized intersection is observed that the degree of saturation values at each Approach, at Alemgena Approach decreased about 17.65%, at Torhayloch Approach decreased about 31.49%, at Jamo Approach increased about 13.28% and at Alembank Approach increased about 14.89%. Also, it is observed that the degree of saturation values of all intersection decreased about 31.49%.

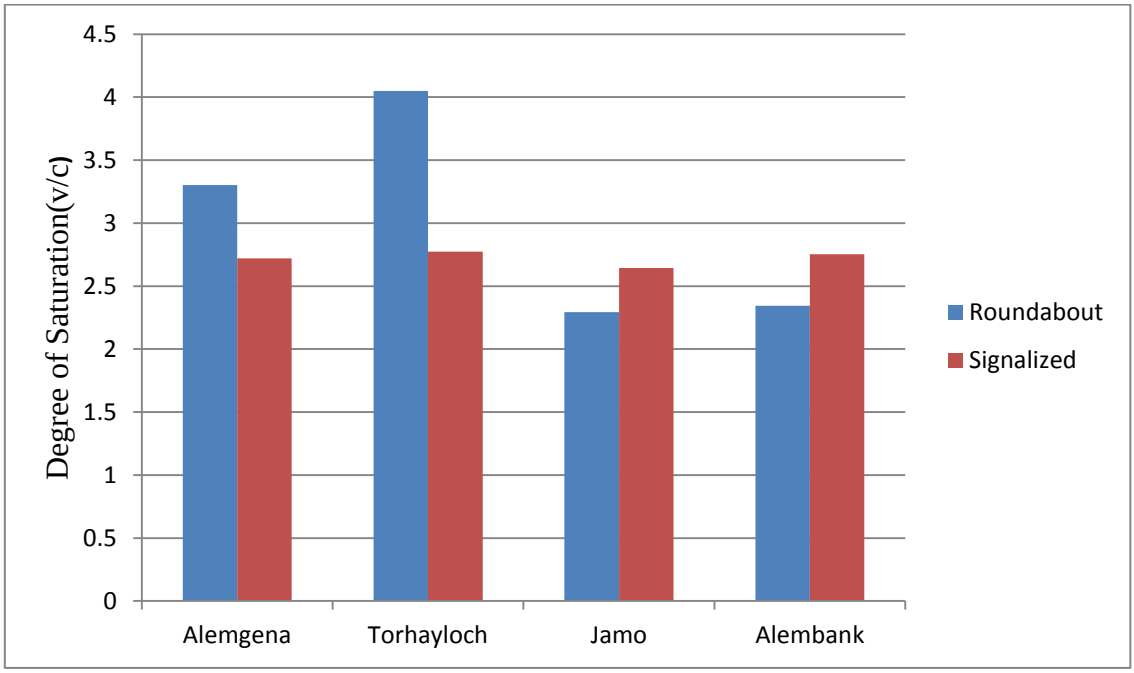


Figure 4.34: Degree of Saturation Comparison at Ayer-Tena Junction for roundabout and signalized

4.2.4.4 Level of Service

Table 4.16 shows that level of service values do not differ for the roundabout and hypothetical signalized intersection, but it also shows that there is an improvement regarding degree of saturation, delay and capacity values with the signalized intersection.

Table 4.16: LOS Comparison at Ayer-Tena Junction for roundabout and signalized intersection

Approach Name	Roundabout Level of Service (LOS)	Signalized Level of Service (LOS)	Remark
Alemgena	F	F	Same
Torhailoch	F	F	Same
Jomo	F	F	Same
Alembank	F	F	Same

4.3 The effect of pedestrians and heavy vehicles in the performance of intersections

From the analysis of the intersections both the intersections have poor performance and to know the causes of this among other thing is distinguishing proportion of heavy vehicle and pedestrian traffic at the intersection areas is the one.

4.3.2 Performance of roundabout Without Pedestrians

4.3.2.1 Analysis results of Ayer-Tena roundabout for without pedestrians

Table 4.17: Output Summary of Ayer-Tena roundabout for without pedestrians

AyerTena Roundabout
Roundabout

Lane Use and Performance

	Demand Flows L veh/h	T veh/h	R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
South: Jamo Approach																
Lane 1	150	168	0	318	24.1	359	0.886	100	25.9	LOS C	8.3	69.8	500	–	0.0	0.0
Lane 2	0	378	0	378	23.4	427	0.886	100	23.2	LOS C	9.1	76.3	500	–	0.0	0.0
Lane 3	0	166	170	335	20.9	379	0.886	100	25.1	LOS C	8.5	70.1	500	–	0.0	0.0
Approach	150	712	170	1032	22.8		0.886		24.6	LOS C	9.1	76.3				
East: Torhailoch Approach																
Lane 1	231	354	0	585	19.3	425	1.376	100	181.7	LOS F	59.5	485.5	500	–	0.0	4.1
Lane 2	0	595	0	595	18.3	433	1.376	100	181.4	LOS F	60.5	489.9	500	–	0.0	4.4
Lane 3	0	0	813	813	7.5	604	1.347	98[5]	165.7	LOS F	76.6	570.6	500	–	0.0	9.0
Approach	231	949	813	1994	14.2		1.376		175.1	LOS F	76.6	570.6				
North: Alembank Approach																
Lane 1	694	257	0	951	11.7	445	2.137	100	520.3	LOS F	170.9	1316.4	500	–	0.0	57.9
Lane 2	0	442	462	904	15.3	423	2.137	100	520.7	LOS F	162.8	1289.6	500	–	0.0	54.8
Approach	694	700	462	1855	13.5		2.137		520.5	LOS F	170.9	1316.4				
West: Alemgena Approach																
Lane 1	256	776	0	1032	12.4	519	1.988	100	453.9	LOS F	174.4	1350.1	500	–	0.0	62.6
Lane 2	0	733	298	1031	12.4	519	1.988	100	453.9	LOS F	174.3	1350.0	500	–	0.0	62.6
Approach	256	1509	298	2063	12.4		1.988		453.9	LOS F	174.4	1350.1				
Intersection				6944	14.7		2.137		327.8	LOS F	174.4	1350.1				

Table 4.18: Performance Comparison at Ayer-Tena roundabout in respect to with & without pedestrians

Measures of performance	With pedestrians	Without pedestrians	% Diff.	Remark
Average Delay, sec/veh (Intersection)	949.5	327.8	65.47	Improved
Degree of saturation, v/c (Intersection)	4.049	2.137	47.22	Improved
Level of service (Intersection)	F	F		Same

In Ayer-Tena roundabout in without pedestrians, there was a 65.47% and 47.22% decrease in the average delay and degree of saturation respectively. It is better to separate the pedestrians from vehicular traffic at the intersections where high pedestrian flows were observed since they affect normal traffic flows.

4.3.2.2 Analysis results of Gergi-imperial roundabout for without pedestrians

Table 4.19: Output Summary of Gergi-imperial roundabout for without pedestrians

GERJI IMPERIAL ROUNDABOUT
Roundabout

Lane Use and Performance

	Demand Flows L veh/h	T veh/h	R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
South: Bole Airport Approach																
Lane 1	141	674	0	815	9.3	799	1.019	100	37.4	LOS D	29.9	226.0	500	–	0.0	0.0
Lane 2	0	994	0	994	9.7	975	1.019	100	34.1	LOS C	33.9	256.6	500	–	0.0	0.0
Lane 3	0	0	252	252	8.0	636	0.396	39[s]	4.6	LOS A	2.3	17.1	500	–	0.0	0.0
Approach	141	1669	252	2061	9.3		1.019		31.8	LOS C	33.9	256.6				
East: Gergi Approach																
Lane 1	497	0	0	497	5.8	209	2.378	100	643.2	LOS F	103.6	761.2	500	–	0.0	19.2
Lane 2	0	369	306	675	3.3	288	2.349	99[s]	626.6	LOS F	136.7	984.1	500	–	0.0	31.4
Approach	497	369	306	1172	4.4		2.378		633.6	LOS F	136.7	984.1				
North: Megenagna Approach																
Lane 1	465	694	0	1159	6.2	934	1.240	100	117.8	LOS F	88.8	655.2	500	–	0.0	13.6
Lane 2	0	1376	0	1376	7.9	1110	1.240	100	115.9	LOS F	102.7	767.8	500	–	0.0	19.6
Lane 3	0	0	228	228	4.9	716	0.319	26[s]	3.0	LOS A	1.7	12.1	500	–	0.0	0.0
Approach	465	2070	228	2763	7.0		1.240		107.4	LOS F	102.7	767.8				
West: Hayahulet Approch																
Lane 1	471	0	0	471	4.5	155	3.037	100	949.3	LOS F	115.6	840.0	500	–	0.0	23.4
Lane 2	0	311	248	559	5.0	216	2.583	85[s]	741.2	LOS F	124.0	904.9	500	–	0.0	26.9
Approach	471	311	248	1030	4.7		3.037		836.3	LOS F	124.0	904.9				
Intersection				7027	6.9		3.037		279.9	LOS F	136.7	984.1				

Table 4.20: Performance Comparison at Gergi-Imperial roundabout in respect to with & without pedestrians

Measures of performance	With pedestrians	Without pedestrians	% Diff.	Remark
Average Delay sec/veh (Intersection)	450.3	279.9	37.84	Improved
Degree of saturation v/c (Intersection)	3.725	3.037	19.47	Improved
Level of service (Intersection)	F	F		Same

In Gergi-imparial roundabout in without pedestrians there was a 37.84% and 19.47% decrease in the average delay and degree of saturation respectively. It is better to separate the pedestrians from vehicular traffic at the intersections where high pedestrian flows were observed since they affect normal traffic flows.

4.3.3 Performance of roundabout without heavy vehicles

4.3.3.2 Analysis results of Ayer-Tena roundabout for without heavy vehicles

Table 4.21: Output Summary of Ayer-Tena roundabout for without heavy vehicles

AyerTena Roundabout
Roundabout

Lane Use and Performance

	Demand Flows L veh/h	T veh/h	R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
South: Jamo Approach																
Lane 1	113	153	0	265	0.0	150[2]	1.770	100	377.4	LOS F	39.5	276.5	500	–	0.0	0.0
Lane 2	0	265	0	265	0.0	150[2]	1.770	100	377.6	LOS F	39.4	275.6	500	–	0.0	0.0
Lane 3	0	127	139	265	0.0	150[2]	1.770	100	377.4	LOS F	39.5	276.5	500	–	0.0	0.0
Approach	113	545	139	796	0.0		1.770		377.4	LOS F	39.5	276.5				
East: Torhailoch Approach																
Lane 1	183	296	0	479	0.0	202	2.372	75[5]	637.5	LOS F	92.8	649.4	500	–	0.0	13.3
Lane 2	0	479	0	479	0.0	202	2.372	75[5]	637.5	LOS F	92.8	649.4	500	–	0.0	13.3
Lane 3	0	0	753	753	0.0	237	3.182	100	998.3	LOS F	170.1	1190.5	500	–	0.0	45.4
Approach	183	775	753	1711	0.0		3.182		796.2	LOS F	170.1	1190.5				
North: Alembank Approach																
Lane 1	637	165	0	803	0.0	416	1.931	100	429.2	LOS F	131.3	919.1	500	–	0.0	27.7
Lane 2	0	386	416	803	0.0	416	1.931	100	429.2	LOS F	131.3	919.1	500	–	0.0	27.7
Approach	637	552	416	1605	0.0		1.931		429.2	LOS F	131.3	919.1				
West: Alemgena Approach																
Lane 1	199	704	0	904	0.0	350	2.578	100	721.7	LOS F	183.6	1285.4	500	–	0.0	54.3
Lane 2	0	666	237	904	0.0	350	2.578	100	721.7	LOS F	183.6	1285.4	500	–	0.0	54.3
Approach	199	1370	237	1807	0.0		2.578		721.7	LOS F	183.6	1285.4				
Intersection				5919	0.0		3.182		617.6	LOS F	183.6	1285.4				

Table 4.22: Performance Comparison at Ayer-Tena roundabout in respect to with & without heavy vehicle

Measures of performance	With heavy vehicle	Without heavy vehicle	% Diff.	Remark
Average Delay sec/veh (Intersection)	949.5	617.6	34.95	Improved
Degree of saturation v/c (Intersection)	4.049	3.182	21.41	Improved
Level of service (Intersection)	F	F		Same

The percentages of heavy vehicles at Ayer-Tena roundabouts have high, out of the total number of vehicles counted at those junctions. These junctions are a link between ring road and a collector road; mostly, heavy vehicles travel along the ring road. According to Table 4.22 performance result after removing the heavy vehicle from the roundabout 34.95% and 21.41% decrease in the average delay and degree of saturation respectively.

4.3.3.1 Analysis results of Gergi-imperial roundabout for without heavy vehicles

Table 4.23: Output Summary of Gergi-imperial roundabout for without heavy vehicles

GERJI IMPERIAL ROUNDABOUT
Roundabout

Lane Use and Performance

	Demand Flows L veh/h	T veh/h	R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
South: Bole Airport Approach																
Lane 1	130	599	0	729	0.0	308	2.365	100	630.9	LOS F	140.4	982.8	500	–	0.0	31.3
Lane 2	0	909	0	909	0.0	384	2.365	100	628.0	LOS F	174.0	1217.9	500	–	0.0	47.7
Lane 3	0	0	232	232	0.0	247	0.940	40[s]	27.2	LOS C	4.6	31.9	500	–	0.0	0.0
Approach	130	1507	232	1869	0.0		2.365		554.6	LOS F	174.0	1217.9				
East: Gergi Approach																
Lane 1	468	58	0	526	0.0	483	1.090	100	67.1	LOS E	26.5	185.6	500	–	0.0	0.0
Lane 2	0	299	296	595	0.0	546	1.090	100	65.1	LOS E	29.2	204.4	500	–	0.0	0.0
Approach	468	357	296	1121	0.0		1.090		66.1	LOS E	29.2	204.4				
North: Megenagna Approach																
Lane 1	448	592	0	1040	0.0	533	1.949	100	436.9	LOS F	171.4	1200.1	500	–	0.0	46.2
Lane 2	0	1314	0	1314	0.0	674	1.949	100	434.9	LOS F	214.5	1501.3	500	–	0.0	100.0
Lane 3	0	0	217	217	0.0	429	0.506	26[s]	5.5	LOS A	2.2	15.4	500	–	0.0	0.0
Approach	448	1906	217	2571	0.0		1.949		399.4	LOS F	214.5	1501.3				
West: Hayahulet Approch																
Lane 1	450	0	0	450	0.0	307	1.465	100	235.6	LOS F	55.8	390.9	500	–	0.0	0.0
Lane 2	0	300	232	531	0.0	382	1.389	95[s]	200.1	LOS F	59.0	412.7	500	–	0.0	0.0
Approach	450	300	232	981	0.0		1.465		216.4	LOS F	59.0	412.7				
Intersection				6542	0.0		2.365		359.2	LOS F	214.5	1501.3				

Table 4.24: Performance Comparison at Gergi-Imperial roundabout in respect to with & without heavy vehicle

Measures of performance	With heavy vehicle	Without heavy vehicle	% Diff.	Remark
Average Delay sec/veh (Intersection)	450.3	359.2	20.23	Improved
Degree of saturation v/c (Intersection)	2.725	2.365	13.21	Improved
Level of service (Intersection)	F	F		Same

The percentages of heavy vehicles at Gergi-Imperial roundabouts have high, out of the total number of vehicles counted at those junctions. These junctions are a link between ring road and a collector road; mostly, heavy vehicles travel along the ring road. According to Table 4.24 performance result after removing a heavy vehicle from the roundabout 20.23% and 13.21% decrease in the average delay and degree of saturation respectively.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The performance of signalized intersection was evaluated regarding the delay, degree of saturation, capacity and level of service in comparison to the performance of roundabout. In summary, the following conclusions were drawn from this study.

- ✓ In general, it was found that the hypothetical signalized intersection in Ayer-Tena and the real signalized Gergi-Imperial Intersections operated more efficiently/performed than the roundabout.
- ✓ There was a 13.68% and 31.49% decrease in the Average delay and Degree of saturation respectively and the capacity increased with 11.18%, in the condition after the proposed signalized intersection at Ayer-Tena intersection.
- ✓ There was a 22.28% and 36.09% decrease in the Average delay and Degree of saturation respectively and the capacity increased with 3.00%, in the condition after the installation of the signalized intersection at Gergi-Imperial intersection.
- ✓ For both intersection approaches the Average delay has the morning and evening peak period.
- ✓ High Pedestrians at the intersection areas and it was the cause for the intersections to have poor performance. And heavy vehicles cover high of the whole vehicular traffic at intersection areas, and they have also obviously a significant influence on the performance of intersections.
- ✓ Some improvements have been seen at Ayer-Tena and Gergi-Imperial Intersections, the delay and degree of saturation values decreased, and the

capacity values increased with the proposed or converted signalized intersection. However, it is found that Ayer-Tena and Gergi-Imparial Intersection works at "F" level of service. This finding reveals that new solutions to manage traffic flows have to be considered in the intersection.

5.2 Recommendations

Based on results of the study and literature review made on the subject matter, the following were commendations have been drawn.

- ✓ It is better to allocate adequate parking arrangements and a separate way for pedestrian, like an overpass or underpass, to cross the road at the Ayer-Tena intersection areas should be prepared to increase the performance of the intersections about 65.47% decrease in the average delay.
- ✓ From the analysis result, it shows that converted to signalized intersections are serving above their capacity. Therefore, the city administration should consider this issue and formulate capacity improvement methods such as, improving the capacity of roads, improving public transport and creating awareness to pedestrian travel on walk ways.
- ✓ Redirecting heavy vehicles from the route in the morning and evening peak hours to other appropriate route will somehow lessen the volume flow in the Ayer-Tena and Gergi-Imperial roundabout and should be prepared to increase the performance of the intersections about 34.95% and 20.23% decrease in the average delay respectively.
- ✓ Transport related office especially Addis Ababa Road transport office should work further on traffic flow and capacity issue.

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Appendix-A

Traffic Volume

Table A-1: Traffic volume at Gergi-Imperial roundabout

Gergi-Imperial (Before)	**Traffic Volume**															
	Bole Approach				Megenagna Approach				Gergi Approach				Hayahulet Approach			
	TH	R	L	Ped	TH	R	L	Ped	TH	R	L	Ped	TH	R	L	Ped
7:00-7:15 AM	211	47	12	371	394	13	37	107	26	64	50	64	25	8	20	20
7:15-7:30AM	236	34	21	406	409	21	49	112	69	58	99	57	20	14	22	48
7:30-7:45 AM	203	39	17	405	422	25	60	139	57	44	115	62	27	23	27	59
7:45-8:00AM	229	54	23	324	346	23	60	115	100	58	97	67	48	45	49	65
8:00-8:15 AM	261	44	27	385	317	31	60	134	77	43	99	111	48	58	56	79
8:15-8:30 AM	193	25	21	262	270	29	63	88	102	63	118	93	62	67	65	65
8:30-8:45 AM	290	37	28	237	354	17	66	174	76	47	103	73	29	41	63	69
8:45-9:00AM	252	37	29	227	301	35	65	207	71	45	86	55	31	49	41	51
9:00-9:15AM	246	47	20	185	343	27	60	151	72	48	63	63	60	55	85	30
9:15-9:30 AM	264	34	15	181	368	26	66	157	80	55	73	47	27	39	52	31
9:30-9:45 AM	261	41	18	205	337	46	77	97	84	59	65	44	44	31	51	40
9:45-10:00AM	192	27	23	141	388	35	73	77	66	70	73	53	29	21	57	18
10:00-10:15AM	265	26	21	147	384	30	72	73	72	46	60	57	47	23	78	34
10:15-10:30AM	234	34	24	106	282	51	51	119	90	56	69	52	46	25	70	27
10:30-10:45AM	220	39	24	147	297	33	53	94	70	59	68	47	43	27	69	44
10:45-11:00AM	270	31	25	157	363	40	85	95	67	43	51	54	43	43	52	32
11:00-11:15AM	207	28	15	147	196	34	75	99	75	43	58	50	36	35	47	28
11:15-11:30AM	233	29	24	132	369	37	72	90	58	55	59	48	57	30	91	40
11:30-11:45AM	251	20	19	122	292	56	94	111	65	57	59	50	57	20	59	41
11:45-12:00AM	276	31	25	104	276	42	85	104	49	52	61	54	59	15	59	36
12:00-12:15AM	284	23	34	114	280	45	76	95	54	28	70	61	52	19	68	36
12:15-12:30AM	288	32	25	138	254	39	132	131	81	47	80	67	65	25	59	31

12:30-12:45AM	305	39	25	116	241	43	81	118	53	39	47	47	58	21	49	22
12:45-1:00AM	149	9	10	124	160	40	64	48	45	40	60	50	57	25	102	40
1:00-1:15PM	238	42	28	116	310	28	76	111	68	64	65	77	48	44	72	19
1:15-1:30 PM	267	45	18	191	322	27	75	109	74	49	56	75	63	26	71	43
1:30-1:45PM	217	39	22	170	244	34	73	124	74	50	52	90	67	17	78	55
1:45-2:00PM	281	39	20	138	286	39	67	76	69	46	54	56	77	27	70	45
2:00-2:15PM	310	42	21	109	294	42	70	95	58	65	73	56	59	26	84	32
2:15-2:30PM	339	39	21	130	306	45	74	77	68	58	72	69	58	20	60	25
2:30-2:45PM	327	35	24	108	274	45	61	66	78	57	52	50	66	31	75	20
2:45-3:00PM	269	45	24	106	231	46	66	71	42	37	34	40	51	11	64	14
3:00-3:15PM	289	30	24	99	280	27	85	87	54	51	74	46	64	32	71	22
3:15-3:30PM	270	30	25	117	248	35	68	81	85	45	87	63	71	47	99	31
3:30-3:45PM	287	31	26	105	313	27	81	69	52	49	63	43	58	39	85	34
3:45-4:00PM	156	32	18	113	324	38	77	83	26	38	45	65	37	21	62	17
4:00-4:15PM	244	37	31	245	279	25	97	112	66	48	66	57	65	26	94	22
4:15-4:30PM	261	46	22	132	277	28	63	98	87	52	66	57	42	24	85	38
4:30-4:45PM	219	34	20	181	211	40	77	94	64	53	59	69	65	34	86	39
4:45-5:00PM	304	24	26	158	246	33	91	125	68	51	78	80	54	21	75	50
5:00-5:15PM	216	24	19	192	266	44	79	140	67	44	79	76	48	18	51	54
5:15-5:30PM	294	26	17	268	217	31	76	180	45	40	47	103	69	30	95	89
5:30-5:45PM	267	20	12	313	274	21	81	159	45	50	61	119	55	28	101	47
5:45-6:00PM	274	16	17	246	236	17	68	193	42	47	61	149	67	25	149	45
6:00-6:15PM	308	18	18	287	237	17	92	196	32	37	49	129	58	20	94	43
6:15-6:30PM	285	33	13	218	254	23	66	140	39	50	59	114	80	21	104	31
6:30-6:45PM	86	9	2	231	81	21	19	210	10	14	18	117	29	16	51	48

Table A-2: Traffic volume at Gergi-Imparial signalized intersection

Gergi-Imperial (after)	**Traffic Volume**															**21/07/2017**
	Bole Approach				Megenagna Approach				Gergi Approach				Hayahulet Approach			
	TH	R	L	Ped	TH	L	R	Ped	TH	R	L	Ped	TH	R	L	Ped
7:00-7:15AM	241	51	27	422	304	43	35	103	30	45	56	67	28	53	31	36
7:15-7:30AM	310	38	33	371	348	48	35	138	70	41	90	87	25	58	36	75
7:30-7:45AM	231	45	28	381	353	55	38	158	67	49	101	72	30	61	38	75
7:45-8:00AM	238	38	30	423	252	51	31	135	83	48	94	95	42	75	40	87
8:00-8:15AM	260	52	32	436	288	54	37	150	85	42	105	101	31	79	38	88
8:15-8:30AM	282	54	34	372	292	67	26	120	76	35	87	111	47	79	42	75
8:30-8:45AM	260	46	34	303	268	46	36	165	55	45	98	79	54	89	38	68
8:45-9:00AM	253	42	33	268	228	56	22	150	82	41	106	80	51	85	37	81
9:00-9:15AM	241	38	28	187	251	48	29	162	79	41	80	91	53	91	39	72
9:15-9:30AM	271	31	18	181	274	65	23	155	68	41	74	69	42	112	35	63
9:30-9:45AM	245	42	23	224	283	58	36	125	74	42	57	67	44	52	26	54
9:45-10:00AM	219	33	26	119	303	50	47	115	73	42	69	53	38	45	28	42
10:00-10:15AM	216	43	25	168	317	54	42	132	63	43	67	79	42	51	44	57
10:15-10:30AM	248	38	28	143	262	64	33	156	79	38	81	64	37	59	37	47
10:30-10:45AM	237	38	18	186	308	56	24	139	70	44	61	59	33	41	35	70
10:45-11:00AM	276	35	21	187	268	68	41	80	56	44	72	61	38	79	32	63
11:00-11:15AM	243	26	20	167	221	62	51	129	63	40	86	40	33	58	28	32
11:15-11:30AM	259	27	23	152	280	57	40	105	58	39	53	75	40	73	47	42
11:30-11:45AM	262	29	24	149	308	70	56	88	74	44	56	61	34	53	27	34
11:45-12:00AM	270	33	25	155	295	60	33	138	50	35	50	79	49	56	29	60
12:00-12:15AM	275	44	40	165	262	62	37	137	51	28	61	89	68	70	49	64
12:15-12:30AM	220	28	36	160	224	73	41	145	92	38	69	83	70	77	58	56

12:30-12:45AM	241	43	30	136	245	64	33	156	48	38	64	68	63	88	53	44
12:45-1:00AM	189	28	30	149	228	65	51	108	72	24	83	75	63	53	38	70
1:00-1:15PM	241	40	29	122	232	42	34	147	65	37	58	90	76	80	38	30
1:15-1:30PM	192	35	31	218	205	71	49	124	57	29	80	70	61	75	38	52
1:30-1:45PM	251	31	28	206	209	58	40	148	68	40	75	104	55	58	47	60
1:45-2:00PM	268	24	23	218	224	60	38	123	57	38	81	63	61	59	35	71
2:00-2:15PM	224	43	26	125	229	74	41	108	64	40	82	73	46	57	37	26
2:15-2:30PM	232	32	26	151	236	56	33	114	51	36	57	89	41	67	39	52
2:30-2:45PM	242	42	28	127	230	55	45	111	69	40	60	59	52	52	30	38
2:45-3:00PM	242	45	26	128	234	45	37	118	49	26	52	71	48	55	29	28
3:00-3:15PM	251	31	25	136	223	60	54	126	54	34	70	84	58	53	35	32
3:15-3:30PM	239	39	27	159	225	57	27	132	71	27	84	98	57	63	49	50
3:30-3:45PM	274	27	27	143	221	61	57	122	49	37	54	76	49	45	37	30
3:45-4:00PM	199	27	26	112	284	61	57	130	38	28	46	80	41	42	30	44
4:00-4:15PM	227	30	37	236	234	55	43	153	67	31	79	76	73	62	43	62
4:15-4:30PM	260	36	33	173	222	41	49	133	70	30	81	71	49	71	30	52
4:30-4:45PM	240	43	22	108	249	63	33	179	68	36	45	82	72	47	33	70
4:45-5:00PM	294	26	28	191	242	61	52	185	55	32	65	88	58	59	56	78
5:00-5:15PM	268	55	30	211	248	49	39	180	42	28	52	73	81	75	69	88
5:15-5:30PM	293	29	37	360	169	65	30	219	54	26	73	119	69	112	80	92
5:30-5:45PM	280	43	21	297	237	54	48	210	52	17	75	110	70	80	73	98
5:45-6:00PM	336	42	30	267	252	42	60	187	53	14	58	154	46	78	53	84
6:00-6:15PM	336	40	38	257	289	57	73	214	36	26	65	148	69	81	54	92
6:15-6:30PM	305	45	30	200	266	68	52	169	46	34	64	120	81	80	53	81
6:30-6:45PM	291	39	36	282	262	55	54	186	37	29	76	128	70	69	46	77
6:45-7:00PM	283	27	24	268	238	59	46	193	26	30	47	111	65	65	37	56

Gergi-Imperial (after)	**Traffic Volume**															**17/07/2017**
	Bole Approach				Megenagna Approach				Gergi Approach				Hayahulet Approach			
	TH	L	R	Ped	TH	L	R	Ped	TH	L	R	Ped	TH	L	R	Ped
7:00-7:15AM	242	25	36	273	240	51	30	108	31	57	18	53	21	24	47	30
7:15-7:30AM	276	32	28	259	202	62	34	92	41	56	26	92	20	29	52	53
7:30-7:45AM	261	16	26	269	223	53	26	168	32	68	23	92	23	33	55	91
7:45-8:00AM	295	25	28	279	203	54	44	213	21	39	22	104	35	31	69	73
8:00-8:15AM	292	33	32	401	225	38	32	178	82	97	34	74	25	34	73	85
8:15-8:30AM	271	25	35	365	146	54	23	219	73	79	29	61	38	37	72	74
8:30-8:45AM	275	31	38	325	214	43	41	150	50	90	38	54	45	33	83	71
8:45-9:00AM	250	19	27	289	226	31	53	163	77	98	35	67	44	30	80	82
9:00-9:15AM	198	21	34	248	206	40	31	136	74	67	39	82	39	30	87	69
9:15-9:30AM	202	22	21	216	190	27	41	127	63	55	36	73	34	32	90	60
9:30-9:45AM	211	22	31	210	220	48	23	106	69	50	39	64	43	23	50	56
9:45-10:00AM	211	21	35	228	210	46	42	94	68	46	26	52	41	21	40	65
10:00-10:15AM	220	18	22	202	288	40	32	108	49	59	26	77	51	27	49	34
10:15-10:30AM	209	22	30	192	233	50	25	129	66	77	31	67	50	40	54	46
10:30-10:45AM	246	22	18	182	275	42	16	107	44	51	38	90	41	30	31	73
10:45-11:00AM	168	21	18	196	240	54	31	105	35	59	25	83	34	24	64	54
11:00-11:15AM	202	31	20	205	201	60	35	100	43	68	34	65	66	35	55	45
11:15-11:30AM	231	28	26	201	208	42	24	98	48	72	24	75	42	23	66	40
11:30-11:45AM	215	17	31	205	202	41	33	86	52	40	33	67	64	26	47	36
11:45-12:00AM	265	20	17	213	206	31	20	167	48	53	27	93	51	49	48	88
12:00-12:15AM	249	27	35	209	270	32	28	132	60	50	31	79	62	47	77	44
12:15-12:30AM	194	33	17	221	318	37	28	157	52	72	23	71	74	47	88	55
12:30-12:45AM	215	21	34	181	329	44	31	102	63	67	32	59	63	39	76	49

12:45-1:00AM	163	27	19	187	233	41	24	99	52	73	33	85	60	30	68	57
1:00-1:15PM	215	31	31	220	210	31	27	130	46	53	20	61	70	31	63	48
1:15-1:30PM	166	31	26	216	183	60	42	171	84	61	34	83	55	30	68	59
1:30-1:45PM	225	33	22	246	185	44	33	181	43	56	30	91	47	39	67	53
1:45-2:00PM	242	26	15	178	200	48	31	156	67	75	16	102	42	30	43	58
2:00-2:15PM	205	23	29	155	193	48	37	118	61	79	26	60	45	32	46	35
2:15-2:30PM	244	13	22	181	252	43	32	99	46	60	30	86	36	29	75	48
2:30-2:45PM	214	18	34	143	280	51	50	109	64	51	27	72	37	27	42	41
2:45-3:00PM	189	21	24	123	267	43	25	133	44	59	26	62	31	24	42	36
3:00-3:15PM	190	19	34	141	195	46	40	114	52	44	21	61	35	37	43	38
3:15-3:30PM	216	23	29	175	196	43	19	123	54	65	19	79	29	30	54	47
3:30-3:45PM	211	13	29	135	193	47	51	115	64	67	13	59	27	28	43	37
3:45-4:00PM	251	16	27	179	253	47	49	112	45	50	10	73	34	25	43	44
4:00-4:15PM	207	15	15	178	257	43	63	154	64	81	21	90	25	21	51	51
4:15-4:30PM	227	18	18	178	237	54	44	134	65	46	31	80	33	39	67	46
4:30-4:45PM	225	19	20	202	234	41	48	109	65	45	31	98	28	19	41	55
4:45-5:00PM	245	20	24	224	210	45	36	279	50	46	24	106	40	22	52	69
5:00-5:15PM	215	29	50	188	262	45	65	240	58	62	38	132	77	63	71	67
5:15-5:30PM	271	25	29	242	243	57	45	234	74	72	24	136	62	72	87	87
5:30-5:45PM	192	27	43	274	240	45	47	158	65	48	30	142	63	69	63	108
5:45-6:00PM	222	22	34	334	216	48	39	219	51	43	31	128	37	46	63	85
6:00-6:15PM	241	21	42	307	229	37	22	238	25	48	37	139	60	42	72	90
6:15-6:30PM	264	23	45	277	252	54	16	213	67	82	33	128	62	52	70	103
6:30-6:45PM	224	19	30	283	261	48	27	203	62	93	41	124	57	46	66	96
6:45-7:00PM	232	20	25	249	280	39	40	223	79	86	40	103	56	33	53	99

Gergi-Imperial (after)	**Traffic Volume**															**19/07/2017**
	Bole Approach				Megenagna Approach				Gergi Approach				Hayahulet Approach			
	TH	L	R	Ped	TH	L	R	Ped	TH	L	R	Ped	TH	L	R	Ped
7:00-7:15AM	214	23	45	154	285	51	39	125	45	58	37	87	29	24	44	37
7:15-7:30AM	235	35	31	209	261	28	24	180	63	75	44	112	25	31	47	52
7:30-7:45AM	224	23	40	232	266	57	37	159	40	53	50	98	31	35	54	72
7:45-8:00AM	255	24	33	244	249	41	31	193	31	54	33	129	39	37	40	64
8:00-8:15AM	282	30	46	280	283	35	33	156	78	94	38	119	37	37	29	76
8:15-8:30AM	267	32	48	252	232	51	21	100	69	76	53	127	52	40	42	83
8:30-8:45AM	233	33	37	259	285	40	34	170	52	87	38	108	32	37	57	91
8:45-9:00AM	224	29	35	223	313	29	54	160	73	95	37	129	28	31	54	54
9:00-9:15AM	207	21	33	213	257	33	25	117	29	55	51	86	50	32	42	39
9:15-9:30AM	189	16	23	215	245	36	18	107	37	53	46	74	21	34	74	67
9:30-9:45AM	193	20	34	233	261	35	27	112	29	69	35	39	37	24	41	53
9:45-10:00AM	207	23	26	289	277	27	34	128	20	37	49	72	41	24	40	72
10:00-10:15AM	204	20	35	178	296	45	30	121	33	41	33	76	41	28	52	63
10:15-10:30AM	204	28	30	164	285	49	26	109	45	62	29	68	34	42	74	47
10:30-10:45AM	218	15	32	198	280	55	17	123	59	68	29	86	31	31	56	90
10:45-11:00AM	158	18	27	174	316	57	32	152	48	71	28	71	32	27	54	38
11:00-11:15AM	199	20	16	169	278	40	33	139	54	65	34	69	28	37	38	60
11:15-11:30AM	205	20	18	193	260	26	39	135	49	69	44	77	43	24	70	47
11:30-11:45AM	207	19	20	195	302	48	45	158	65	37	48	82	43	28	41	34
11:45-12:00AM	235	24	24	185	274	41	25	89	41	50	43	89	43	51	46	50
12:00-12:15AM	214	36	36	189	352	42	62	108	56	42	20	67	45	49	50	60
12:15-12:30AM	171	32	18	179	327	54	42	105	54	68	31	82	65	48	64	54
12:30-12:45AM	203	27	36	161	314	41	46	120	45	59	40	72	46	41	70	33

12:45-1:00AM	165	27	20	197	285	46	36	153	45	47	40	68	46	34	38	43
1:00-1:15PM	171	27	32	148	300	24	24	156	46	56	39	77	44	34	66	60
1:15-1:30PM	176	27	29	196	285	30	25	136	44	48	40	112	51	32	61	72
1:30-1:45PM	226	25	23	220	326	38	31	132	27	43	25	67	53	41	55	45
1:45-2:00PM	244	20	19	200	240	33	19	135	60	75	39	92	58	30	46	34
2:00-2:15PM	182	27	34	173	316	61	34	94	57	76	52	62	45	34	81	62
2:15-2:30PM	240	25	23	158	321	58	28	99	42	57	46	77	47	30	90	33
2:30-2:45PM	203	22	35	148	342	49	35	118	60	48	48	64	55	19	45	49
2:45-3:00PM	191	26	34	136	309	37	25	93	42	56	27	51	43	23	35	38
3:00-3:15PM	174	24	23	149	333	37	42	103	54	57	40	83	57	39	42	69
3:15-3:30PM	198	25	31	167	274	44	18	108	70	68	34	70	66	31	47	38
3:30-3:45PM	186	28	19	174	335	34	48	99	61	40	38	32	51	30	32	53
3:45-4:00PM	229	28	22	139	343	41	49	120	47	42	28	55	29	27	64	37
4:00-4:15PM	171	31	20	164	274	47	38	123	60	78	39	97	55	23	51	50
4:15-4:30PM	208	35	27	196	280	40	32	114	61	43	42	69	36	41	58	71
4:30-4:45PM	194	19	34	199	344	46	23	149	61	42	43	85	52	21	42	50
4:45-5:00PM	227	22	18	220	354	48	43	144	46	43	42	73	48	24	43	59
5:00-5:15PM	185	28	44	267	343	46	27	169	70	64	36	98	47	68	67	69
5:15-5:30PM	228	29	33	337	343	59	20	174	59	52	45	113	61	74	84	71
5:30-5:45PM	180	20	45	253	319	38	29	201	65	47	49	124	49	71	69	88
5:45-6:00PM	176	28	34	249	266	48	14	177	67	43	61	148	56	45	68	58
6:00-6:15PM	203	33	33	282	324	55	29	148	47	46	26	93	57	43	68	78
6:15-6:30PM	211	26	37	258	358	65	33	102	62	77	38	81	66	53	66	60
6:30-6:45PM	202	31	36	292	351	56	25	188	41	51	40	80	28	46	50	68
6:45-7:00PM	184	22	31	276	318	57	43	221	62	71	35	96	56	38	54	65

Table A-2: Traffic volume at Ayer-Tena intersection

Ayer-Tena	**Traffic Volume**															**09/06/2017**
	Torhayloch Approach				Alembank Approach				Alemgena Approach				Jamo Approach			
	TH	R	L	Ped	TH	R	L	Ped	TH	R	L	Ped	TH	R	L	Ped
7:00-7:15AM	90	109	22	417	118	53	128	188	297	47	23	156	69	18	13	386
7:15-7:30AM	88	110	23	473	132	81	155	330	290	55	14	208	53	17	14	420
7:30-7:45AM	93	112	26	602	127	78	166	462	258	50	14	303	60	16	14	560
7:45-8:00AM	74	90	16	588	81	48	101	504	249	49	13	305	71	25	19	548
8:00-8:15AM	100	109	19	578	95	64	115	544	228	40	27	240	100	27	19	562
8:15-8:30AM	92	107	16	690	87	77	101	429	185	19	20	219	92	25	17	477
8:30-8:45AM	93	92	19	582	75	77	88	449	211	23	26	171	80	23	15	458
8:45-9:00AM	90	103	17	700	85	82	79	504	233	22	28	223	68	17	16	492
9:00-9:15AM	122	132	28	406	86	72	95	571	202	23	21	218	85	24	19	421
9:15-9:30AM	112	111	26	510	71	78	81	380	189	21	22	186	84	24	19	435
9:30-9:45AM	132	128	31	473	82	58	81	285	220	27	26	170	83	23	16	412
9:45-10:00AM	118	114	29	483	72	85	80	298	205	20	19	210	72	26	17	421
10:00-10:15AM	96	123	20	332	86	55	98	309	197	32	30	210	73	27	14	337
10:15-10:30AM	96	126	23	402	74	57	89	253	196	23	22	201	73	24	15	342
10:30-10:45AM	97	127	23	336	77	60	67	428	216	22	29	118	85	24	16	337
10:45-11:00AM	91	134	22	429	74	60	70	290	197	23	25	119	76	23	17	358
11:00-11:15AM	103	115	15	266	89	77	76	342	186	43	7	167	91	28	19	405
11:15-11:30AM	90	105	18	354	90	52	77	331	206	31	20	133	90	26	20	331
11:30-11:45AM	118	128	27	367	67	78	64	345	162	26	17	228	89	27	19	342
11:45-12:00AM	115	134	22	390	65	68	48	340	176	26	18	133	86	27	17	354
12:00-12:15AM	108	113	21	371	64	76	65	220	170	11	35	170	72	25	17	370
12:15-12:30AM	100	101	16	348	73	54	66	270	155	20	32	202	90	23	21	402

12:30-12:45AM	105	104	19	298	64	58	61	278	181	20	37	111	96	21	20	371
12:45-1:00AM	83	93	24	347	75	62	57	249	157	18	35	185	62	21	16	260
1:00-1:15PM	92	96	23	425	57	54	41	294	160	13	25	112	66	23	16	310
1:15-1:30PM	81	69	15	458	69	81	71	281	136	20	24	200	82	25	17	417
1:30-1:45PM	88	88	18	409	74	58	63	294	208	23	22	220	80	28	19	343
1:45-2:00PM	100	91	17	346	75	60	64	309	165	13	28	195	80	17	23	422
2:00-2:15PM	144	78	16	400	60	65	69	278	178	25	30	94	79	14	15	260
2:15-2:30PM	134	73	19	441	75	47	74	271	148	24	27	136	80	16	12	346
2:30-2:45PM	154	84	21	257	59	89	75	210	195	35	33	153	81	16	17	314
2:45-3:00PM	145	87	20	229	69	65	60	452	201	36	32	168	89	24	15	307
3:00-3:15PM	105	104	22	361	83	62	76	410	116	23	26	149	88	24	15	367
3:15-3:30PM	124	127	28	271	73	52	71	478	158	23	34	176	97	23	18	332
3:30-3:45PM	126	125	29	307	80	65	78	370	141	20	38	156	99	25	17	324
3:45-4:00PM	134	138	32	340	75	86	79	394	152	29	34	213	91	22	13	311
4:00-4:15PM	131	136	31	461	63	38	63	327	173	25	23	195	85	18	19	358
4:15-4:30PM	136	146	27	495	63	44	76	464	175	27	25	211	78	15	16	358
4:30-4:45PM	127	132	30	444	81	38	72	440	152	24	17	163	94	26	20	417
4:45-5:00PM	120	129	28	473	70	63	74	381	163	24	21	189	72	15	14	406
5:00-5:15PM	129	126	39	589	73	47	72	394	162	27	32	223	104	27	23	513
5:15-5:30PM	130	123	35	578	74	54	68	404	164	25	24	301	108	21	24	430
5:30-5:45PM	100	98	33	640	67	51	78	449	163	40	23	192	116	30	22	607
5:45-6:00PM	124	128	36	704	75	48	90	528	121	17	22	247	116	28	26	576
6:00-6:15PM	142	151	23	579	69	54	77	503	168	23	26	185	98	27	19	551
6:15-6:30PM	125	132	18	592	67	44	68	533	126	20	25	218	106	22	20	607
6:30-6:45PM	117	123	26	683	70	36	75	473	124	20	17	301	117	22	18	530
6:45-7:00PM	136	135	24	461	66	46	73	478	132	19	29	248	95	23	16	549

Ayer-Tena					Traffic Volume											05/06/2017
	Torhayloch Approach				Alembank Approach				Alemgena Approach				Jamo Approach			
	TH	R	L	Ped	TH	R	L	Ped	TH	R	L	Ped	TH	R	L	Ped
7:00-7:15AM	107	115	33	430	103	45	115	359	219	46	22	194	72	25	12	481
7:15-7:30AM	112	112	29	472	122	77	145	371	234	54	14	180	65	20	13	398
7:30-7:45AM	94	87	27	442	117	74	156	423	215	49	14	190	72	25	13	575
7:45-8:00AM	97	117	30	418	71	44	91	481	238	48	14	200	71	26	18	544
8:00-8:15AM	98	140	17	502	85	60	105	487	205	39	27	307	76	23	18	564
8:15-8:30AM	112	121	12	538	77	73	91	539	169	18	20	271	72	23	16	620
8:30-8:45AM	111	112	20	661	65	73	78	494	196	22	28	231	77	21	14	543
8:45-9:00AM	120	124	18	802	75	77	69	519	195	21	27	195	64	16	15	562
9:00-9:15AM	106	116	23	447	70	62	78	428	155	24	29	191	62	13	13	416
9:15-9:30AM	93	96	22	357	58	68	65	442	125	23	26	159	66	16	10	384
9:30-9:45AM	102	112	26	312	65	48	62	436	172	34	32	153	68	17	15	377
9:45-10:00AM	89	99	24	357	55	76	64	420	178	35	31	171	76	23	14	497
10:00-10:15AM	77	107	13	363	69	45	82	330	93	22	25	163	74	23	14	388
10:15-10:30AM	65	111	17	321	57	47	73	354	135	22	33	153	83	21	17	380
10:30-10:45AM	79	112	22	399	60	50	51	335	118	19	37	143	77	22	14	367
10:45-11:00AM	65	108	23	315	57	50	54	334	129	28	33	157	78	20	11	264
11:00-11:15AM	102	88	13	315	65	67	60	284	150	24	22	162	71	16	16	321
11:15-11:30AM	94	90	11	378	66	42	61	282	152	26	24	158	62	14	14	380
11:30-11:45AM	106	104	16	312	54	68	48	248	129	23	16	162	83	25	17	369
11:45-12:00AM	107	98	13	420	48	59	49	319	140	23	20	170	58	14	12	233
12:00-12:15AM	99	102	17	246	63	40	61	318	155	26	31	169	65	20	16	257
12:15-12:30AM	100	90	12	330	64	47	56	361	157	24	23	181	83	17	20	364
12:30-12:45AM	99	93	15	387	58	45	65	311	142	39	23	141	89	14	19	290

12:45-1:00AM	100	82	20	570	65	42	78	313	114	16	21	147	55	23	14	369
1:00-1:15PM	110	85	17	665	63	48	64	330	151	22	25	169	59	34	15	351
1:15-1:30PM	88	58	11	545	57	37	56	367	109	19	24	165	75	20	16	372
1:30-1:45PM	89	77	12	479	60	33	62	388	107	19	16	195	73	25	20	404
1:45-2:00PM	117	80	11	506	59	39	60	374	115	18	28	127	73	20	22	373
2:00-2:15PM	105	59	9	326	44	55	47	291	166	22	18	153	70	22	15	301
2:15-2:30PM	97	49	13	353	59	39	58	274	157	20	19	179	74	22	15	315
2:30-2:45PM	114	65	16	374	42	59	57	280	184	26	23	141	72	21	12	292
2:45-3:00PM	117	65	15	392	50	55	44	303	173	19	18	121	63	23	13	301
3:00-3:15PM	101	87	14	315	66	52	60	278	171	31	28	130	62	19	10	313
3:15-3:30PM	92	108	18	423	60	42	55	255	152	22	20	164	59	22	10	318
3:30-3:45PM	89	96	17	375	60	55	63	244	192	23	26	124	72	23	11	313
3:45-4:00PM	93	109	18	348	62	77	63	225	164	24	23	168	63	22	12	334
4:00-4:15PM	101	103	19	422	50	28	47	418	142	42	10	129	78	25	15	431
4:15-4:30PM	82	110	15	458	50	35	60	264	165	30	18	129	77	24	16	357
4:30-4:45PM	86	103	20	398	68	28	57	245	149	25	14	153	78	25	14	368
4:45-5:00PM	89	102	18	602	57	50	58	399	132	25	16	175	69	25	13	427
5:00-5:15PM	102	91	16	633	61	74	58	490	185	10	34	187	87	25	22	439
5:15-5:30PM	97	99	17	741	65	52	56	525	173	19	31	241	85	23	23	473
5:30-5:45PM	109	101	22	609	59	57	51	486	184	19	36	273	91	25	21	613
5:45-6:00PM	81	79	13	561	70	58	51	572	204	17	34	333	106	26	22	601
6:00-6:15PM	94	117	20	633	51	52	40	522	182	12	24	281	107	24	18	559
6:15-6:30PM	104	96	17	876	63	78	67	562	171	19	23	251	109	25	19	474
6:30-6:45PM	87	81	21	546	68	57	56	612	183	22	21	257	106	23	19	455
6:45-7:00PM	88	92	17	606	69	58	57	688	155	12	27	223	85	20	15	489

Ayer-Tena	Traffic Volume														07/06/2017	
	Torhayloch Approach				Alembank Approach				Alemgena Approach				Jamo Approach			
	TH	R	L	Ped	TH	R	L	Ped	TH	R	L	Ped	TH	R	L	Ped
7:00-7:15AM	93	102	23	473	90	37	83	368	272	44	19	187	69	15	16	386
7:15-7:30AM	92	99	22	417	105	67	110	394	261	43	10	243	63	13	17	375
7:30-7:45AM	77	114	23	541	98	66	102	383	199	36	14	265	59	15	18	437
7:45-8:00AM	69	86	14	569	76	39	71	404	220	41	11	277	66	22	25	501
8:00-8:15AM	97	106	14	610	74	52	76	381	183	32	25	286	73	21	15	548
8:15-8:30AM	95	102	8	534	71	62	91	354	154	20	21	258	58	23	18	561
8:30-8:45AM	89	90	18	618	75	63	57	443	176	20	23	266	67	18	15	652
8:45-9:00AM	94	94	10	606	77	67	62	468	187	22	28	230	57	15	15	430
9:00-9:15AM	85	93	24	494	51	52	54	283	139	19	25	198	57	18	12	428
9:15-9:30AM	73	81	22	350	55	43	59	271	144	17	24	200	63	15	12	469
9:30-9:45AM	89	88	27	486	45	75	60	275	140	25	29	218	68	17	15	285
9:45-10:00AM	78	80	25	498	50	49	45	288	145	24	26	174	57	19	17	257
10:00-10:15AM	72	95	14	338	61	48	60	279	115	17	30	170	64	14	14	406
10:15-10:30AM	80	94	17	410	48	38	58	263	119	16	33	156	59	20	12	316
10:30-10:45AM	76	102	19	358	63	51	65	271	119	18	35	190	60	14	14	352
10:45-11:00AM	70	98	18	270	48	71	64	291	119	23	32	166	65	18	11	385
11:00-11:15AM	73	77	11	385	49	24	49	284	142	18	22	166	70	15	14	357
11:15-11:30AM	60	80	12	401	48	29	62	277	146	21	21	190	59	20	13	391
11:30-11:45AM	86	96	17	429	58	27	59	297	128	20	19	192	74	22	16	340
11:45-12:00AM	85	87	14	405	47	48	59	226	144	13	23	182	59	19	10	321
12:00-12:15AM	88	97	18	419	66	33	57	287	145	24	27	184	67	18	14	455
12:15-12:30AM	80	85	13	383	66	41	53	289	116	26	26	174	67	16	18	406
12:30-12:45AM	85	88	16	363	67	37	63	312	164	21	25	156	67	17	16	343

12:45-1:00AM	63	77	21	279	51	33	75	357	131	20	23	192	51	15	12	344
1:00-1:15PM	72	80	18	511	60	39	63	374	112	25	24	148	74	15	15	510
1:15-1:30PM	71	53	12	327	51	29	53	355	111	20	24	196	87	21	13	460
1:30-1:45PM	68	72	13	427	43	23	60	345	97	22	12	220	79	19	13	509
1:45-2:00PM	80	75	12	327	42	30	58	337	100	19	27	200	65	12	17	508
2:00-2:15PM	106	55	10	419	75	58	78	283	144	18	24	152	65	8	15	310
2:15-2:30PM	102	50	15	367	50	64	64	288	130	16	21	138	53	13	13	414
2:30-2:45PM	117	61	17	275	71	44	64	308	157	21	23	128	63	10	13	377
2:45-3:00PM	117	62	16	387	51	72	63	290	122	14	15	116	73	20	10	387
3:00-3:15PM	78	81	15	376	66	40	71	266	156	25	23	131	90	16	10	332
3:15-3:30PM	94	104	20	224	68	42	73	268	130	16	23	149	77	16	14	402
3:30-3:45PM	95	102	22	316	71	46	52	261	172	17	32	155	86	19	13	336
3:45-4:00PM	102	95	25	508	67	46	54	271	157	17	28	121	66	14	12	429
4:00-4:15PM	110	91	25	366	83	65	60	312	140	25	13	165	71	14	18	376
4:15-4:30PM	98	91	21	426	61	37	62	303	162	27	23	197	77	8	18	464
4:30-4:45PM	97	97	24	402	59	65	49	334	126	21	18	199	85	23	17	477
4:45-5:00PM	92	96	22	374	57	52	33	326	144	24	17	221	72	9	15	457
5:00-5:15PM	120	97	33	548	60	64	73	494	184	11	34	236	79	27	21	466
5:15-5:30PM	114	109	26	588	63	46	95	492	170	19	26	306	97	20	19	522
5:30-5:45PM	112	85	28	684	65	47	95	525	198	23	34	222	104	24	19	651
5:45-6:00PM	120	111	31	600	63	50	72	292	194	24	35	218	125	25	20	637
6:00-6:15PM	125	133	21	616	57	48	81	503	170	19	25	238	108	23	22	454
6:15-6:30PM	115	112	22	612	59	71	76	491	157	21	21	214	93	16	20	566
6:30-6:45PM	110	105	22	676	65	51	77	498	199	23	23	248	103	20	25	458
6:45-7:00PM	120	119	19	268	62	51	58	675	168	19	22	232	91	17	21	576

APPENDIX-B

SIDRA INTERSECTION OUTPUT DATA

Output data for Gergi-Imparial Roundabout

Site Properties	
Site (Intersection) Type	Roundabout
Model Name	Standard Right
Drive Rule	Right-hand side of the road
New Zealand Rule	No
HCM Version	No
Units	Metric

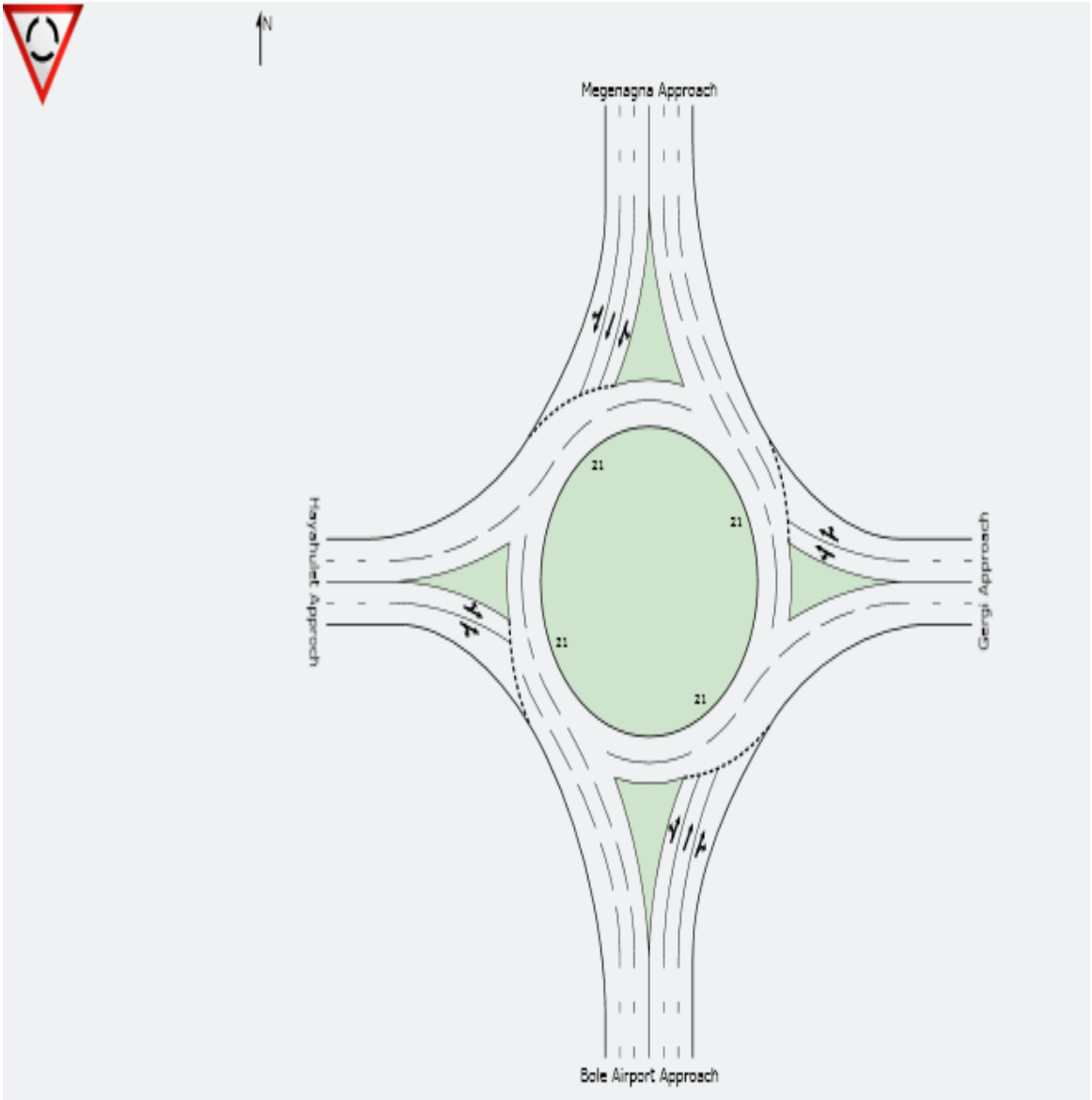


Figure B-1: Intersection Layout

Table B-1: Gergi-Imparial roundabout performance analysis result (output)

GERJI IMPERIAL ROUNDABOUT
Roundabout

Lane Use and Performance

	Demand Flows L veh/h	T veh/h	R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
South: Bole Airport Approach																
Lane 1	141	698	0	839	9.3	284	2.954	100	896.5	LOS F	184.0	1390.7	500	–	0.0	69.8
Lane 2	0	970	0	970	9.7	329	2.954	100	894.3	LOS F	212.0	1606.8	500	–	0.0	100.0
Lane 3	0	0	252	252	8.0	199	1.266	43[5]	153.4	LOS F	21.6	161.3	500	–	0.0	0.0
Approach	141	1669	252	2061	9.3		2.954		804.7	LOS F	212.0	1606.8				
East: Gergi Approach																
Lane 1	497	78	0	575	5.5	470	1.224	100	119.7	LOS F	44.0	322.5	500	–	0.0	0.0
Lane 2	0	292	306	598	3.3	488	1.224	100	119.1	LOS F	45.6	328.0	500	–	0.0	0.0
Approach	497	369	306	1172	4.4		1.224		119.4	LOS F	45.6	328.0				
North: Megenagna Approach																
Lane 1	465	710	0	1175	6.3	506	2.320	100	603.5	LOS F	223.7	1650.1	500	–	0.0	100.0
Lane 2	0	1360	0	1360	7.9	586	2.320	100	602.1	LOS F	257.7	1926.5	500	–	0.0	100.0
Lane 3	0	0	228	228	4.9	351	0.650	28[5]	9.5	LOS A	3.1	22.7	500	–	0.0	0.0
Approach	465	2070	228	2763	7.0		2.320		553.7	LOS F	257.7	1926.5				
West: Hayahulet Approch																
Lane 1	471	17	0	488	4.4	318	1.535	100	262.9	LOS F	64.2	466.7	500	–	0.0	3.0
Lane 2	0	294	248	542	5.0	353	1.535	100	261.4	LOS F	70.8	516.5	500	–	0.0	6.0
Approach	471	311	248	1030	4.7		1.535		262.1	LOS F	70.8	516.5				
Intersection				7027	6.9		2.954		512.1	LOS F	257.7	1926.5				

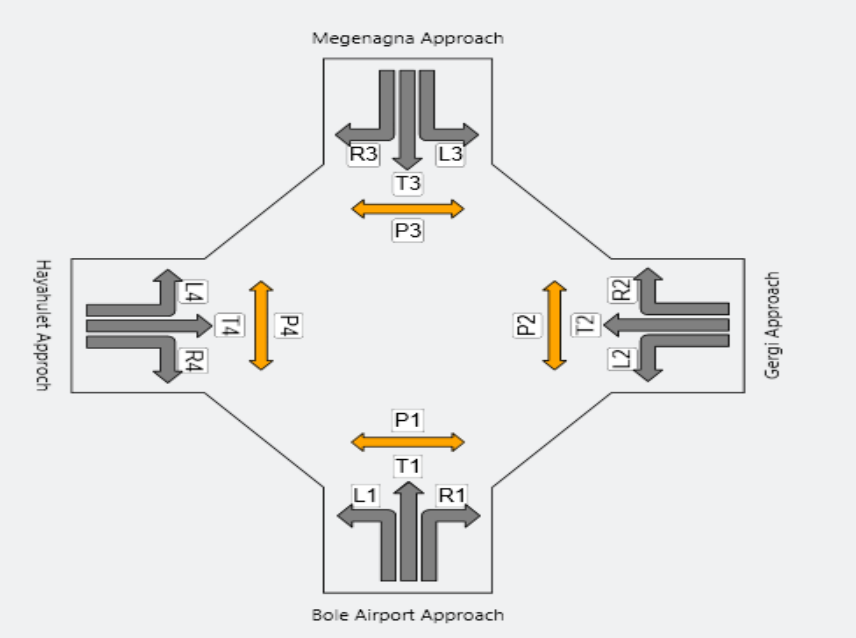


Figure B-2: Movement Id

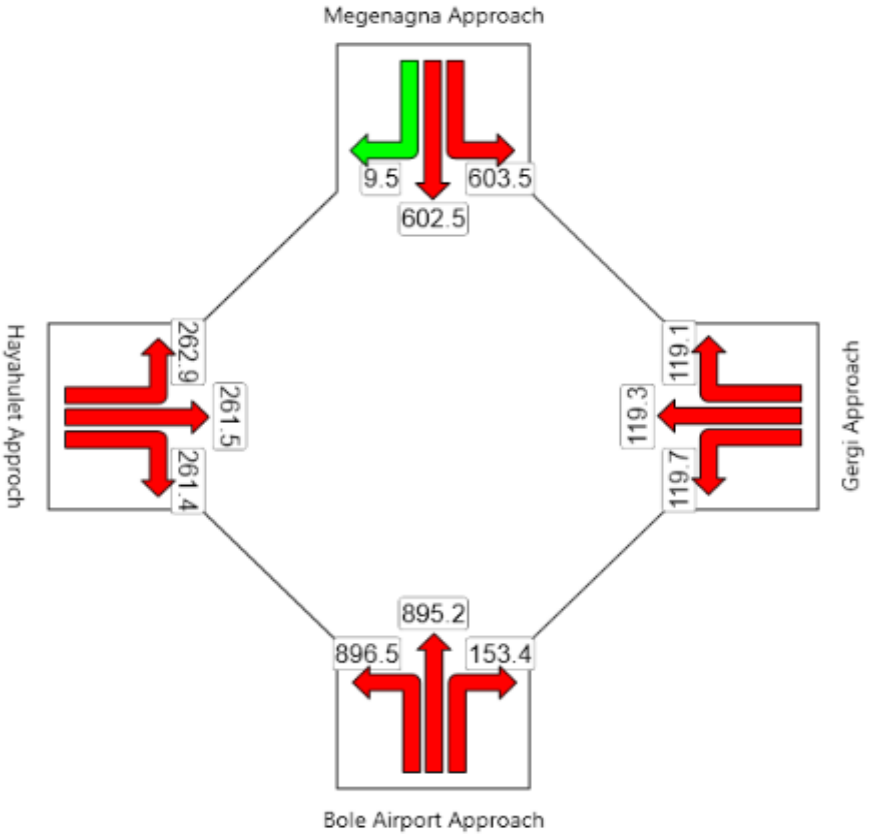


Figure B-3: Delay in Second

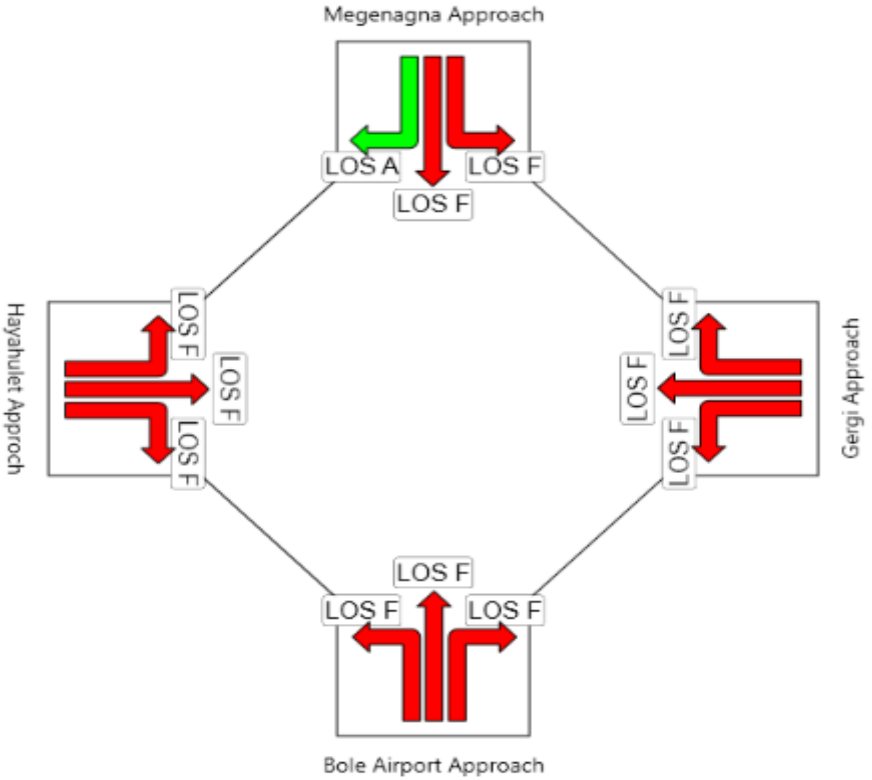


Figure B-4: Level of service

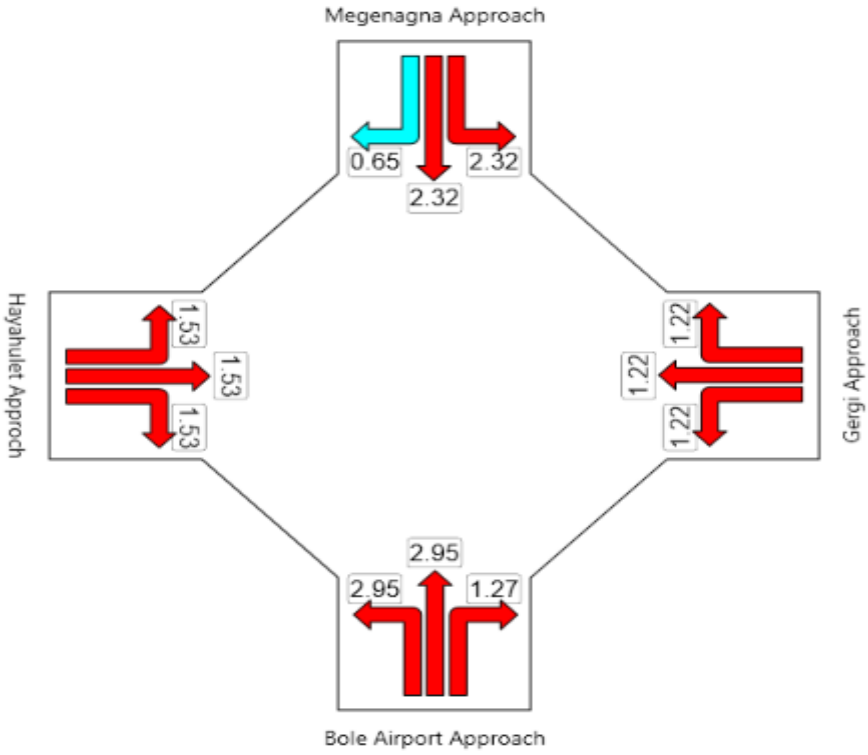


Figure B-5: Degree of Saturation

Output data for Gergi-Imparial Signalized Intersection

Site Properties	
Site (Intersection) Type	Signals
Model Name	Standard Right
Drive Rule	Right-hand side of the road
New Zealand Rule	No
HCM Version	No
Units	Metric

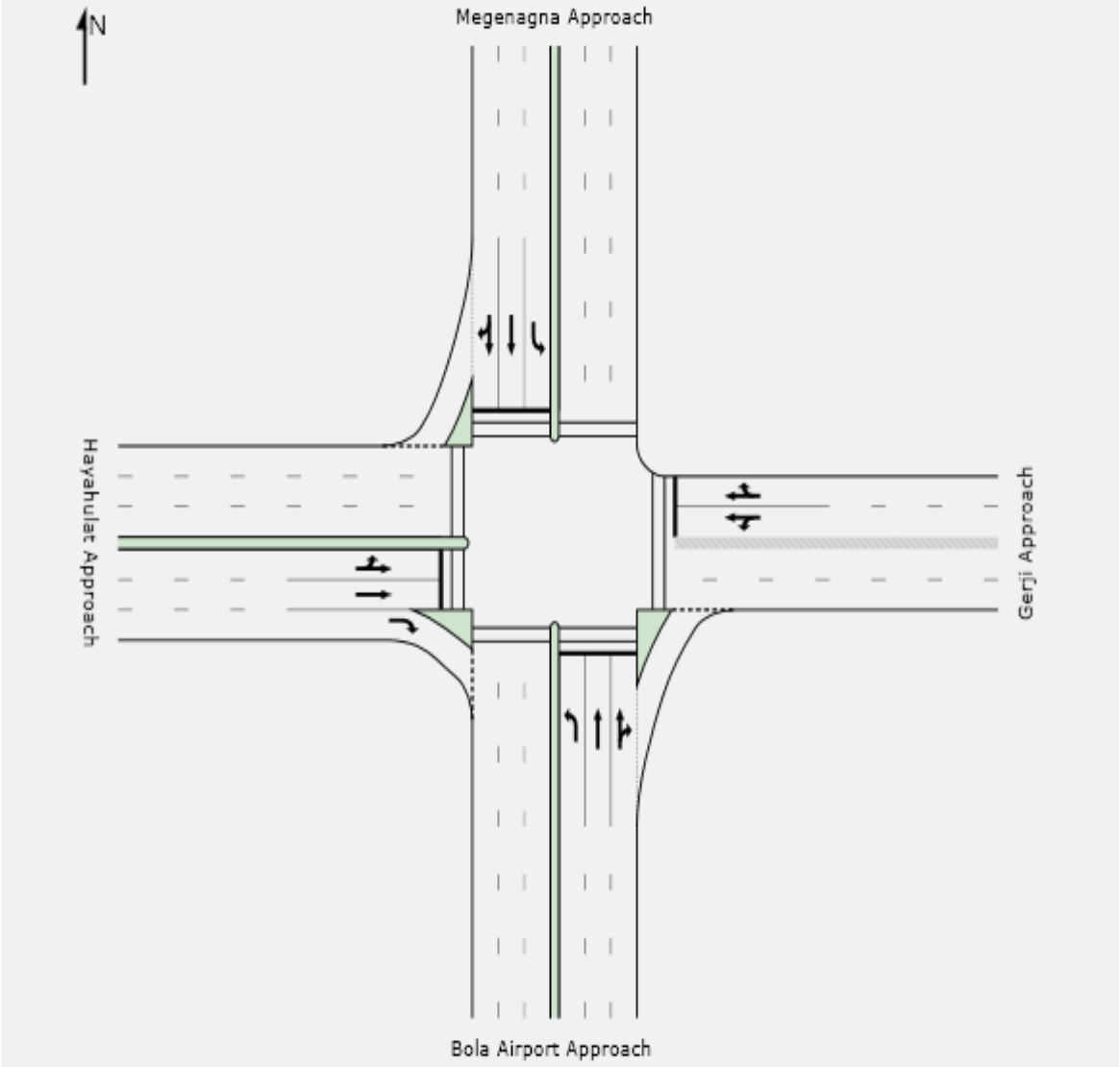


Figure B-1: Intersection Layout

PHASING SUMMARY

Site: New Site - 1

IMPARIAL SIGNALIZED INTERSECTION
Signals - Fixed Time Cycle Time = 203 seconds (User-Given Phase Times)

Phase times specified by the user
Sequence: Split Phasing
Input Sequence: A, B, C, D, E
Output Sequence: A, B, C, D, E

Phase Timing Results

Phase	A	B	C	D	E
Green Time (sec)	30	20	48	30	50
Yellow Time (sec)	3	3	3	3	3
All-Red Time (sec)	2	2	2	2	2
Phase Time (sec)	35	25	53	35	55
Phase Split	17 %	12 %	26 %	17 %	27 %

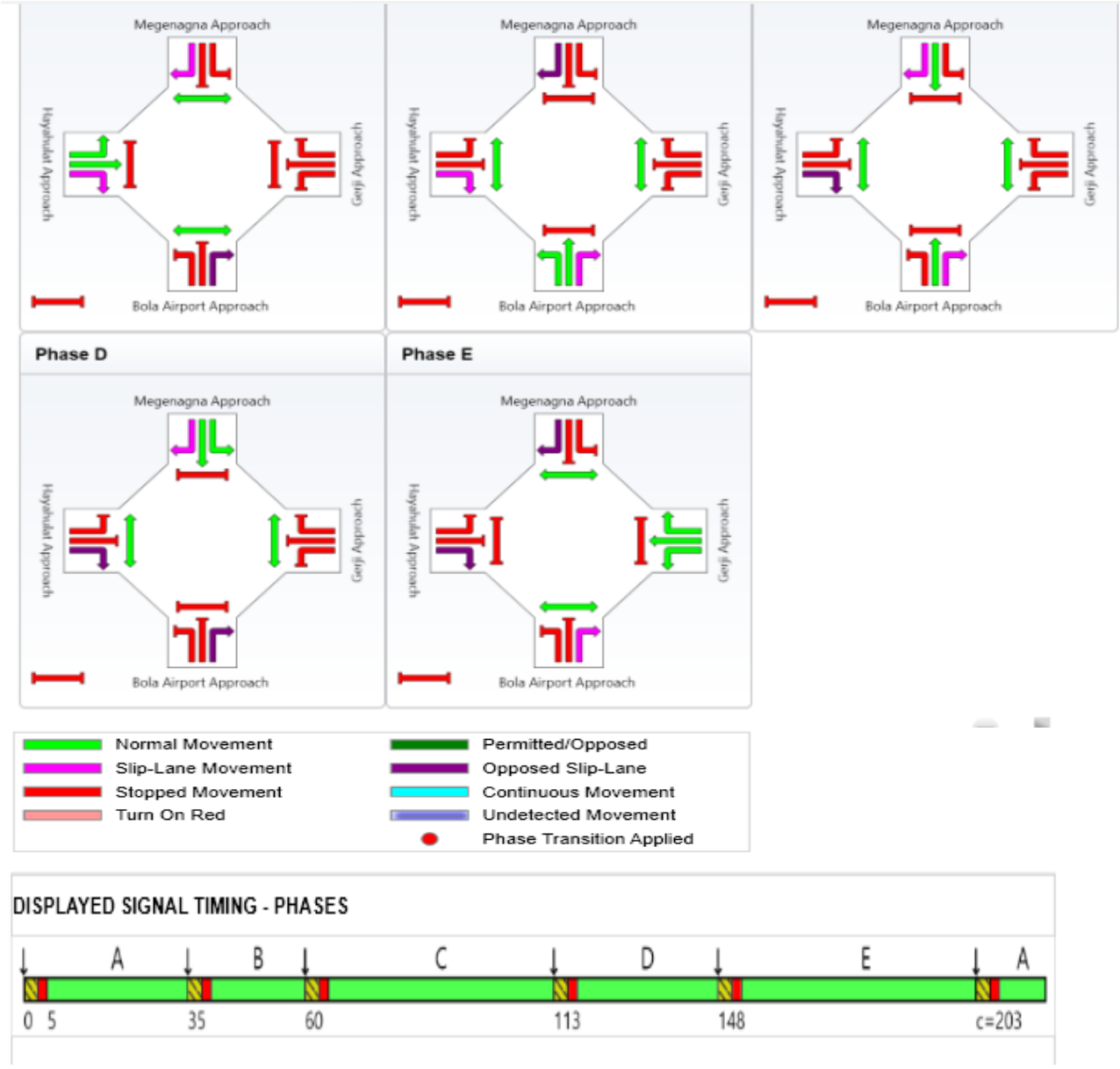


Figure B-2: Phase time results of traffic signal

Table B-1: Gergi-Imparial Signalized Intersection performance analysis result (output)

IMPARIAL SIGNALIZED INTERSECTION
Signals - Fixed Time Cycle Time = 203 seconds (User-Given Phase Times)

Lane Use and Performance

	Demand Flows L veh/h	T veh/h	R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
South: Bola Airport Approach																
Lane 1	177	0	0	177	7.1	131	1.347	100	275.7	LOS F	28.8	214.0	500	–	0.0	0.0
Lane 2	0	936	0	936	10.1	496	1.888	100	506.5	LOS F	195.2	1484.4	500	–	0.0	100.0
Lane 3	0	674	275	949	9.4	503	1.888	100	473.2	LOS F	168.7	1276.3	500	–	0.0	93.3
Approach	177	1610	275	2062	9.5		1.888		471.4	LOS F	195.2	1484.4				
East: Gerji Approach																
Lane 1	520	35	0	555	5.8	342	1.623	100	390.9	LOS F	105.1	772.3	500	–	0.0	44.8
Lane 2	0	322	257	580	3.2	357	1.623	100	390.3	LOS F	109.5	787.7	500	–	0.0	46.7
Approach	520	357	257	1135	4.5		1.623		390.6	LOS F	109.5	787.7				
North: Megenagna Approach																
Lane 1	335	0	0	335	3.8	207	1.615	100	392.7	LOS F	62.6	452.2	500	–	0.0	0.0
Lane 2	0	968	0	968	8.8	585	1.655	100	395.2	LOS F	188.4	1417.7	500	–	0.0	100.0
Lane 3	0	730	248	979	7.7	591	1.655	100	368.8	LOS F	166.8	1245.1	500	–	0.0	90.8
Approach	335	1698	248	2282	7.6		1.655		383.5	LOS F	188.4	1417.7				
West: Hayahulat Approach																
Lane 1	328	0	0	328	5.8	188	1.750	100	454.8	LOS F	64.6	474.8	500	–	0.0	0.3
Lane 2	0	336	0	336	3.9	200	1.677	96[5]	421.0	LOS F	64.3	464.9	500	–	0.0	0.0
Lane 3	0	0	421	421	5.3	400	1.052	100	74.4	LOS F	45.2	330.9	500	–	0.0	0.0
Approach	328	336	421	1085	5.0		1.750		296.7	LOS F	64.6	474.8				
Intersection				6564	7.2		1.888		398.0	LOS F	195.2	1484.4				

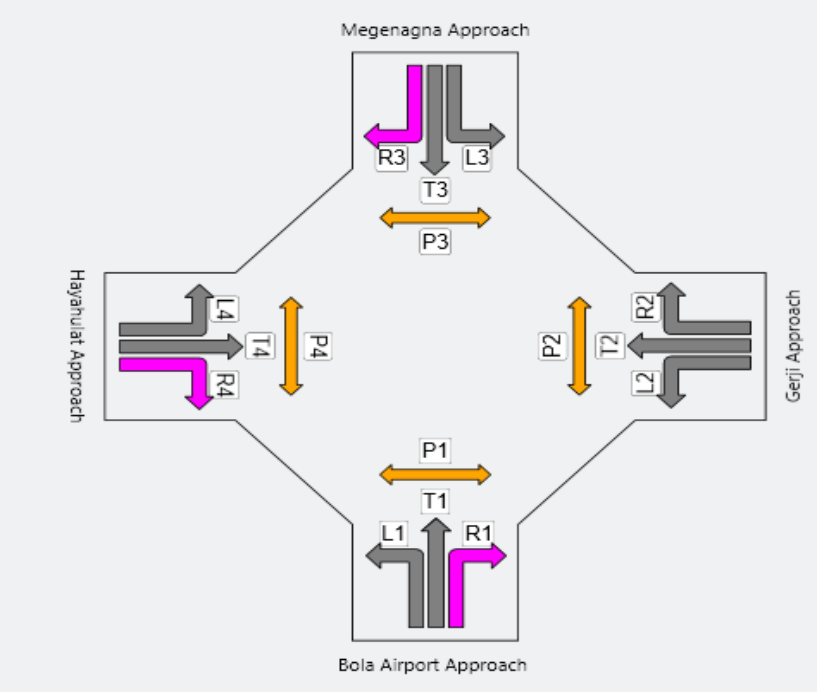


Figure B-2: Movement Id

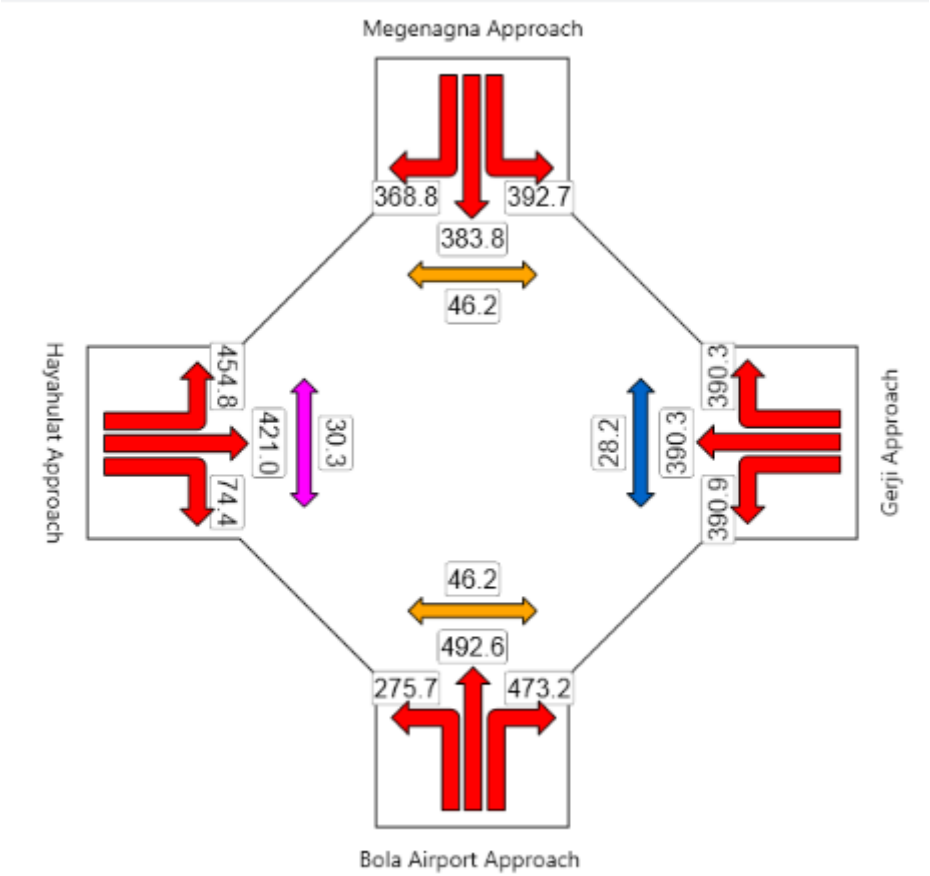


Figure B-3: Delay in Second

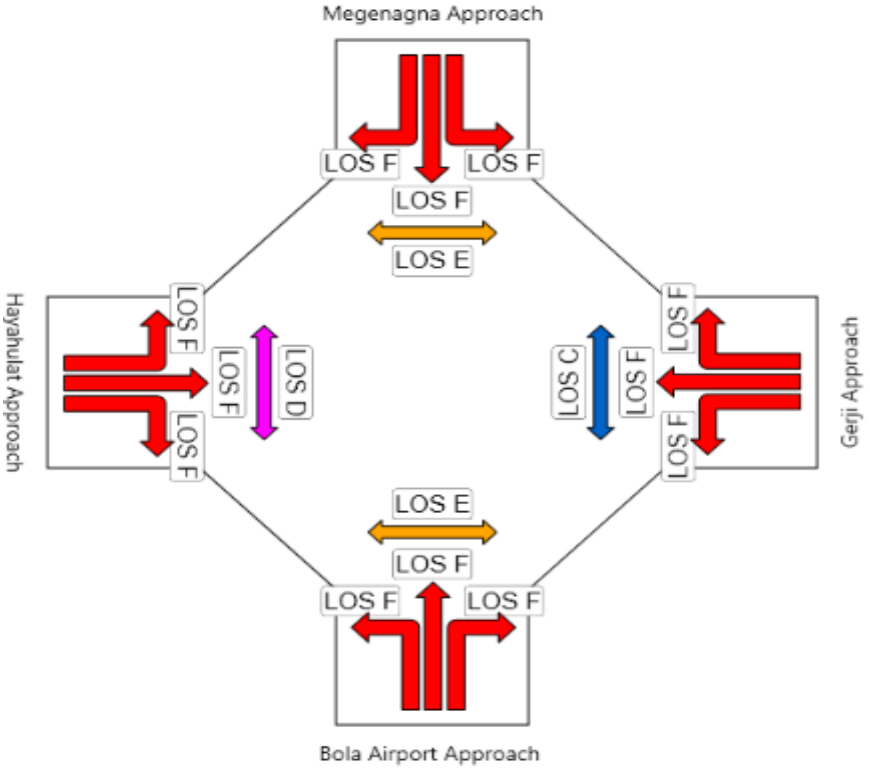


Figure B-4: Level of service

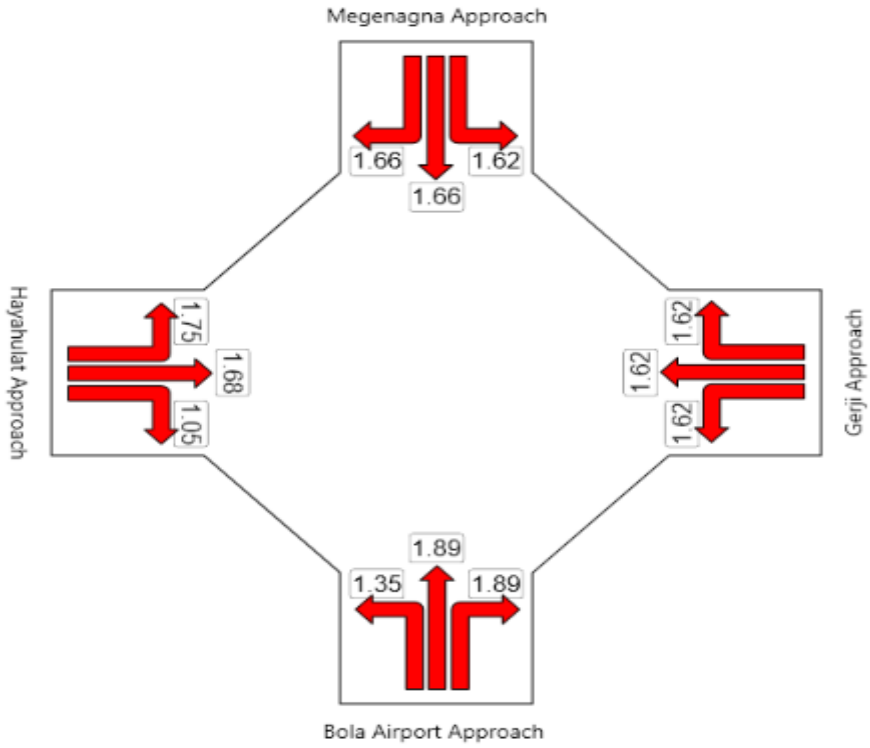


Figure B-5: Degree of Saturation

Output data for Ayer-Tena Roundabout

Site Properties	
Site (Intersection) Type	Roundabout
Model Name	Standard Right
Drive Rule	Right-hand side of the road
New Zealand Rule	No
HCM Version	No
Units	Metric

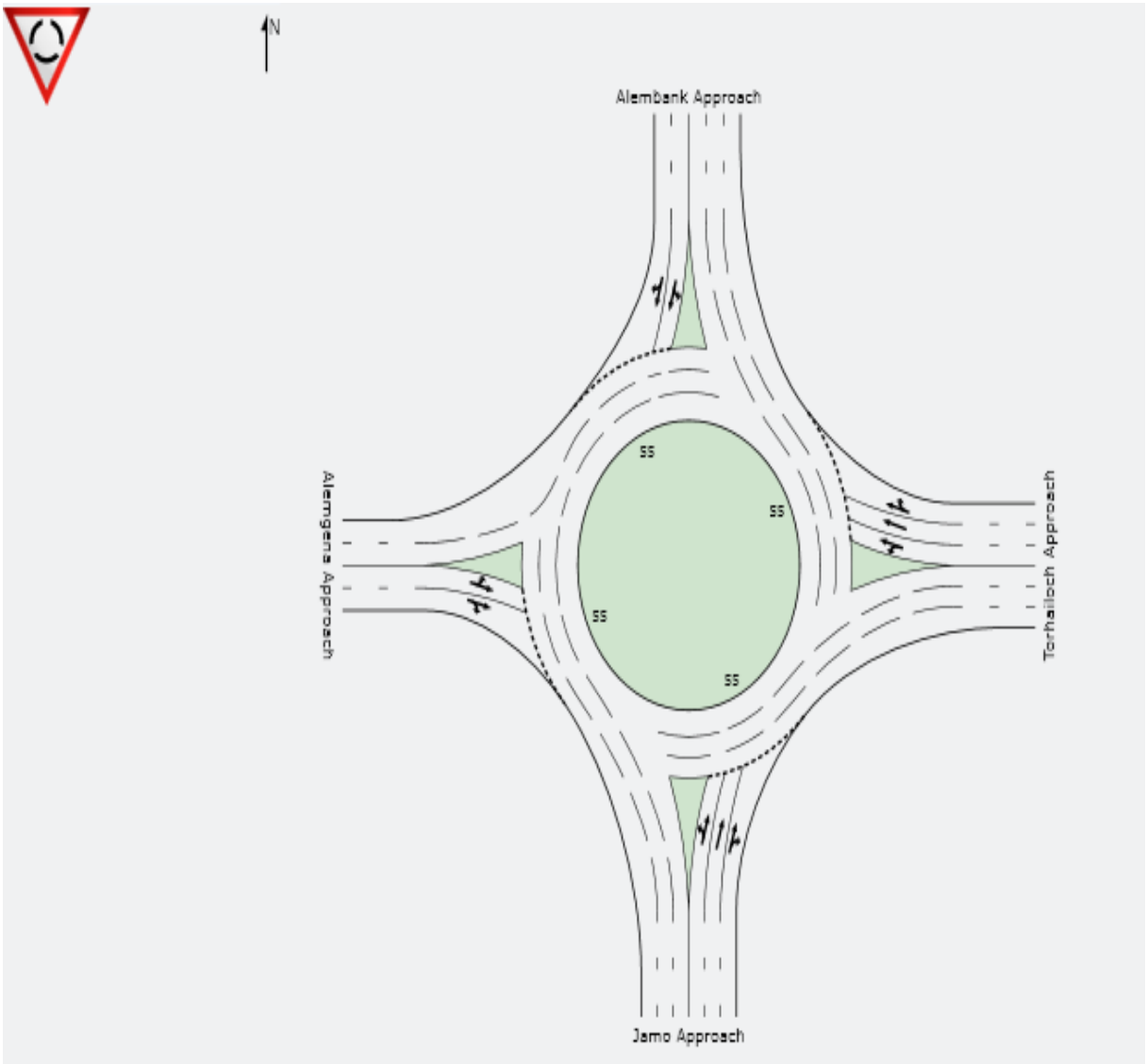


Figure B-1: Intersection Layout

Table B-1: Ayer-Tena roundabout performance analysis result (output)

AyerTena Roundabout
Roundabout

Lane Use and Performance

	Demand Flows L veh/h	T veh/h	R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
South: Jamo Approach																
Lane 1	150	194	0	344	24.1	150[2]	2.293	100	611.0	LOS F	65.3	551.3	500	–	0.0	8.0
Lane 2	0	344	0	344	23.4	150[2]	2.293	100	611.1	LOS F	65.1	547.2	500	–	0.0	7.7
Lane 3	0	174	170	344	21.0	150[2]	2.293	100	611.1	LOS F	65.2	538.5	500	–	0.0	7.2
Approach	150	712	170	1032	22.8		2.293		611.0	LOS F	65.3	551.3				
East: Torhailoch Approach																
Lane 1	231	354	0	585	19.3	153	3.820	94[5]	1293.9	LOS F	142.1	1159.6	500	–	0.0	42.9
Lane 2	0	595	0	595	18.3	156	3.820	94[5]	1293.5	LOS F	144.5	1170.7	500	–	0.0	43.8
Lane 3	0	0	813	813	7.5	201	4.049	100	1390.6	LOS F	200.2	1491.4	500	–	0.0	100.0
Approach	231	949	813	1994	14.2		4.049		1333.2	LOS F	200.2	1491.4				
North: Alembank Approach																
Lane 1	694	255	0	948	11.6	405	2.343	100	614.9	LOS F	182.4	1404.4	500	–	0.0	72.9
Lane 2	0	445	462	907	15.4	387	2.343	100	615.4	LOS F	174.7	1383.6	500	–	0.0	68.4
Approach	694	700	462	1855	13.5		2.343		615.1	LOS F	182.4	1404.4				
West: Alemgena Approach																
Lane 1	256	776	0	1032	12.4	312	3.303	100	1048.6	LOS F	237.2	1836.7	500	–	0.0	100.0
Lane 2	0	733	298	1031	12.4	312	3.303	100	1048.6	LOS F	237.1	1836.2	500	–	0.0	100.0
Approach	256	1509	298	2063	12.4		3.303		1048.6	LOS F	237.2	1836.7				
Intersection				6944	14.7		4.049		949.5	LOS F	237.2	1836.7				

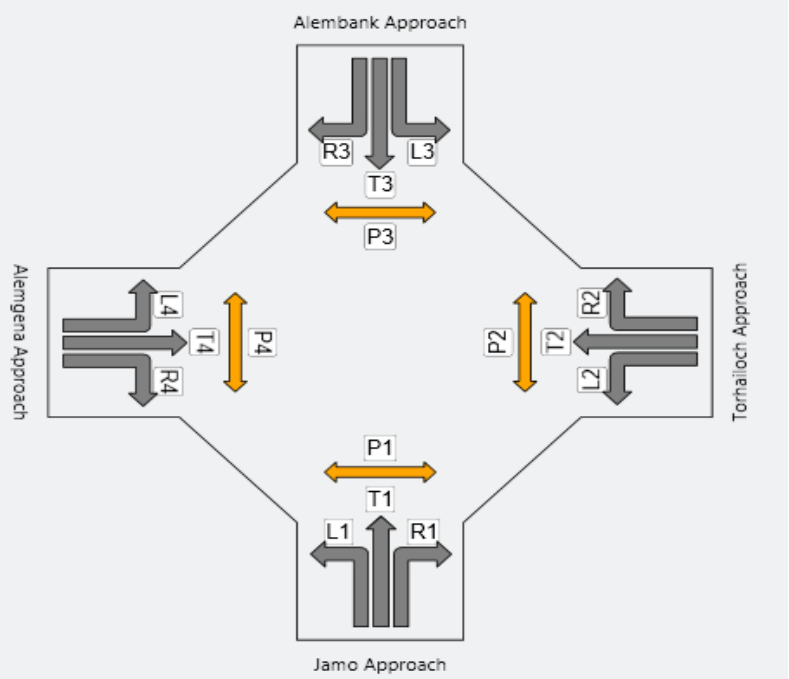


Figure B-2: Movement Id

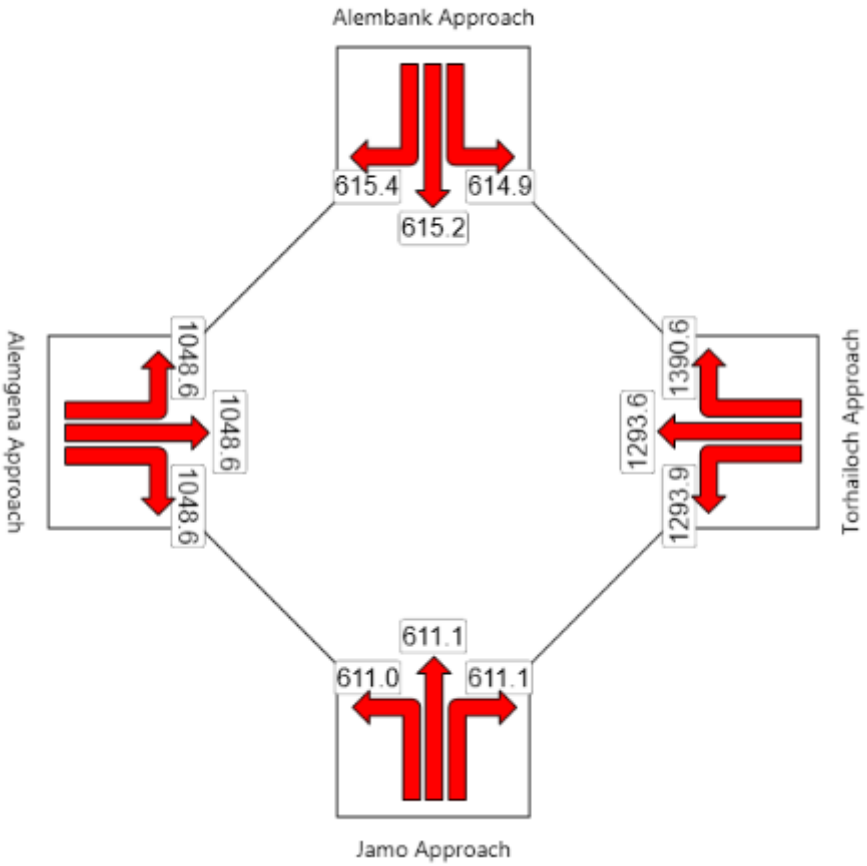


Figure B-3: Delay in Second

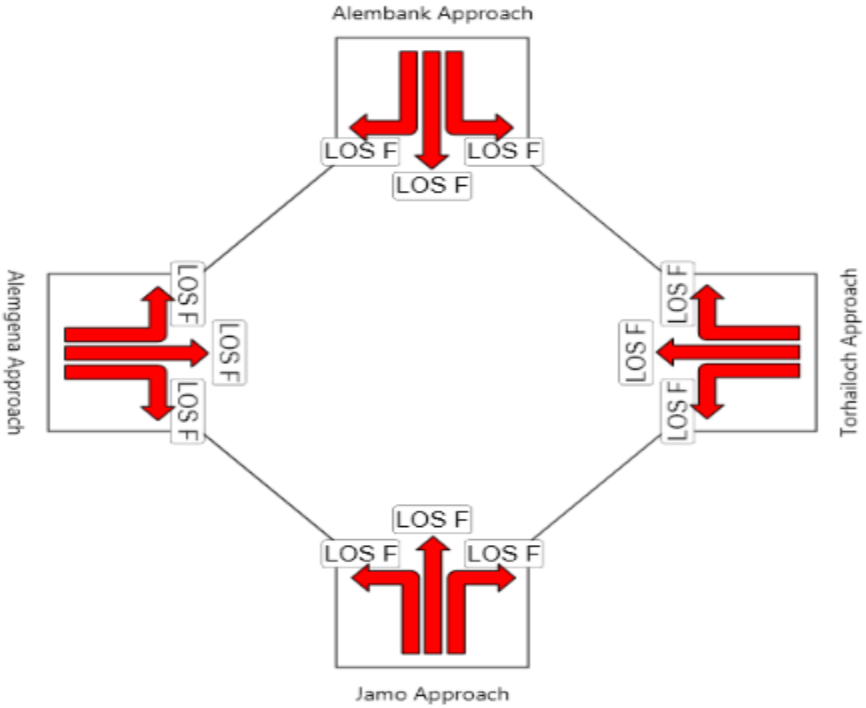


Figure B-4: Level of service

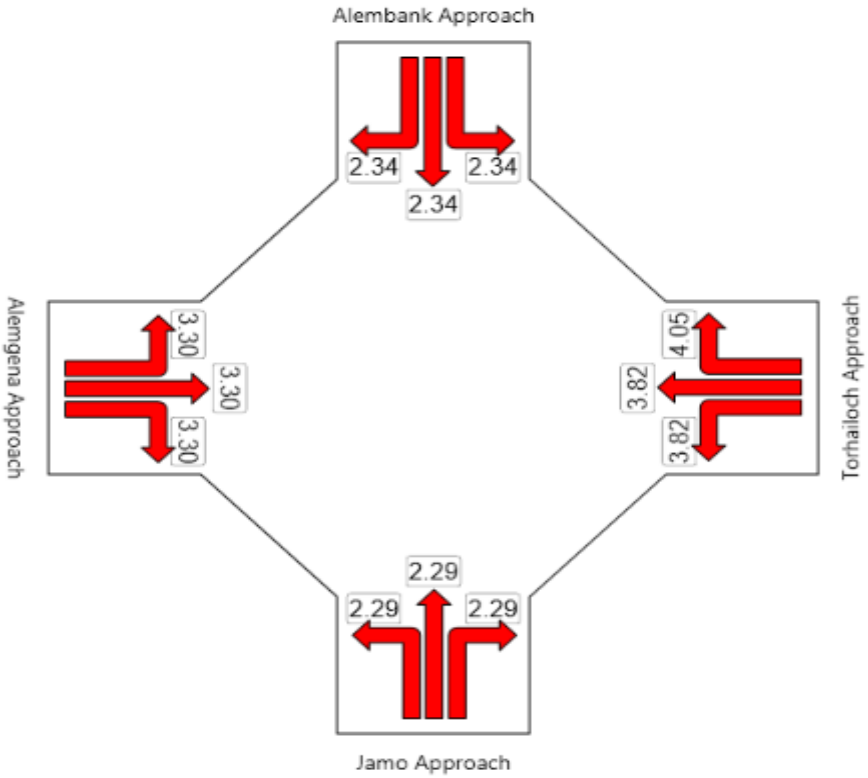


Figure B-5: Degree of Saturation

Output data for Ayer-Tena Signalized Intersection

Site Properties	
Site (Intersection) Type	Signals
Model Name	Standard Right
Drive Rule	Right-hand side of the road
New Zealand Rule	No
HCM Version	No
Units	Metric

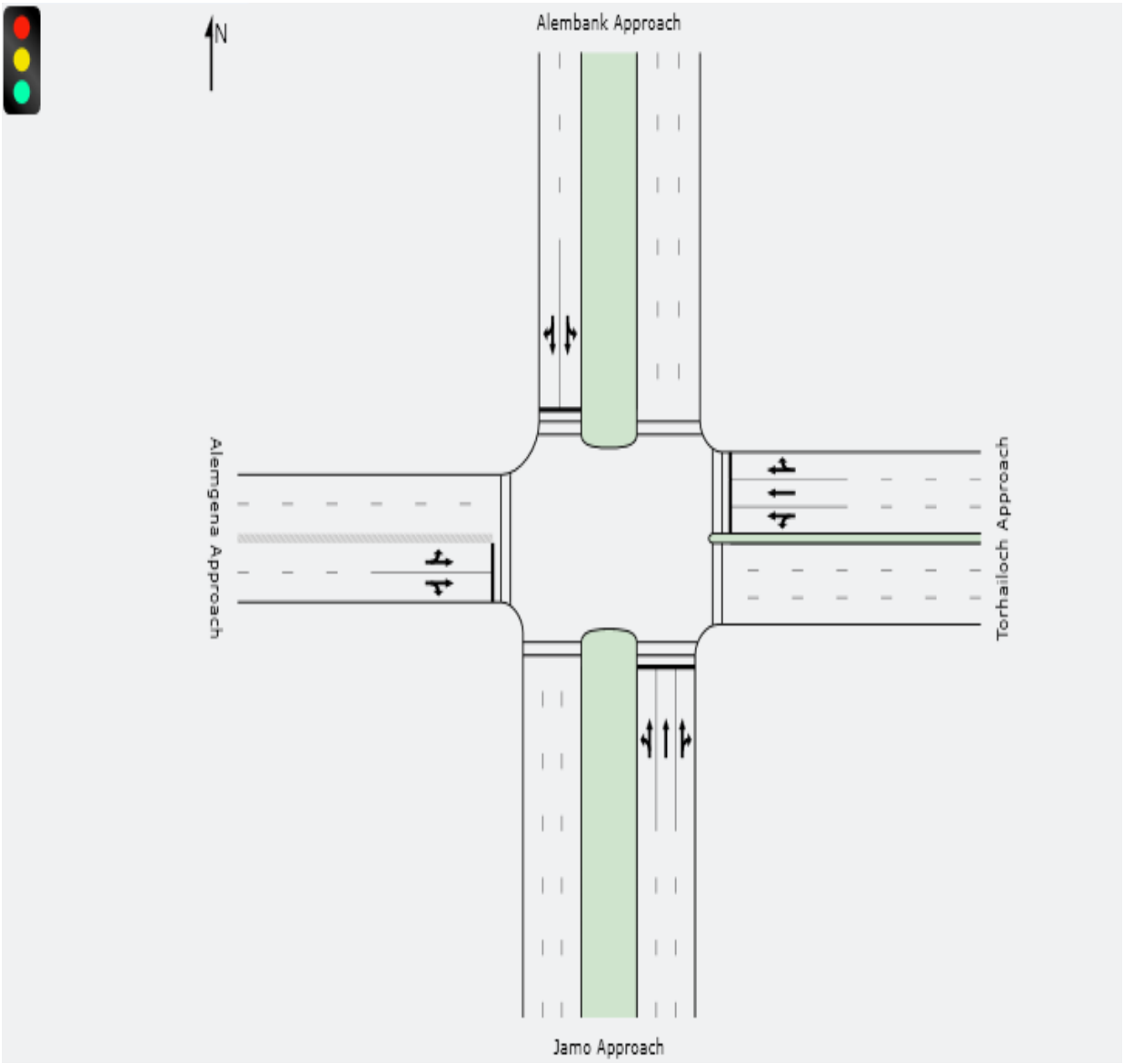


Figure B-1: Intersection Layout

Table B-1: Ayer-Tena Signalized Intersection performance analysis result (output)

AYERTENA SIGNALIZED INTRSECTION
Signals - Fixed Time Cycle Time = 150 seconds (Optimum Cycle Time - Minimum Delay)

Lane Use and Performance

	Demand Flows L veh/h	T veh/h	R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
South: Jamo Approach																
Lane 1	150	188	0	338	24.1	128	2.644	100	834.2	LOS F	70.3	593.9	500	–	0.0	20.6
Lane 2	0	349	0	349	23.4	132	2.644	100	833.6	LOS F	72.6	609.9	500	–	0.0	23.0
Lane 3	0	174	170	344	21.0	130	2.644	100	834.2	LOS F	71.5	590.3	500	–	0.0	20.1
Approach	150	712	170	1032	22.8		2.644		834.0	LOS F	72.6	609.9				
East: Torhailoch Approach																
Lane 1	231	350	0	581	19.3	281	2.067	75[5]	569.6	LOS F	109.0	889.3	500	–	0.0	58.1
Lane 2	0	599	0	599	18.3	290	2.067	75[5]	569.3	LOS F	112.3	909.4	500	–	0.0	60.2
Lane 3	0	0	813	813	7.5	293	2.774	100	892.7	LOS F	172.4	1284.0	500	–	0.0	93.9
Approach	231	949	813	1994	14.2		2.774		701.3	LOS F	172.4	1284.0				
North: Alembank Approach																
Lane 1	694	223	0	917	11.3	333	2.753	100	883.8	LOS F	194.5	1493.3	500	–	0.0	100.0
Lane 2	0	445	462	906	15.4	329	2.753	100	883.9	LOS F	192.3	1523.5	500	–	0.0	100.0
Approach	694	668	462	1823	13.3		2.753		883.8	LOS F	194.5	1523.5				
West: Alemgena Approach																
Lane 1	256	777	0	1033	12.4	380	2.720	100	870.0	LOS F	220.0	1703.6	500	–	0.0	100.0
Lane 2	0	732	298	1030	12.4	379	2.720	100	870.0	LOS F	219.5	1700.0	500	–	0.0	100.0
Approach	256	1509	298	2063	12.4		2.720		870.0	LOS F	220.0	1703.6				
Intersection				6911	14.7		2.774		819.6	LOS F	220.0	1703.6				

PHASING SUMMARY

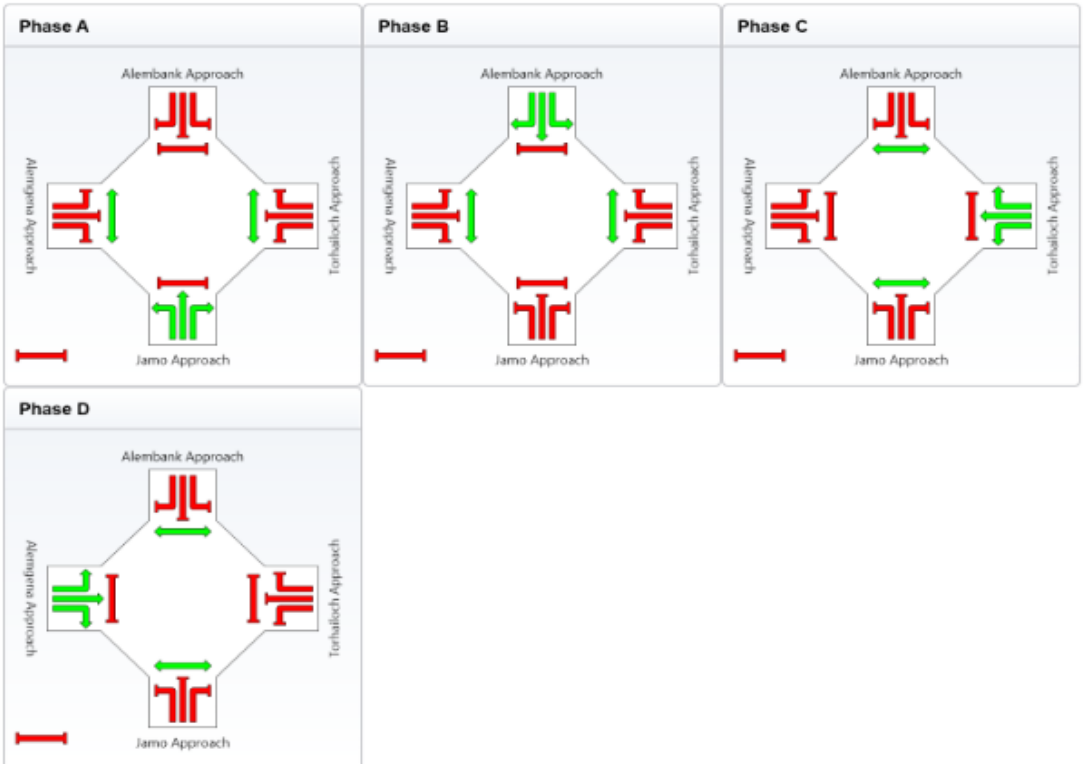
Site: New Site - 1

AYERTENA SIGNALIZED INTRSECTION
Signals - Fixed Time Cycle Time = 150 seconds (Optimum Cycle Time - Minimum Delay)

Phase times determined by the program
Sequence: Leading Right Turn
Input Sequence: A, B, C, D
Output Sequence: A, B, C, D

Phase Timing Results

Phase	A	B	C	D
Green Time (sec)	14	37	31	48
Yellow Time (sec)	3	3	3	3
All-Red Time (sec)	2	2	2	2
Phase Time (sec)	19	42	36	53
Phase Split	13 %	28 %	24 %	35 %



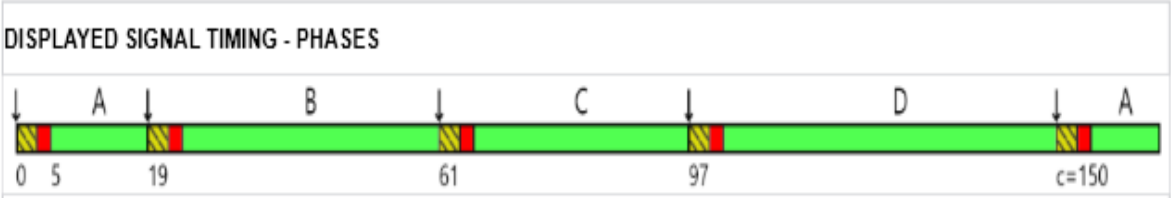


Figure B-2: Phase time results of traffic signal

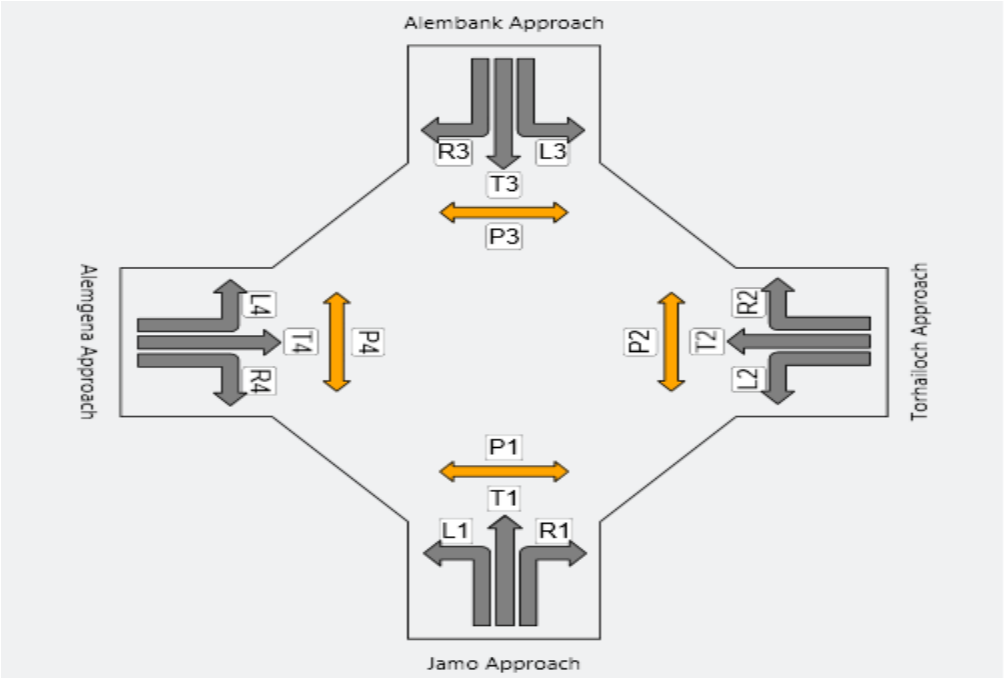


Figure B-3: Movement Id

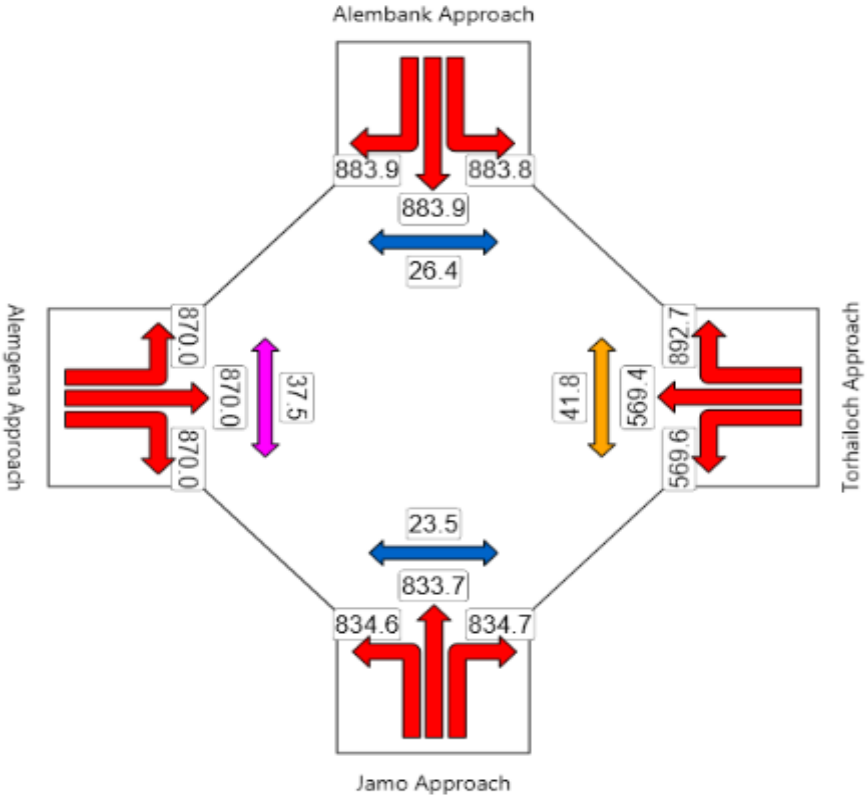


Figure B-4: Delay in Second

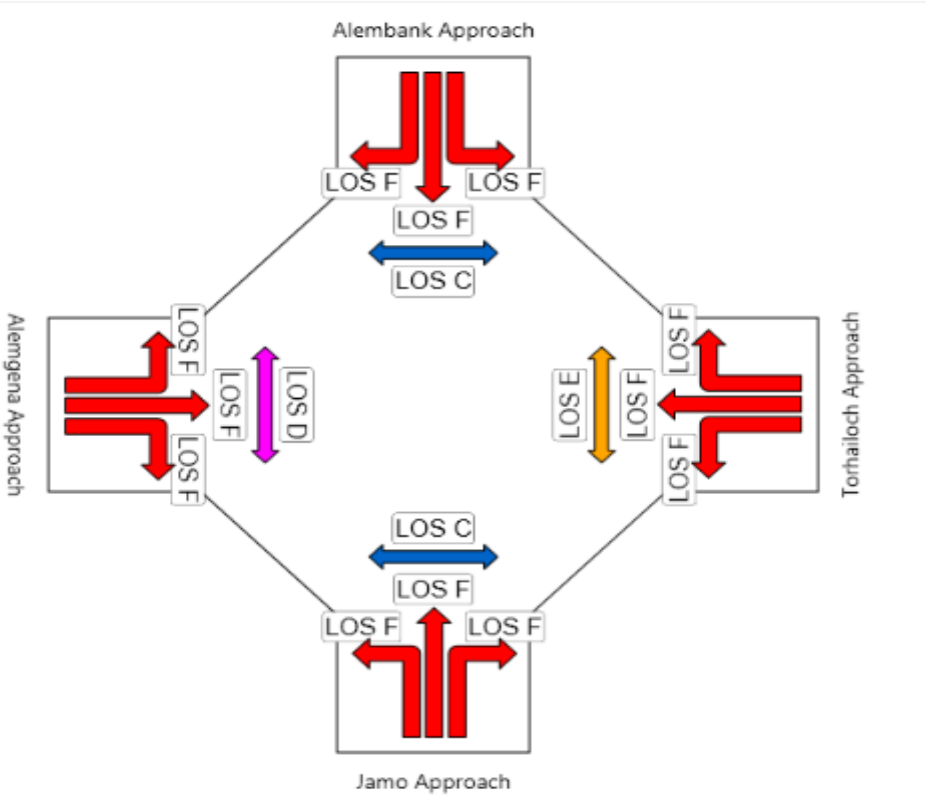


Figure B-5: Level of service

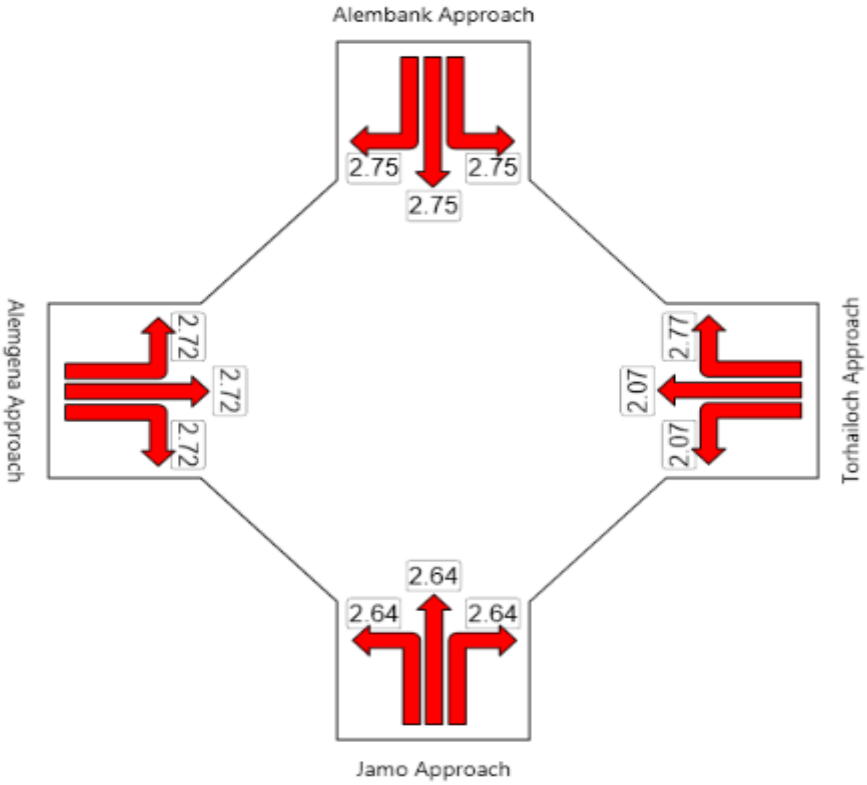


Figure B-6: Degree of Saturation

APPENDIX-C

SATURATION FLOW RATE ANALYSIS

Table C-1: Elevation for each approach at Gergi-Imperial Intersection

Approach Name		Distance (m)	Easting	Northing	Elevation (ft)
Bole	Approach	0	38°47'59.60''	9°00'07.86''	7659
		100	38°47'57.91''	9°00'05.08''	7650
	Exit	0	38°47'59.28''	9°00'08.11''	7657
		100	38°47'57.59''	9°00'05.32''	7649
Megenagna	Approach	0	38°48'00.15''	9°00'09.64''	7661
		100	38°48'01.78''	9°00'12.45''	7666
	Exit	0	38°48'00.43''	9°00'09.32''	7663
		100	38°48'02.10''	9°00'12.18''	7668
Gergi	Approach	0	38°48'00.51''	9°00'08.56''	7663
		100	38°48'03.30''	9°00'06.66''	7678
	Exit	0	38°48'00.43''	9°00'08.17''	7663
		100	38°48'03.27''	9°00'06.54''	7677
Hayahulet	Approach	0	38°47'58.87''	9°00'09.01''	7655
		100	38°47'55.96''	9°00'10.54''	7648
	Exit	0	38°47'59.08''	9°00'09.33''	7656
		100	38°47'56.10''	9°00'10.73''	7648

Table C-2: Elevation for each approach at Ayer-Tena Intersection

Approach Name		Distance (m)	Easting	Northing	Elevation (ft)
Alemgena	Approach	0	38°41'47.90''	8°58'57.67''	7632
		100	38°41'44.77''	8°58'56.79''	7628
	Exit	0	38°41'47.79''	8°58'57.93''	7634
		100	38°41'44.65''	8°58'56.97''	7630
Alembank	Approach	0	38°41'48.22''	8°58'59.41''	7639
		100	38°41'45.94''	8°59'01.79''	7647
	Exit	0	38°41'48.66''	8°58'59.84''	7639
		100	38°41'46.36''	8°59'02.49''	7646

Torhailoch	Approach	0	38°41'54.17''	8°58'59.29''	7626
		100	38°41'50.96''	8°58'58.59''	7626
	Exit	0	38°41'51.11''	8°58'58.29''	7624
		100	38°41'54.32''	8°58'58.97''	7621
Jomo	Approach	0	38°41'50.77''	8°58'57.05''	7619
		100	38°41'52.81''	8°58'54.48''	7605
	Exit	0	38°41'50.31''	8°58'56.83''	7619
		100	38°41'52.44''	8°58'54.36''	7604

Table C-3: Saturation flow rate Analysis for Ayer-Tena intersection

Approach Name		Distance (m)	Elevation (m)	Difference b/n elevation	Grade/ slope	Speed limit (km/hr)	No. of TH Lanes	Saturation flow rate
Alemgena	Approach	0	2326.2336	+1.2192	+1.22%	30	0	1213
		100	2325.0144					
	Exit	0	2326.8432	-1.2192	-1.22%	30	0	1278
		100	2325.624					
Alembank	Approach	0	2328.3672	-2.4384	-2.44%	30	0	1311
		100	2330.8056					
	Exit	0	2328.3672	+2.3336	+2.33%	30	1	1470
		100	2330.7008					
Torhailoch	Approach	0	2324.4048	+0.6096	+0.61%	30	1	1517
		100	2323.7952					
	Exit	0	2323.7952	-0.9144	-0.91%	30	1	1558
		100	2322.8808					
Jomo	Approach	0	2322.2712	+4.2672	+4.27%	30	1	1419
		100	2318.004					
	Exit	0	2322.2712	-4.372	-4.37%	30	1	1650
		100	2317.8992					

Table C-4: Saturation flow rate Analysis for Gergi-Imperial intersection

Approach Name		Distance (m)	Elevation (m)	Difference b/n elevation	Grade/ slope	Speed limit (km/hr)	No. of TH Lanes	Saturation flow rate
Bole	Approach	0	2334.4632	+2.7432	+2.74%	30	1	1460
		100	2331.72					
	Exit	0	2333.8536	-2.6384	-2.64%	30	1	1604
		100	2331.2152					
Megenagna	Approach	0	2335.0728	+1.524	+1.52%	30	1	1493
		100	2336.5968					
	Exit	0	2335.6824	-1.524	-1.52%	30	1	1574
		100	2337.2064					
Gergi	Approach	0	2335.6824	-4.572	-4.57%	30	0	1368
		100	2340.2544					
	Exit	0	2335.6824	+4.3172	+4.32%	30	0	1129
		100	2339.9996					
Hayahulet	Approach	0	2333.244	+2.1336	+2.13%	30	1	1476
		100	2331.1104					
	Exit	0	2333.3488	-2.2384	-2.24%	30	1	1593
		100	2331.1104					