Jimma University

School of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Highway Engineering Stream

Evaluation of Driving Behavior at Roundabout: A Case Study in Bole Sub City

By: Tesfaye Negash

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

January, 2018

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Main Advisor: Eng. Elmer C. Agon

Co-advisor: Eng. Teyba Wedajo (MSc)

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SCHOOL OF POST GRADUATE STUDIES

JIMMA UNIVERSITY

This thesis is my original work and I have made all necessary effort as it has not been presented for a master's degree in any other university and that all sources used for the research paper have been duly acknowledge.

By

Tesfaye Negash	……………	……………
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DECLARATION

I, the undersigned, declare that this thesis entitled "**Evaluation of Driving Behavior at Roundabout: A Case Study in Bole Sub City**". This thesis is my original work, and has not been presented for a degree in this or any other University.

Name: **Tesfaye Negash**

Signature: _____________Date ___________

CERTIFICATION

I, the signers, confirm that I read and hereby recommend for the receipt by the Jimma University a paper entitled: "**Evaluation of Driving Behavior at Roundabout: A Case Study in Bole Sub City**" in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Civil Engineering (Highway Engineering).

Advisor: Eng. Elmer C. Agon.

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ABSTRACT

The capacity of roundabout depends on several factors which include the high traffic volume of vehicle, geometry of roundabout, high pedestrian volume and driving behavior. This research focused on the study of driving behavior at roundabout and the factors that influence the priority right. Always, the vehicles that inside the roundabout have the priority right, while the vehicle that approaching to the roundabout have to wait and look for gap accepted. However, the driving behavior in Bole Sub City was different and many drivers did not give priority for the vehicle inside the roundabout. Due to this reason, the vehicles in the circulating flow have forced to stop and wait for gap to cross the roundabout. This behavior reduces the performance of the roundabout.

The objective of the study were to describe the general characteristics of driving behavior at roundabout, to identify the percent of drivers who are familiar with traffic law at roundabout especially priority rule, to analyze the reasons behind that make drivers not to follow priority rule as well as to evaluate capacity of roundabout.

The pivotal necessary for this study was used primary data such as geometrical or road data during site survey and field measurement comparing with HCM standard, interview and questionnaire, and secondary data were collected from traffic office and referring journals and books. Data analysis was made by aaSIDRA and SPSS software. The results were presented in the form of pie charts, bar charts, figures and tables.

After analyzing driver survey data and questionnaire, the result showed that 85.8% of the study sample knows the base of priority right, while the practical results obtained from video analysis proved that only 42% of the sample gives priority right at the roundabout. Regarding to speed, the video result showed that, 47% of drivers did not reduce their speed when they enter to the roundabout and they drive beyond the permission speed. Based on questionnaire and field survey, the problem showed in Bole sub city roundabout was due to the several reasons such as inadequate island diameter, inadequate lane number and width, absence of geometric features of roundabout, inadequate circulatory lane width, driving over speed, high pedestrian volume and unfamiliarity with the knowledge of traffic rule at roundabout.

Based on the result of aaSIDRA software, the studied roundabouts found in Bole sub city were under critical condition that all studied samples were categorized under LOS F according to Highway Capacity Manual. And it cannot handle the current traffic volume. It was recommended that the geometry of roundabouts must be revised and the education of traffic rule at roundabout have to be given to the drivers and pedestrians. By detail study, it was recommended that changing roundabout to traffic light control was preferable to reduce delay time and increase safety and capacity.

Key words: *Driving behavior, Roundabout, Priority Right*

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ACRONOMY

AACRA	Addis Ababa City Road Authority
AADT	Annual Average Daily Traffic
ERA	Ethiopian Road Authority
ETB	Ethiopian Birr
FHWA	Federal Highway Administration
HCM	Highway Capacity Manual
JiT	Jimma institute of Technology
LOS	Level of Service
NCHRP	National Cooperative Highway Research Program
PCU	Passenger Car Unit
PDO	Property Damage Only
PCU/h	Passenger Car Unit per Hour
SPSS	Statistical Package for Social Science
UK	United Kingdom
Veh/h	Vehicle per Hour
Veh/s	Vehicle per Second

CHAPTER ONE
INTRODUCTION

1.1 Background of study

Transport Research Laboratory of England first introduced modern roundabout facilities in the early 1960s, United Kingdom. These facilities were introduced in order to solve the problems of existing rotaries and traffic circles; using the principle that entering traffic yields to circulating traffic, or the "give way" rule. And almost all city planners soon accepted it. Above all, improvement in safety is the most distinct advantage of roundabouts. Most areas that implement roundabouts rules experience an impressive impact on their accident numbers. Because of this reputation, some countries have converted many ordinary intersections into roundabouts. Norway and Ireland were the first countries to follow England; the first roundabout in Norway was built in 1971. For instance, France is building almost 1500 roundabouts a year In the Netherland, since the late 1980s, approximately 400 roundabouts have been built over a period of only six years. (1)

The construction of roundabout appeared even before the automobile was invented: during their early stages, roundabouts were only an architectural component for monuments and fountains. Formal rules for their use had to be created as a result of the appearance of more sophisticated vehicles such as horse-drawn carriages, tramways, bicycles and cars. Initially successful with the right hand priority rule, roundabout become unpopular as speed and traffic increased in the central circle, that roundabouts emerged as safer intersections (2)

Moreover, roundabouts include additional features whose purpose is to enhance safety (or even capacity) in the intersection. Safety advantages of roundabouts are mainly due to their design: since vehicles travel in the same direction, right angle and left turn conflicts present in regular intersections are eliminated; speed control is also present due to the intersection geometrical characteristics (3)

The vehicular traffic is controlled by traffic light and self – organized scheme in which traffic lights are absent. This controlling method incorporates a yield – at – entry strategy for the approaching vehicles to the circulating traffic flow in the roundabout. The traffic light also known as traffic signal or stop light, is a signalized device positioned at road intersection which is used to control vehicles and passengers so that traffic can flow smoothly and both drivers and passengers are safe. Roundabouts permit a continual flow of traffic to flow through the intersection, whereas a signalized intersection requires traffic to stop completely in one direction. (4)

However, despite the well-known problem of driving behavior and the inadequacy of roundabout capacity, the city administration effort to improve the problem, limited researches have been conducted on roundabout capacity and cities traffic accident. Therefore, proper quantification of driving behavior to determine the percentage of real application of priority rule at roundabout and evaluation of roundabout capacity is an important step for understanding the performance of driver and roundabout. Therefore, this thesis focuses on the driving behavior at roundabout and influencing factors in the selected study area of Bole Sub City roundabouts.

1.2 Statement of the problem

In developing countries, the driving behavior is different. Drivers are aggressive so that gap acceptance behavior is rather uncommon. Big percentages of drivers in approaching traffic do not give priority to the circulating flow. In many cases drivers who are already in the roundabout are forced to stop and look for a gap to move. This behavior affects the traffic performance at roundabout. (5)

Now days, it is common to see traffic congestion at junction in Addis roundabout at peak hour in morning and afternoon. Hence, the traffic police must to intervene in the situation to regulate the traffic flow by over – riding the traffic control device. Otherwise, it would be practically impossible to have normal traffic flow at roundabout, which is more dependent on driving behavior and balanced traffic flow between the approaches. This problem will continue and it may worse in the future due to the rapid growth of population and vehicle numbers in Addis Ababa. (6)

The capacity of roundabout depends on several factors which include the high traffic volume of vehicle, geometry of roundabout, high pedestrian volume and driving behavior. Always, the vehicles that inside the roundabout have the priority right, while the vehicle that approaching to the roundabout have to wait and look for gap accepted. However, the driving behavior in Addis Ababa is different and many drivers did not give priority for the vehicle inside the roundabout. Due to this reason, the vehicles in the circulating flow have forced to stop and wait to gap to cross the roundabout. This behavior reduces the performance of the roundabout.

Some of the problems related to driving behavior at roundabouts are absence of important geometric features of roundabout such as flare, yield line, deflection and apron. In some roundabouts, there are the problem of visibilities caused by plants or elevated masonry. This causes the entering driver to hesitate on entering the circulating traffic and affect the driving behavior and capacities of the roundabouts. Roundabouts' central islands are retrieved by pedestrians and the traffic sign that is very important to all drivers and pedestrian such as road sign and road mark does not exist. (6)

These and other problems related to this are reduce the capacity of roundabout and affect the driving behavior. The driver play vital role on the capacity of roundabout at every time. This study was carried out to evaluate the driving behavior at roundabout and factors that affect priority right at roundabout in Bole Sub city and if possible to establish basis for further studies.

1.3 Research Question

1. What are the general characteristics of driving behavior at roundabout?
2. How to determine the percent real application of priority rule at roundabout and what factors make drivers not to follow priority rule?
3. What are the methods used to evaluate the capacity of roundabout?
4. What are the possible appropriate interventions can be recommended for roundabout to increase its capacity?

1.4 Objective of the Study

1.4.1 General objective

The main objective of this research was the evaluation of driving behavior at roundabout in Bole Sub city.

1.4.2 Specific objective

- To describe the general characteristics of driving behavior at roundabout.
- To determine the percent of real application of priority rule at roundabout and analyze factors that makes drivers not to follow priority rule.
- To evaluate the capacity of roundabout
- To recommend appropriate interventions that could help to increase the capacity of roundabout

1.5 Significance of the study

The research study assessed the driving behavior at roundabout and factors affecting the priority right. Understanding this factor is helpful for the construction of professionals who work on the initial phases of construction planning. The main goal of this research study is to provide important information about driving behavior at roundabout and factors that affect the priority right.

Even though the study is foreseen to specific area in the Bole Sub city, the result obtained from this research could be to have a deeper knowledge about the complex problem of driving behavior at roundabout in beginning in studying road transport in general and road traffic accident in particular. This study is help full for further research studies on driving behavior at roundabout in other areas of Ethiopia. The findings of this study inform the stakeholders about driving behavior at roundabout and factors that affect priority right in Bole Sub city.

For the road construction companies in Ethiopia, this research study gives guidelines and an overview on factors that affect priority right and reduce the capacity of roundabout.

1.6 Scope of the study

The scope of this study was focused on three roundabouts that are founds in Bole Sub City namely Safari, Urael and Bole-Medhanialem. The main purpose of constructing roundabout was to reduce the number of accident and reduce the speed of driver when they enter to the roundabout. Whilst much traffic congestion may appear at roundabout in Bole sub city, it was nevertheless hoped that the problem was the same at every place. The problem regard to roundabout capacity and driving behavior was different within the place. One of the common problems of traffic accident at roundabout was driving behavior. Therefore, this study was focused on the evaluation of driving behavior at roundabout in Bole Sub City and factors that affect priority right by questionnaire, interviews and site visited.

1.7 Limitation of the study

During the research the secondary data were not available enough especially the document of the geometric design on the existing road. There was no geometric design of roundabouts in AACRA office, because many roundabouts are constructed before 20 years and there was no documented data.

The study was done under some important group such as interview and questionnaires distribution to driver and traffic police. During the questionnaire some respondents were not interested to fill the questionnaire and others were not careful answered due to misunderstanding the question and even some questionnaire format paper not return to the researcher. In addition to this, recording of videos for six days at roundabout to know the traffic flow was very difficult since it is not economic.

1.8 Structure of the thesis

This research study comprised of five chapters and their contents are outlined below:

In the first chapter one overview of the background of the research, statement of the problem, objective of the study, research question, significance of the study, scope of the study and limitation of the study was discussed. The second chapter deals with the literature review about characteristics of driving behavior at roundabout, factors that affect priority right, priority right, geometry of roundabout and capacity of roundabout. The third chapter deals with the research methods. The fourth chapter deals with analysis and discussion of the results that are gathered from field measurement, questionnaires and software output, whether it satisfies the requirements set in the specification of Highway Capacity Manual and the remedial measure to be taken on unsatisfied section. The last chapter five, a conclusion and recommendation are derived from results and discussion.

CHAPTER TWO
LITERATURE REVIEW

2.1 Basic Concepts of Roundabout and Definitions

Roundabouts are intersection of two or more roads that are made up of a one-way circulating roadway that has priority over approaching traffic. Yield signs control the approaching traffic and the driver can only the right turn onto the circulating roadway. The only decision the entering motorist needs to make once they reach the yield line is whether or not a gap in the circulating traffic is large enough for them to enter. The vehicles then exit the circulating roadway by making a right turn toward their destination (6)

Roundabouts are increasingly popular due to their performance and advantages in terms of safety, capacity, and cost. Roundabouts have the potential to reduce accident risks because of low speeds and small angles of merging and diverging for traffic flows. Under certain conditions, roundabouts also improve the flow of traffic at the intersection, compared to other choices. Roundabout capacity depends on a number of factors, including the total traffic flow rate from each approaching arm that can join the circulatory traffic during the analysis period, geometry, vehicle mix, and driver behavior. Usually, the circulatory traffic has priority, while the approaching traffic has to yield and look for an acceptable gap to enter the circulating flow. The minimum accepted gap (critical gap) is different from driver to driver, since each driver has his own considerations for safety, urgency and vehicle type. (7)

2.2 History and Evaluation of Roundabouts

The history of roundabout and in particular its evolution from the old traffic circles and rotaries built in the first half of the 20th century is summarized below.

- The idea of one-way rotary system was first proposed in 1903 for Columbus circle in New York City by William Phelps Eno, "the father of traffic control." Other circular places existed prior to 1903; however, they were built primarily as architectural features and permitted two-way circulation around a central island. One-way circulation was implemented around Columbus Circle in November 1904.
- In 1906, Eugene Henard, the Architect for the City of Paris, proposed gyratory traffic scheme (one-way circulation around a central island) for some major intersections in Paris.
- In 1907 the place de 1'Etoile became the first French gyratory, followed by several others built in 1910. In general, the right-of-way rule was not too critical in the early days because traffic volumes were fairly low.

- Wisconsin, in 1913, was the first state to adopt the “yield to right rule”, meaning entering vehicles had the right-of-way. The yield sign, however, was unknown in the United States until the early 1950s.
- In 1929, Eno pointed out the main drawback of the “yield to right rule” (i.e., that traffic locks up at higher volumes) and recommended changing to the yield-to-left rule.
- In the 1950s, traffic circles fell out of favor in the United States largely because of the locking problem. In many cases they were replaced with signalized intersections, or signals were simply added to the circle.
- Between 1950 and 1977, eight jurisdiction passed laws to reverse the right-of-way rules that gave priority to the vehicles in the circle, but signals generally were not removed from traffic circles. (8)

2.3 The Beginnings of the Modern Roundabout

Progress in roundabout design began early in Great Britain, where one-way streets and gyratory systems had existed since the mid-1920s, partially as the result of the consulting work by Eno. It was also in Great Britain where the term “roundabout” was officially adopted in 1926 to replace the term “gyratory.” In the 1950s, British traffic engineers started questioning the American practice of large circles, arguing that weaving sections, combined with the higher speeds made possible with the larger radii, were detrimental to high capacities. The American view that weaving volumes that in excess of 1,500 hourly vehicles were impractical was challenged in Great Britain, although British traffic engineers continued analyzing roundabout capacity in terms of weaving capacity. The off-side priority was officially adopted for roundabouts in Great Britain in 1966. From then on, roundabout design changes from larger circles to smaller roundabouts where the driver’s task was to accept a gap in the circulating flow. Capacities of large roundabouts were increased by 10 to 50 percent by reducing the size of the central island, bringing the yield line closer to the center of the circle, and widening the entries to the roundabout. (8)

In general form, roundabout connects incoming and outgoing flow directions. In principle, each incoming vehicle approaching to the roundabout can exit from each of the out-going directions via making appropriate turning maneuvers around the central island of the roundabout. Under the off side priority rule, the vehicles waiting at the roundabout entrance needs to give way the vehicles inside the roundabout. Drivers need to determine how much space in the roundabout is sufficient for them to drive to the required position. (9)

2.4 The Difference between Roundabout and Traffic Circle/Rotaries

Roundabouts are often confused with traffic circles or rotaries and it is important to be able to distinguish between them. According to (6) information guide, roundabouts have five main characteristics that identify them when compared to traffic circles.

I. Traffic control: Yield control is used in all entries at roundabouts. The circulatory roadway has no control.

II. Priority to circulating vehicles: Circulating vehicles have the right of way in roundabouts. Some traffic circles require circulating traffic to yield to entering traffic.

III. Pedestrian access: Pedestrian access is allowed only across the legs of the roundabout, behind the yield line. Some traffic circles allow pedestrian access to the central island.

IV. Parking: No parking is allowed within the circulatory roadway or at the entries at roundabout. Some traffic circles allow parking within the circulating roadway.

V. Direction of circulation: All vehicles circulate counter-clockwise and pass to the right of the central island of the roundabout. Some neighborhood traffic circles allow left-turning vehicles to pass to the left of the central island. (6)

2.5 Major Geometric Features of Modern Roundabout

Since some methodologies (like the UK's –regression capacity analysis) depend totally on roundabout geometric features or elements, it is necessary to identify and clearly understand the geometric features or elements of roundabouts. According to the capacity study of roundabouts play an important part in the efficiency of roundabouts operational performance. Good geometric design improves not only capacity but also safety, which is a major concern for road design.

Basic physical features of roundabouts

Central Island: A central island is a raised in the center of a roundabout around which traffic circulates.

Splitter Island: A splitter is a raised or painted area on an approach used to separate entering from existing traffic, deflect and slow entering traffic, and provide storage space for pedestrians crossing the road in two stages.

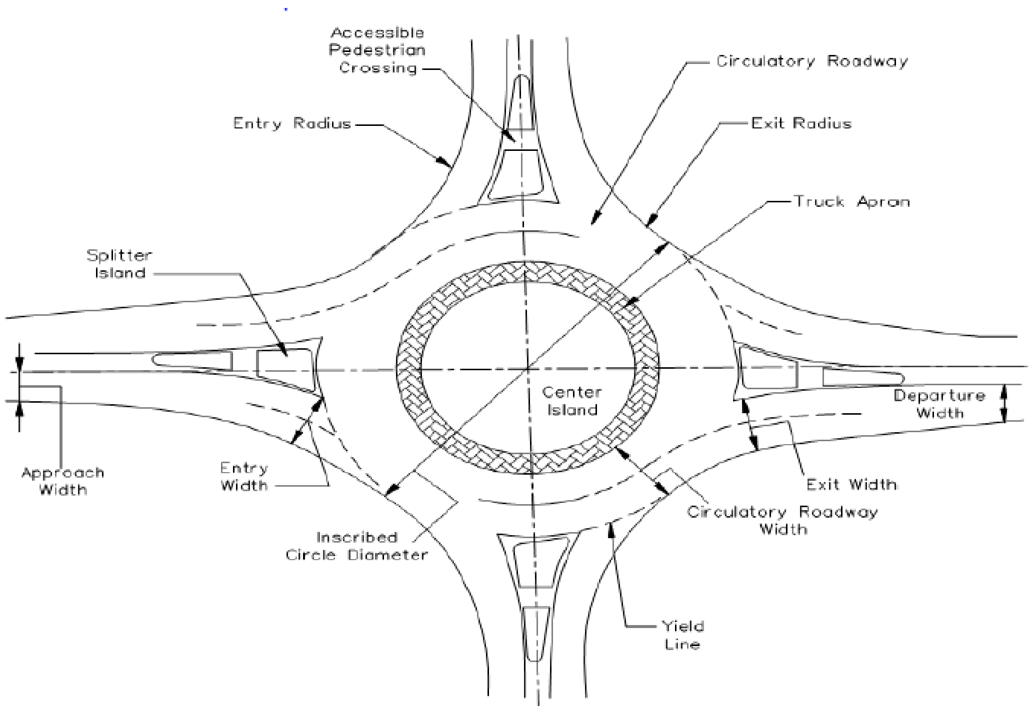

Figure 2.1 Basic geometric elements of roundabout (11)

Circulatory roadway: The circulatory roadway is the curved path used by vehicles to travel in a counter-clockwise fashion around the central island.

Apron: If required on smaller roundabouts to accommodate the wheel tracking of large vehicles, an apron is the mountable portion of the central island adjacent to the circulatory roadway.

Yield line: A yield line is a pavement marking used to mark the point of the entry from an approach into the circulatory roadway and is generally marked along the inscribed circle. Entering vehicles must yield to any circulating traffic coming from the left before crossing this line into the circulatory roadway.

Accessible pedestrian crossing: Accessible pedestrian crossings should be provided at all roundabouts. The crossing location is set back from the yield line, and the splitter island is cut to allow pedestrian, wheelchairs, strollers, and bicycles to pass through.

Bicycle treatments: Bicycle treatments at roundabouts provide bicyclists the option of traveling through the roundabout either as a pedestrian, depending on the bicyclist's level of comfort.

Landscaping buffer: Landscaping buffers are provided at most roundabouts to separate vehicular and pedestrian traffic and to encourage pedestrians to cross only at the designated crossing locations. Landscaping buffers can also significantly improve the aesthetics of the intersection.

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

Circulatory roadway width: The circulatory roadway width defines the roadway width for vehicle circulation around the center island. It is measured as the width between the outer edge of this roadway 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.

Departure width: 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 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.

2.6 Appropriate Sites for Roundabouts

1. Heavy delay on minor road.
2. Traffic signals result in greater delay.
3. Intersection with heavy left turning traffic.
4. Intersection with more than four legs or unusual geometry.

5. At rural intersection (including those in high speed areas) at which there is an accident involving crossing traffic.
6. Where major intersects at “Y” or “T” junctions.
7. At locations where traffic growth is expected to be high and where future traffic patterns are uncertain or changeable.
8. At intersection where U-turns are desirable.
9. At freeway interchange Ramps.
10. High accident intersection where right angle accidents are prominent. (12)

2.7 How to Use Roundabouts

To use roundabout, the next process of driving a car is followed

1. Slow down as you approach the intersection;
2. Yield to pedestrians and bicyclists crossing the roadway;
3. Watch for signs and pavement markings
4. Enter the roundabout if gap in traffic is sufficient;
5. Drive in a counter-clockwise direction around the roundabout until you reach your exit;
6. Do not stop or pas other vehicles.
7. If you miss your exit, continue around until return to your exit. If you within a roundabout when an emergency vehicle approaches, exit the roundabout and pull over to the right. If you outside the roundabout, immediately pull over to the right. When driving a truck or large vehicle, you may need to use the full width of the roadway, including the mountable concrete truck apron around the central island. Take in consideration location of all other users of the roundabouts. Proceed like any other vehicle. (13)

2.8 Driving Behavior at Roundabout

Drivers approaching roundabouts have two options to make: select the correct lane for their intended destination, and yield to those who have priority of movement. Drivers must adjust to the decision that in roundabouts are generally more complex than for other intersection types, mainly because drivers typically must yield and give priority those who have the right-of-way and the drivers may not always be able to see their exit or destination, possibly disorienting or confusing the driver. The geometric design of roundabouts also has the positive influence on driver behavior. Roundabouts have many design features that improve driver behavior. It forces drivers to operate at slower speeds, yield to oncoming traffic and be aware enough to accept gaps in traffic large enough to enter the flow of traffic. (5; 14)

Common effect of being fatigued while driving is lack of attention, poor vigilance and perhaps even falling asleep behind the wheel. To avoid any ambiguity or misunderstanding a behavioral state is defined as follows. A behavior state is a condition (an emotional condition, mood or condition of fatigue or intoxication) that the driver finds himself in, that has a substantial effect on the way the person drives. A driver in this state exhibits behavior that can be attributed to being overworked. Drivers' perception is various sensory organs these can be referred to as channel receives information about the world around us. Perception deals with extraction and analyses of raw sensory data in such a way that meaningful information is produced that can be used for further mental processing. There are many factors that can degrade the level of perception or how well something is perceive such as weather conditions, intoxication, age and the effective state of the driver (14)

Observational and questionnaire surveys were conducted to assess how the proposed roundabout marking system affected driver behavior, level of service, and safety performance. Generally, drivers preferred the spiral-marking roundabout to conventional roundabouts, especially after trailing the new marking system. Because of the increased safety level, reduced congestion level, and increased ease of navigation (15)

Driving behavior with respect to different road events, such as different curve radii, roundabouts or road altitude variation, is assessed in relation to driving-efficiency. Finally, drivers are ranked with respect to driving-efficiency using a grading system based on relevant driving parameters. The ability to limit the speed variations was the most important for driving-efficiency, as expected, but also the variations of angle on both throttle and brake pedals were identified as relevant. This work can be used as a platform for application of similar methods to larger sets of data and preferably using naturalistically collected driving. Therefore, the speed at which drivers choose to drive in various road and traffic conditions is important to verify characteristics of their behavior and better understanding of the variety of those factors that influence the divers' speed choice (16)

The research done on drivers after being involved in motor accidents reported that, alcohol is the most prevalent source of driver's impairment other drugs or substance abuse can also contribute to the problem. (17). Furthermore, fatigue- related crashes occur more frequently on weekends than weekdays and they typically occur in early morning. Most of the crashes also the less experienced and non-professional drivers. (18)

The driver's age is also known to be an important factor contributing to occurrence of accidents. The study by (19) reported that motor accidents were prevalent in certain age group and they occurred at certain hours of the day and week and at certain locations.

(20)States, that traffic crash can result from situations involving a conflict with the driver with environment (perhaps a vehicle) driver with an important role to perform evasive action or dodge anything.

With regards to gender, it appears that males are more at risk than females for all age groups, when traffic accident is thrown in a limelight. The preponderance of males may be attributed due to their greater exposure to traffic and other associated factors. Concerning drivers the relevance of gender to road safety has long being recognized and it is the contribution of male drivers to accidents which has attracted much attention (21). This is because driving as a profession is mostly dominated by men. The driver's behavioral characteristics, such as inattention, fatigue, inexperience, and risk-taking behavior (speeding, drunk-driving, and failure to wear a seat-belt), have all been identified as factors that significantly contribute to increased crash and injury risk on rural roads.

2.9 Methods of Roundabout Capacity Evaluation

Capacity is the main determinant of the performance measures such as delay, queue length and stop rate. The relationship between a given performance measure and capacity is often expressed in terms of degree of saturation (demand volume – capacity ratio). Capacity is the maximum sustainable flow rate that can be achieved during specific time period under prevailing road, traffic and control condition. The "Prevailing condition" is important since capacity is not constant value, but varies as a function of traffic flow levels. Capacity represents the service rate (queue clearance rate) in the performance (delay, queue length, stop rate) functions, and therefore is relevant to both under saturated and over saturated conditions. Conceptually, this is different from the maximum volume that the intersection can handle which is the practical capacity (based on a target degree of saturation) under increased demand volumes, not the capacity under prevailing conditions (17)

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

i. The empirical method, and
ii. The analytical or gap acceptance based method.

2.9.1 Emperical method

2.9.1.1 The UK Capacity Formula

The UK roundabout capacity formula is based on Kimber's study in 1980. The first approach is a linear approximation used to determine the entry capacity of a roundabout. (1)

$Q_e = F - f_c * Q_c$…………………………………. (2-1)

Where;

Q_e = Entering capacity (veh/h)

Q_c = Circulating flow (veh/h)

F, f_c = parameters defined by roundabout geometry

Kimber's (1980) equation could be used for both large and small roundabouts. Kimber used a number of parameters to describe the geometry, which is the entry width, the circulation width, the inscribed diameter, the effective length, the approach road half width, the entry radius, and the angle of entry. (1)

$S = (e – v)/l$ or $S = 1.6(e – v)/1'$………………. (2-2)

Where:

S = the sharpness of the flare

e = entry width

v = the approach road half width (m)

l' = the effective length

The ranges of the geometric parameters in the tested data base were

e: 3.6 m – 16.5 m

v: 1.9 m – 12.5 m

l' : 1 - µ m

S: 0 2.9 m

D: 13.5 m – 171.6 m

Φ: 0° - 77°

r: 3.4 m – infinite m

Kimber (1980) continued to use a passenger car unit (pcu) of heavy vehicles like 2 in the analysis.

Kimber regress the number of entry lanes, n, with the effective entry width, X_2, given by the equation.

$X_2 = V + ((e- v)/ (1 + 2S))$…………………………. (2-3)

He then sough equations for the slope and intercept of the entry /circulation flow formula by linear regression of F and as function of X_2. Although the inscribed diameter largely distinguished the larger conventional roundabouts from the smaller off – side priority ones, the entry capacity was greater on larger roundabouts with the same entry flow and geometry. Hence, the magnitude of the slope, fc, decreased as the diameter increased and accordingly, a factor, td, was included in the in the equation for fc to account for this effect. In addition, Kimber established the following equation:

$fc = 0.210 (1+ 0.2 X 2) td$……………………………..(2-4)

For the slope, and the equation

$F = 303X_2$…………………………………………………………… (2-5)

For the intercept, where

$td = 1+ 0.5/ [1+e^{((D-60)/10}]$…………………………….(2-6)

Where value of td equal to 1.0 m for large diameters, and 1.5m for every small diameter. For all but the largest roundabouts (D >30M) td can be set to1.48.

Kimber also find that the angle of entry, f, and the radius, r, have a slight effect on the capacity. As their effect was small, Kimber decided to modify the equation 2-1 by including a correction factor to equation 2-7 such that

$Qe = k\,(F - fcQc)$………………………………….. (2-7)

Where

$k = 1.151 - 0.00347\phi - 0.978/r$ …………... (2-8)

r = the entry radius

ϕ = the angle of entry (degree)

For Kimber's typical sites, ϕ was about 30°, r was about 20 m and under these conditions k was equal to 1. Values of k can be generally expected to be within 0.9 to 1.1.

Kimber tested for linearity, concluded that parabolic did not significantly improve the predictive ability and he decided to accept the linear approximation. The resulting standard error of prediction for a typical site for which Qe = 1300pcu/h or so it about 200pcu/h or about 15 percent of the entry capacity.

2.9.1.2 Germany's Capacity Formula

In Germany, they use an approach similar to that of the UK. Germany researchers investigated both regression and gap theory and decided to utilize the UK regression analysis. However, in contrast with the UK linear approximation, an exponential regression line was used to describe the entry/ circulating flow relationship because of the better agreement with the gap acceptance capacity formula developed by Siegloch in 1973. In England, drivers use the full width of the lane marking, may give a limitation in Germany (and Scandinavia) the vehicles will follow the road marking. If there is one lane marked there will be only one line of cars. If there are two marked lanes, there will be two lines of cars, etc. Thus Kimber's formula did not fit very well outside the UK. (1)

Germany's Formula

$Qe = A * e\,(-BQc/1000)$……………………….. (2-9)

Where

Qe = entering capacity (veh/h)

Qc = circulating flow (veh/h)

A, B = defined parameters.

Several types of roundabout were investigated. The parameters A and B in this equation have been determined separately from the measurements by the regression calculation for different number of entries. The value of A and B are shown in Table 2.1

Table 2.1 Formula for calculating roundabout capacity (Brilon 1990)

Number of Lanes		Defined parameters	
Entry	Circulating roadway	A	B
1	1	1089	7.42
2-3	1	1200	7.30
2	2	1553	6.69
3	2	2018	6.68

The German results are between 0.7 and 0.8 of the English values. In Birgit Stuwe's opinion (Stuwe 1991), this difference can be explained by different driving behavior. It is assumed that drivers in England are more familiar with roundabouts because this type of intersection control has been in place for a long time.

Recently, continuing research from the federal government in Germany shows that the linear function instead of an exponential function has a better agreement of the variance of data (Brilon, Wu, and Bonzio 1997) capacity formula is

$Qe = C + DQc$ …………………………………………..2.10

Where C and D are as shown in the table below

Table 2.2 Parameters for linear regression (Brilon 1997)

Number of Lanes			N
Entry/ Circle	C	D	(Sample size)*
1/1	1218	-0.74	1504
1/2 or 1/3	1250	-0.53	879
2/2	1380	-0.50	4574
2/3	1409	-0.42	295

*no. of observed 1- minute interval

2.9.2 Analytical Method

- **Tanner's basic capacity equation**

❖ A aaSIDRA gap-acceptance method

The empirical formulation has some drawbacks, for example, data has to be collected at over saturated flow (or at capacity) level. It is painstaking task to collect enough amounts of data to ensure reliability of results, and this method sometimes inflexible under unfamiliar circumstances, for example, when the volume is far out of the range of regressed data. Consequently, researchers looked for other reliable methods of determining roundabout capacity. Many researchers agree that the gap acceptance theory (Analytical method) is more appropriate tool. An advantage of this method is that the gap acceptance technique offers a logical basis for the evaluation of capacity. Secondly, it is easy to appreciate the meaning of the parameters used and to make adjustments for unusual conditions. Moreover, gap acceptance conceptually relates traffic intersections at roundabouts with the availability of gap in the traffic streams. (1)

2.9.2.1 Tanner's Basic Capacity equation

Tanner (1962) analyzed the delays at an intersection of two streams in which the major stream has priority. He assumed that both major and minor stream arrivals are random, but that a major stream vehicle cannot enter the intersection sooner than D seconds after the preceding major stream vehicle. The minor stream vehicle then enters when any available gap is greater than T seconds. If the chosen gap is large enough, several minor streams vehicles then follow each other through the intersection at intervals of T0 seconds. Tanner's equation would then be:

$qe = qc(1- Dqc)e^{qc(T-D)}/ 1-e^{-qcT0}$ ………………….(2-11)

Where

qe = entering capacity (veh/s)

qc = circulating flow (veh/s)

T = critical gap

T0 = follow-up time

D = minimum headway

2.9.2.2 aaSIDRA Gap-Acceptance Method

In aaSIDRA, the roundabout capacity is estimated from:

$Q = s\ u = (360/\beta)\ u$………………………….. (2-12)

Where

s = 3600/β is the saturation flow rate (veh/h)

β = the follow-up headway (saturation headway) and

u = is the unblocked time ratio.

The maximum capacity is obtained under very low circulating flow conditions (for example, β_0 = 3.0means a maximum capacity of 3600/3.0 = 1200veh/h). The follow-up headway and unblocked time ratio decrease with increasing circulating flow rate. The net result is decreased capacity with increasing circulating flow rate.

All roundabout capacity models predicted decreased capacity with increased circulating flow. In gap-acceptance modeling, this is due to the blocked periods that result when the approach vehicles cannot find an acceptable gap in the circulating stream. Unblocked periods occur when queued or not queued vehicles can enter the circulating road when a gap is available in the circulating flow. Blocked and unblocked periods are like effective red and green times at signals. And the sum of blocked and unblocked times can be called the gap-acceptance cycle time. Thus, roundabout gap-acceptance capacity can be expressed in the same way as capacity at traffic signals. (18)

Many different forms of roundabout capacity formula based on gap-acceptance method that exist, including the HCM capacity formula, can be explained in terms of the expressed by (equation 2.13). aaSIDRA uses this concept directly to calculate the gap acceptance capacity. In aaSIDRA version 2.1, the gap acceptance capacity, Qe incorporates the following effects

i. Critical gap and follow-up headway of the entry stream depend on the roundabout geometry (inscribed diameter, number of entry lanes, average entry lane width and number of circulating lanes), the type of lane (dominant or subdominant) as well as the circulating flow and arrival (demand) flow rates and an environment factor for local conditions;
ii. At low circulating flow rates, critical gap and follow-up headway decrease with increasing ratio of demand flow rate to circulating flow rate (a calibration factor is available for determining an appropriate level of the effect of this factor);
iii. Heavy vehicles in the circulating stream increase the effective circulating rate.
iv. Heavy vehicle in the entry stream increase the follow-up headway and critical gap values (decrease capacity);
v. A bunched exponential distribution of circulating stream headways is used together with the critical gap parameter of the entry stream to determine the average unblocked times, average gap-acceptance cycle time and unblocked time ratio;
vi. Minimum intra bunch headway, proportion bunched (or free) in the circulating stream and an O-D factor are the parameters that affect the distribution of circulating stream headways, therefore the unblocked time ratio;

vii. Effective number of circulating lanes based on the flow pattern in the circulating lanes in front of each approach determines the values of intra bunch headway, proportion bunched and the O-D factor;

viii. The proportion bunched (or free) varies with the circulating flow rate, nad depends on the minimum intra bunch headway (therefore on the effective use of the circulating lanes); see equation 2-13 below;

ix. The O-D factor is determined according to the original-destination flow pattern (establishing dominant flow component of the circulating stream), proportioned queued in the approach lane used by each dominant stream component of the circulating stream, and the circulating lane use of all components of the circulating stream (as affected by the approach lane use); this factor also allows for the effect of any priority sharing between the entry and circulating streams;

x. The critical gap, follow-up headway, average unblocked time, average gap acceptance cycle time and the unblocked time ratio parameters are used not only in the capacity formula but also in all performance equations (delay, queue length, number of stops,and so on).

xi. Proportion bunched; The proportion bunched (or free) in the circulating stream I determined from the following formula (this replace the exponential model used in earlier version of aaSIDRA):

$\phi = (1- \Delta\ q_c)/\ [1-(1-K_d)\ \Delta\ q_c]$……………………………… (2-13)

Subject to $\phi >= 0.001$

Where

ϕ= Proportional unbalanced (free) in the circulating stream,

Δ= Minimum intra bunch headway in the circulating stream (seconds)

q_c= Circulating flow rate including the effect of heavy vehicles in the circulating stream (pcu/h),

K_d= Bunching delay parameter (a constant) Kd 2.2 for roundabout circulating streams.

2.9.3 Akcelick Base Capacity Equation

This analytical method of capacity analysis is carried out by lane-by-lane analysis. According to Akcelick, (1998) unequal lane utilization is an important factor that affects the capacity and performance of roundabouts. It is easy to display the unequal lane utilization when modeling in lane-by-lane fashion.

This formulation, developed for implementation into travel forecasting models, determines lane utilization by equilibrating delay for each of the approach lanes based on user-optimal traffic assignment. This method simulates that each motorist will choose the approach lanes, which allows them to enter the roundabout with the least delay.

Equation 2.14 is used for the capacity portion of the formulation (Akcelick 1994). Several additional equations will be required in order to create inputs to this equation.

$Q_e = (360/\beta) * ((1 - \Delta_C * q_c) + (0.5 * \beta * \Phi_c * q_c)) * e^{-\lambda*(\alpha-\Delta c)}$…………… (2-14)

Where;

Q_e = Capacity of a single entry lane (pcu/h)

β = Follow up headway (seconds/vehicles)

α = Critical gap (seconds/vehicle)

Δ_c = Intra bunch headway (seconds/vehicle)

q_c = Circulating flow at entry (pce/h)

ϕ_c = Proportion of un bunched vehicles in the circulating stream

λ = Parameter in exponential arrival headway

The process first begins with determining the entering and circulating flows. Therefore, the flow element of the formulation should precede the capacity equation.

2.9.3 Determination of Circulating and Entering Flows

Much of the uniqueness of this formulation pertains to the flow equation. A travel-forecasting model attempts to find the path of minimum disutility from origin to destination. Because this formulation is to be used at a macroscopic level, a user is not required to enter turning movements. For the purpose of detailing the flow analysis however, the formulation will be presented as a stand-alone facility.

The first step of the formulation is including the effect of heavy vehicles on the capacity of an opposed traffic stream (entry stream at roundabouts) by using a heavy vehicle equivalent for gap acceptance. This parameter represents the passenger car equivalents (pce) of a heavy vehicle.

Table 2.3 passenger car equivalent factors (U.S DOT's)

Passenger Car Equivalent Factor		
Private Automobile	RV/Bus/Delivery Truck	Tractor-Trailer
1.0	1.5	2.0

Equation 2.15 accomplishes the adjustment for heavy vehicles

VOL'= VOL*Pt*2+VOL*Pr*1.5+VOL*(100-(Pt=Pr………….. (2-15)

Where,

VOL' = Adjusted turning movement volume (passenger car equivalent/h)

VOL = Turning movement volume (vehicles/h)

Pt = Proportion of vehicles that are tractor-trailer

Pr = Proportion of vehicles that are RVs, Buses, or delivery type trucks

The next step is to calculate the approach flow for each lane. This is done by summing the adjusted turning movement volume for each approach and multiplying the total approach flow by the split for each lane. Here is the concept of dominant lane and sub dominant lane, for instance if we have two lanes in one approach, the right lane and left lane do not have equal flow, the one which has a right turn is dominant to the left lane.

To perform this split, a new variable is required. The entering split (ped) is a variable that represents the proportion of the entering vehicles that are using the right side approach lane. This variable can change iteratively based on the equilibrium of entry lane delay. The arrival flow rates are calculated in Equation 2-16 and Equation 2-17

qar = ∑d VOL'e*Ped…………………………………………..(2-16)

qal = ∑d VOL'e*(1-Ped)………………………………..……(2-17)

Where,

VOL'e = Adjusted approach volume (sum of four approach movements) (pce/h)

Ped = Entering split (proportion in right lane) for direction for approach'd'

qar = Arrival flow rate for the right lane (pce/h)

qal = Arrival flow rate for the left lane (pce/h)

d = Direction of approach

Once entering or arrival flow has been calculated, the next step is to calculate the circulating volumes at each approach to determine what flows from other entry will pass by this entry on the circulatory roadway. (13)

CHAPTER THREE
RESEARCH METHODOLOGY

The methology employed for a research work has the critical aspect for ensuring the proper result which aligns with the objective or the research question rose. Hence, this part of the thesis discusses the methodology followed and the reason for the selection of the methods in order to address the research probem stated earlier in chapter 1. It looks at relevant factors, which affect driving behavior at roundabouts by using; interviews, questionnaries visual observation, and data collection. This study was systematic investigation to find answer to the problem. On the other hand, it was a process for collecting, analyzing and interpreting information to provide a reccommendation to the research findings. The methodology of this thesis consists of two major components. The first component was using field survey includes assessing the general geometric condition and Traffic volume of roundabout. The evaluation include general geometric configuration, geometric elements of roundabout and road users facilities. The second component was, a questionnaires and interviews includes asking drivers with regard to experience and safety perception.

Since Emperical method totally depends on the geometric elements of the roundabout, it was difficult to find the necessary geometric elements on roundabout which may be a problem during evaluation. Besides, the analytical method was preffered for this thesis using aaSIDRA software with some geometric elements. In fact, AACRA also recommend aaSIDRA software for capacity analysis, wich was developed by using analytic method with some geometric elements.

3.1 Description of Study area

The study area selected for this research was Bole sub city, in Addis Ababa, which many embassy and Head quarter of African Union found in and the most business centers. Three roundabouts in Bole sub city which has different legs and can represent other was selected and the necessary geometry and peak hour traffic data were collected at this roundabout. These three roundabouts were selected based on the principle of possible representative of the target population of roundabouts in terms of size and numbers. Before the researcher starts his research, there were many roundabouts on major roads in Bole Sub city, but now many of them changed to the traffic light control.

Some of these roundabouts were built before 20 years when rotary and traffic circles were popular but now the drivers have to operate in accordance to modern roundabout traffic rules while, some geometric elements of roundabout do not exist. Since aaSIDRA dependent on traffic rules rather than geometric element of roundabout, by collecting traffic data and by observing some geometric features it was possible to carry out the capacity analysis.

a) Bole-Medhanialem b) Urael

Figure 3.1 Bole- Medhanialem and Urael Roundabout

3.2 Research design

This research study was conducted by both descriptive and analytical methods. Qualitative and quantitative studies were employed in this study area. Qualitative study gives impression on the findings where a quantitative study was used to describe the numerical aspects of the research findings, based from software result.

3.3 Population

The total population of the study includes the population existing within the range of study area, drivers who cross the roundabout, traffic police who involved at that site, pedestrian, accident data, Bole Sub City traffic commission and Roundabout geometry.

3.4 Sample size and Sampling techniques

3.4.1 Sample size

The sample inspections selected were provided by using purposive sampling. There are many mathematical equations to determine statistical sample size. Among these equations, equation of Robert Mason (19) period will be used.

$$N = \frac{M}{(S^2*(M-1)/\, pq) + 1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3\text{-}1)$$

Where:

M = the size of population and here represent the number of drivers.

S = dividing the error rate of 0.05 by standard degree corresponding to level of significance that is equal (1.96) and thus the value of S is equal to 0.0255.

P = proportion of availability of property which is 0.50.

q = the remainder of the property which is 0.50.

N = sample size, statistical.

Substitute in Equation 3.1. Then it gives the result for drivers are 372

Hence, the sample size of drivers according to this equation was 372 in number, but the researcher takes half of the total sample 186. The prepared questionnaires were distributed for 186 drivers and only 120 questionnaires were returned to researcher. In order to select sample size of roundabout the researcher first assessed the areas in the sub city for a short period. Besides, there are 9 numbers of roundabouts and one-third of roundabouts taken as sample size. Therefore, sample size was three roundabouts.

3.4.2 Sample techniques

The sample inspection was used three different sampling techniques in order to fulfill the objective of the research.

- Using post road traffic accident data from Bole sub city traffic office
- Questionnaire survey and interview were designed to allow the researcher to identify the general cause and contributing factor of driving behavior related to roundabout capacity
- Field survey was performed on the existing roundabout geometric design element using road safety checklist with HCM standard

3.5 Research approach

The research approach in this thesis involves both quantitative and qualitative approaches. Quantitative data and analysis were used to determine the level of service of roundabout and to measure the congestion levels quantitatively. The main sources of quantitative data were observation, direct field measurements and secondary data. While qualitative data from questionnarie and interview were also used to determine the driving behavior at roundabout and factors that affect priority right. Observations, collecting relevant data and subsequent analysis of the data help to generate inductive conclusions to evaluate the capacity and level of service of roundabout. Since it was impossible to assess the driving behavior at all roundabouts, representative samples could be taken at specific place where the traffic and pedestrian volume was high to derive a generalized conclusion. However, in this research the selected site was only one sub city; which was connecting the highly populated residential ends and passes through the central business district of the city and have high traffic and pedestrian volume.

In this research, the methods followed were designed in such a way that the key questions of the research answered properly. In order to assess whether the roundabout was congested or not, a key question "Does good driving behavior exist at this location?" was raised and got answer first using congestion indicator parameters.

The congestion indicator parameters used in this research were Level Of Service (LOS) and road user's perception. The LOS creation was according to HCM-2000 and determined using aaSIDRA software and drivers view was collected using questionnarie and analysis with SPSS Version 20 software.

3.6 Data collection techniques and equipment

Road traffic accident data provided by the Bole sub city Police Agency, 2013-2017 G.C. was taken for the analysis of this research. The main RTA input data sets include accident year, accident reason and type of accident.

During site survey and visit gathered the data, Roundabout geometric design element defect are recorded using road safety checklist.

Figure 3.2 Collection of accident data from Bole sub city traffic office

Interview and questioners of drivers were the objective of this thesis and roundabouts geometric, traffic data and response of respondents were required for the success of this research. Since taking video for six days were difficult and expensive, the researcher used skill power to count the vehicle that cross each leg. The traffic data collected for six days by skilled persons and among the six days, the peak hour was taken. The peak hour was one hour when the traffic flow was maximum within a day and it was recorded by dividing 60 minutes in to four. Even if the Addis Ababa Road Authority Traffic Engineering Department has established a computerized data base system for traffic data, the data collected does not current data and it does not relate to peak hour.

Only the Annual Average Daily Traffic (AADT) along some of Addis Ababa major and minor roads was stored in data base. Therefore, it was found necessary to collect the data using skilled persons and by assigning them at the roundabouts leg. It was difficult to collect traffic volume data at entry of roundabout each leg, the researcher finally decided to train University graduate students at reasonable expense. After being skillfully trained, the trainees were able how to over come every thing such as counting the turning movements of traffic at roundabouts, filling general information on appropriate forms for traffic volume and pedestrian counts and how to measure geometric elements of the roundabouts.

Figure 3.3 Interview of traffic police during geometric measurement

Quantitative and qualitative data were utilized based on the necessary input parameters for the analysis by comparing with Highway Capacity Manual. Data collection process included field visual inspection, questionnaires, field investigation, interview, sampling representative samples along study area and field measurements were conducted.

The roundabouts were classified according to their leg number and the level of service was computed. Field measurement and software out puts were comparing with HCM 2000, and finally the results from software out puts were compared with Standard Specification.

For the purpose of this research, different types of data were collected through the primary sources and secondary source. For the primary data collection, internationally recommended techniques of traffic data collection were used to know the priority right and speed of drivers. The primary traffic flow and travel time data collection techniques used were

1. Video recording with manual transcription
2. Manual traffic volume count

In addition to the above information, other field measurements were done to gather data on geometric features of roundabout for capacity analysis. These include number of lanes, lane width, number of circulatory lane, number of entries, island diameter, movement policy and etc. This measure was done for only the roundabout whose level of service going to be determind.

3.6.1 Video recording with manual transcription

In this research, Video recording and manual transcription or tracing were used to know the priority right at the roundabout and to know the speed of drivers when they approach to the roundabout. The location of video capturing to know the priority right was the roof of high-rise building which called Edna mall building. The video was recorded for one hour and it clearly shows the traffic rule of roundabouts. For speed, since getting the radar was very difficult, the researcher used video to know the speed of the vehicle. The researcher takes a point near to the roundabout and mark that point with gypsum powder as it seen well and takes another point that far 30m from the first point. The second point also marked with gypsum powder and the researcher was recording the video being 3m from the first point for 15 minutes. After recording, the researcher count and calculate the speed of drivers. The speed was calculated from distance and time. The time from the front wheel of the vehicle reaches the first marked and the back wheel reach the second wheel.

3.6.2 Manual traffic volume count

Manual traffic counts were conducted at different roundabouts that have different legs to determine the directional traffic volume at every 15 minutes. These counts were not easy and it requires many skilled persons at one roundabout. In this research two skilled persons are assigned to one leg to increase the quality of data. Totally, 24 skilled persons are participating for six days to collect traffic volume continuously. In this counting, the vehicles are classified into three groups (Bus & dump truck, truck & trailer and light vehicles) and direction of flows is clearly identified.

In addition to the primary data acquired in the above methods, some secondary data were taken from other literatures and Journals and all sources of secondary data were properly acknowledged at their respective locations.

3.7 Study variables

3.7.1 Dependent variable

- Driving behavior at roundabout

3.7.2 Independent variable

- Capacity of roundabout
- Geometry of roundabout
- Speed of driver
- Road side element
- Traffic flow

3.8 Software and Instruments

The following software and instruments were used for this study:
aaSIDRA Version 5.1, SPSS Version 20, Meter tape, Digital Camera for documentation.

3.9 Methods of data analysis

3.9.1 Field Work

A preliminary visual survey was undertaken in Bole Sub City area. Field observations and field measurements were carried out and representative samples were taken as raw data. Results from field measurements were compared with the results from HCM. Moreover, results from software output were compared with standard specifications. To determine the factors that affect priority rule and other general characteristics of drivers, a questionnaire was prepared for all sites but the same question. However the questionnaire was distributed to a sample size of drivers, additional information was important to know the practical behavior of driving behavior. To identify the percent of real applications of drivers speed and priority right at roundabout in practice, the researcher used video recording when the drivers cross the roundabout.

3.9.2 Speed

The methodology used to measure the speed of drivers approach to the roundabout was marking the lane horizontally with gypsum powder as it was visible at two points. This video was recorded only at one roundabout (Bole-Medhanialem) and it can represent other roundabout. Because Bole-Medhanialem roundabout has many legs and high traffic volume than other roundabouts in the Bole Sub City. For these studies, the researcher takes 30m length lane that approachs to the roundabout and mark at starting and ending of the length. The video was already started recording and the initial time and final time can be known from the video recorded. It was visible when the front wheel of the vehicle reachs the marked place, and the back wheel of the vehicle leaves the marked place. The video was recorded for 15 minutes continuously to know the speed of drivers when they approachs to the roundabout. So the speed was calculated by formula of

Speed = Distance/time

$V = S/t$

3.9.3 Priority Right

Priority is the main factor to be considered in transportation at roundabout. In this research, priority was one of the most important to evaluate the driving behavior at roundabout. The questionnaire was distributed to the sample drivers to know the knowlegde of drivers about traffic rule at roundabout. To realize how much the drivers respect traffic rule and give priority for the vehicle inside the roundabout in practical, the researcher record video when the drivers cross the roundabout.

3.9.4 Design of questionnaires

The question involved in questionnaire should be answer for each of the research question asked in Chapter one and the questionnaire should include general characteristics of driving behavior and factors that affect driving behavior. Among factors that affect driving behavior, capacity of roundabout was the basic one and it was discussed at the end of this chapter. The same questionnaire was prepared for all sample of roundabouts and for each sample of roundabouts, 62 questionnaires was distributed to drivers who cross the roundabout. The total questionnaires distributed to drivers are 186, but only 120 questionnaires are returned to the researcher. Since different roundabout have different geometric design, different volume, different leg and different characteristics, the researcher also tried to identify the problem at each roundabout individually. Whatever the questionnaire was same, the problem that faces drivers at each roundabout was different.

3.9.5 Geometric Data

To know the level of service of the roundabout, the geometric element of roundabout data and traffic volume are used as input data for SIDRA software.The selected roundabout names are as follows (the name being adopted from the area or publicly declared by the government)

Roundabout name	Number of legs
1. Safari	Three-legs
2. Urael	Four-legs
3. Medhanialem	Five-legs

Based on requirement of both aaSIDRA version 2.1 and Akcelik's base capacity formula, the geometric data used for analysis of roundabout capacity include: island diameter, circulatory width, number of circulatory lanes, number of entry lane and average lane width. These geometric data are measured with a tape meter or observed on the roundabout existing sites. The collected geometric data are summarized as shown in table 3.1

Table 3.1 Summary of Roundabout geometry

No	Roundabout name	Number of legs	Number of circulatory lanes	Island diameter (m)	Circulatory road width (m)	Inscribed circe diameter(m)
1	Safari	3	2	26	12	50
2	Urael	4	3	21	12	45
2	Medhanialem	5	3	36	15	66

Based on the summarized geometric data, it show that the island diameter of the roundabouts range from 21m to 36m. When the their circulatory width added, the ranges becomes 45m to 66m, which can be categorized to Urban double lane to rural double lane according to Roundabout Information Guide. According to Roundabout Information guide, the recommended maximum number of entry lane for urban double lane were 2 and the maximum entry speed was 40km/h. For rural double lane, the recommended maximum number of entry lane was 2 and the maximum entry speed were 50km/h.

When the central island diameter increases, the circulatory lane numbers also increases. It was possible to use aaSIDRA and Akcelik's base capacity formula for roundabout capacity analysis for rondabout that have 2 circulatory lane. Since Akcelik's Base Capacity formula allows calibration only for two lanes circulatory roundabouts, for 3 lanes circulatory roundabouts, the analysis was carried out only using aaSIDRA. Therefore, the capacity analysis of this research was done on the basis of aaSIDRA. Besides to this, other important parameters for the analysis were number of entry lanes and average lane width. These two parameters were carefully measured from the roundabouts approach site. The width of entry lane measured was vary for each lane and it was between 3m to 5m. Also the number of entry lane of roundabout approach were between 1 and 3. Since the lane width were vary along the lanes, the researcher take the average of lane to compute the LOS of the roundabout.

Table 3.2 Summary of legs and entry lane geometry

No	Roundabouts	Leg No.	No. of enty lane	Average lane width (m)

1	Safari	1	2	3.8
		2	2	3.7
		3	2	3.3
2	Urael	1	2	3.3
		2	3	3.6
		3	2	4.2
		4	2	3.4
3	Medhanialem	1	2	3.3
		2	3	3.3
		3	2	4.5
		4	2	4.5
		5	2	4.3

3.9.6 Traffic Data

To analysis the capacity of roundabout using either aaSIDRA or Akcelik's base capacity formula, traffic volume and vehicle's classification are important parameters. In this research, the researcher counted the data by classifying the vehicles in to three category (Truck and Trailer, Dump truck and Bus and Light vehicles). High pedestrian volume also has a significant effect on capacity. Because of this, vehicle and pedestrian volume data were collected for six days and among six days the peak hour data was taken. The peak hour taken for this research was different for each roundabout. The vehicles and pedestrian volume at peak hour were summarized as shown in Table 3.3. The below data was the peak hour data that was taken among the six days which collected for one hour or 60 minutes. Out of the total number of vehicles counted at roundabout, the dominate one was light vehicle and the percentage of heavy vehicles were very less when compared with light vehicle.`Because of the area selected was the center of business and many embassy found in, the traffic flow in this sub city was very high when compared with other sub city.

Table 3.3 Vehicle and pedestrian volume at roundabout at peak hour

No	Roundabout	Bus and Dump Truck	Truck and Trailer	Total Heavy vehicle	Light vehicle	Total Number of Vehicle	Total Traffic (PCU)	Pedes trian Number
1	Safari	112	4	116	5086	5202	5262	3884
2	Urael	112	10	122	5387	5509	5575	5874
3	Medhanialem	96	2	98	5818	5916	5966	4286

The traffic volume of each leg and the direction of flow must be known separately to analysis the capacity of roundabout by aaSIDRA. The traffic volume were converted to passenger car unit by multiplying with passenger car equivalent factor. The passenger car equivalent factors are used to convert the number of heavy vehicles to passenger car equivalent. Actually, the heavy vehicles affect the capacity of roundabout and it also increase the delay time at the roundabout. There are no similar flow of vehicle at each leg. Because of the road direction or the need of the road users, the balanced traffic flow does not showed. The summarized entry traffic flow data on legs are shown in Table 3.4.

From Table 3.4, it was observed that there was unbalanced traffic flow at legs or approaches at roundabouts. However, it was not recommended to build roundabouts as traffic control devices when there was unbalanced traffic on the legs. (6)

Table 3.4 Entry traffic flows on roundabout approaches

Roundabout	Leg Number	Total no. of vehicle entry	Entry traffic on legs (PCU)	Percentage of heavy vehicle
Safari	1	2132	2198	5
	2	1614	1675	4

Urael	1	1696	1713	4
	2	1179	1196	3
	3	1346	1367	4
Medhanialem	1	1576	1586	2
	2	868	878	2
	3	1332	1340	2
	4	1114	1126	2

The traffic volume of above are collected when the vehicles enter the legs. In the same roundabout, there was no equal traffic share at legs. In some legs there are high traffic volume while in other was moderate or low. So it affect the driving behavior and capacity of roundabout.

3.10 Ethical Consideration

In order to attain the purpose of this research work, ethical consideration was concentrating on in the context of quantitative and qualitative data. Before starting any data collection, formal letter was obtained from JiT and official permission was obtained from Addis Ababa Transport Agency and Addis Ababa Police Commission.

3.11 Data quality assurance

In this research, the data was collected in two ways from the source. The first was the primary source of data collection (first witness of fact) and the second was secondary source of data collection (record of an event, books or circumstance). Therefore, the assurance of these data was highly recognized and true. In order to attain quality of data, the researcher would be assured by focusing on the following points.

- Before collecting data, all source of population availability was checked and respondents daily work schedules was recorded.
- All questions and oral interviews were in simple and clear ways.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter describes the analysis and results of both field study and questionnaire. The first part was a questionnaire analysis and the second was a field study analysis and results that describe about the selected roundabouts. The capacity of roundabouts was calculated by entering the geometric data traffic volume collected in to aaSIDRA software and the result was outputted. The Akcelik's base capacity formula cannot use for the roundabout which have 3 circulatory lane. Since some of the sample roundabout have 3 circulatory lane, aaSIDRA was used in this research. However, some additional information are required to represent driving behavior.

4.1 General characteristics of driving behavior at roundabout

Driving at roundabout asks experience and knowlegde of traffic laws. Many drivers did not accept the roundabout rule and they did not give priority for vehicles inside the roundabout and pedestrian. Due to the careless driving, the accident caused was incresed alarmly at the roundabout. According to the Bole Sub City police commission report from 2013-2017 G.C, the number of accident occurred at roundabout was asindicated in table 4.1.

Table 4.1 Variation of road traffic accident frequency in roundabouts

Roundabout	Traffic accident year					Total	%
	2012/13	2013/14	2014/15	2015/16	2016/17		
Safari	26	28	31	41	54	180	29
Urael	29	32	33	40	51	185	30
Bole-Medhanialem	38	41	45	55	69	248	41
Total	93	101	109	136	174	613	100

Source: Compiled from Bole Sub City traffic office (2017)

From the the table 4.1, the traffic accident occured at Bole Sub City dominated the other roundabouts. Out of 613 traffic accident, 248 (41%) occurred at bole-Medhanialem roundabout from 2012/13 to 2016/17 G.C. Safari and Urael roundabout shared 180 (29%) and 185 (30%) of traffic accident in the study period respectively.

4.1.1 Type of traffic accident by severity classes at roundabouts

The accident occurred at each place can classified based on the severity classes. The severity classes are fatal injury, Series injury, possible injury and Property damage Only (PDO). The number of traffic accident was increase from time to time in type of severity class at Safari, Urael and Bole-Medhanialem roundabout in all years.

Table 4.2 Reported traffic accident by severity class, (2013-2017)

Severity Class	Traffic accident year					Total	%
	2012/13	2013/14	2014/15	2015/16	2016/17		
Fatal Injury	13	17	24	29	38	121	14
Series Injury	19	24	32	37	44	156	18
Possible Injury	47	52	59	64	73	295	34
Property Damage only	57	64	48	54	69	292	34
Total	136	157	163	184	218	858	100

Source: Compiled from Bole Sub City traffic office (2017)

4.2 Questionnaire Analysis

4.2.1 Demographic characteristics

Among the total 120 drivers interviewed, the majority (84.2%) of them are male while the rest are female. Regarding the age, 68 (56.7%) drivers are under 30 years old, this means that most of the samples are youth. Concerning the educational level of drivers, 53 (44.1%) are diploma and below while, others are degree and above as indicated in Table 4.3

Table 4.3 Demographic characteristics of drivers

Respondents	Response	
	Number	Percent (%)
Gender		

Male	101	84.2
Female	19	15.8
Age		
18-30	68	56.7
31-40	32	26.7
41-50	8	6.7
51-60	9	7.5
Above 60	3	2.5
Education level		
High school	19	15.8
Diploma	34	28.3
Degree	52	43.3
Masters	15	12.5

Level of education are very important to think and understand every thing.

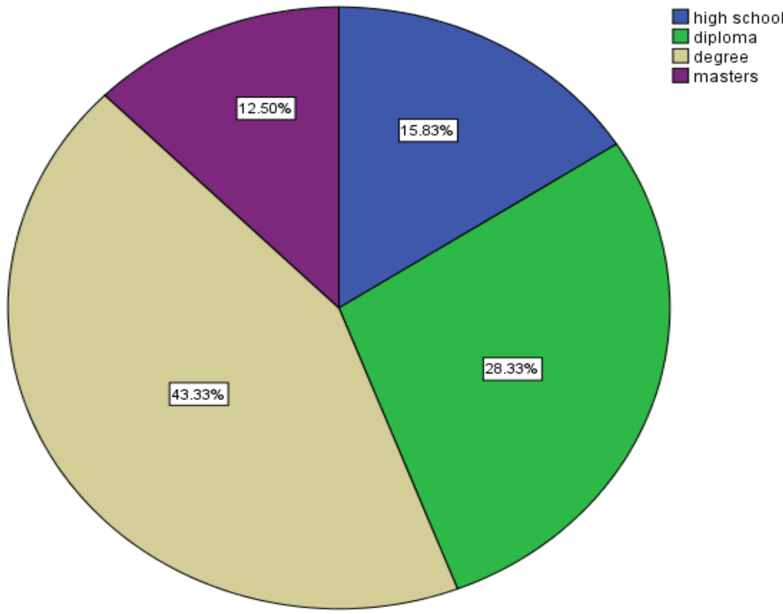

Figure 4.1 Description of education level

4.2.2 Frequency table of driver response

Based on the result, the highest percent of drivers experience is between two and ten years (2-10). The percent of drivers those have less than ten years in this sample are 79.2%. The drivers those have greater than ten years experience are only 20.9%. From the Bole sub city traffic report, most of the drivers that makes accident was the drivers those have less than five years driving experience. therefore, the drivers experience plays a vital role on in their behavior, so it was taken into interpretation.

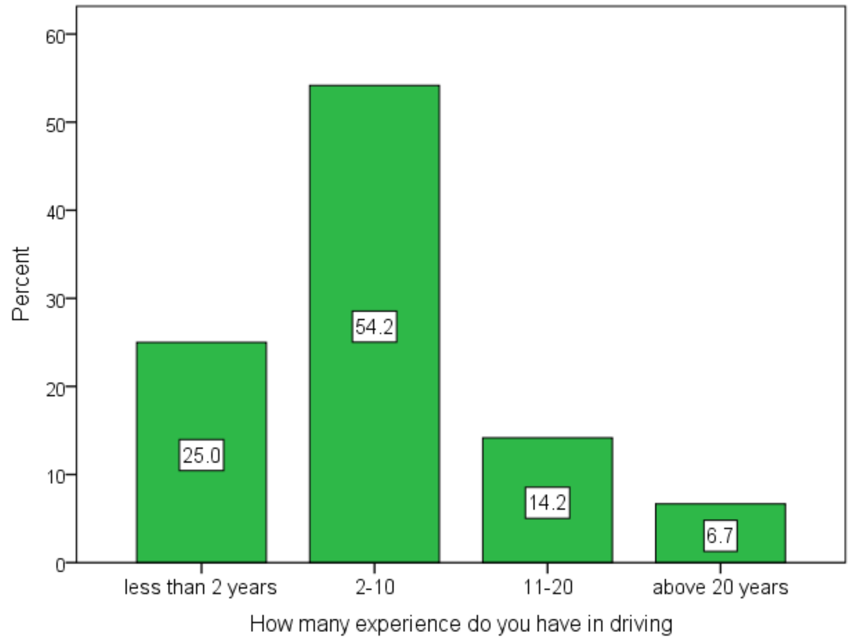

Figure 4.2 Drivers experience year

The type of vehicle were the major feature that affect the driving behavior at roundabout. Long vehicles can not rotate rapidly at the roundabout and it increases the delay time. In Bole Sub City, the dominated vehicles are private and taxi. From the sample data, the highest(60.8%) percent of vehicle was personal. and the second dominate vehicles were taxi 25.8%. The left are heavy vehicle and motorcycle.

The frequency of crossing the roundabout daily was important to change the driving behavior. Drivers, those regularly cross the roundabout, are familiar with a roundabout and they know the rule of roundabouts. Among the sample data, 94.2% of drivers are crossing the roundabout regularly. The left 5.8% are cross occasionally and rarely.

There are many factors that affect the driving behavior at roundabout, among them the listed (Table 4.4) are the major that regularly affect the drivers. The geometric design of the roundabout is the major factor. From the result of respondent, geomety of roundabouts has 55.8% influence on driving behavior. Actually they did not say the word “geometry”, but they said inadequecy of lane width, size of roundabout and inadequacy of circulating lane then the researcher generalize their response under the geometry. The traffic congestion, pedestrian, light from the building at night and road side elements also has their own impacts.

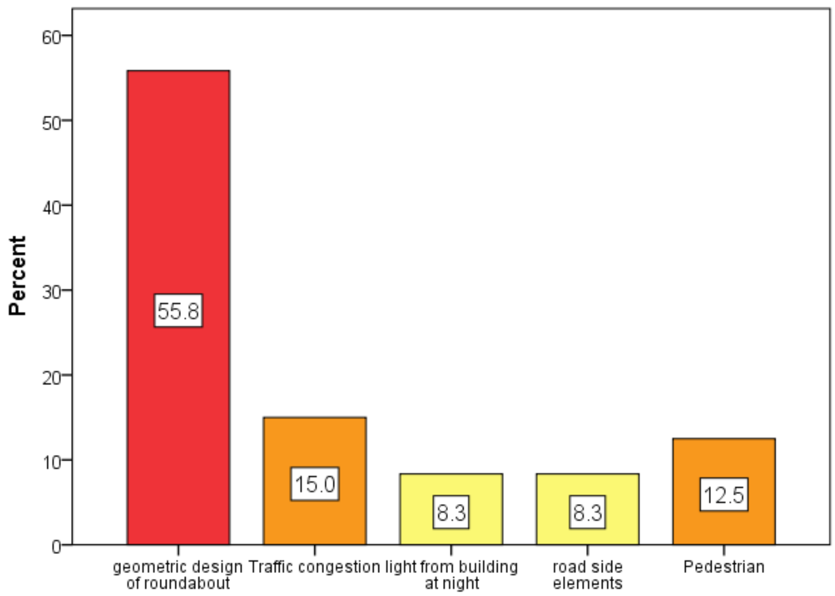

Figure 4.3 Factors affecting driving behavior at roundabout

4.3 Application of priority rule at roundabout and factors that affect priority rule

Some drivers were confused with the idea of priority right. They did not know whether the priority was for the vehicles approaching to the roundabout or for the vehicle which are inside the roundabout. Always, the vehicles that inside the roundabout have the priority right, while the vehicle that approaching to the roundabout have to wait and look for gap accepted. Among the sample respondents, 85.8% of them were knows about the traffic law at the roundabout and the priority was for the vehicle which was inside the roundabout. The rest respondents, (14.2%) did not know who has the priority right at the roundabout and they answer by saying the vehicle that want to cross the roundabout was the priority.

The geometry of roundabouts, traffic volume and pedestrian volumes were influencing factors of driving behavior. Driving was the consecutive process of observing and making sense of the situation and the ability to take action within a seconds. Some traffic control devices road safety treatments were designed to provide information to drivers by means of an explicit alerting function. There are sign that takes warning to the drivers. speed limit sign, yield sign and other warning signs were designed to direct drivers' consideration to road or traffic conditions and accept required driving behavior. Therefore, the major factors that affect the driving behavior at roundabout and reduce the capacity of roundabouts were ; geometry of roundabout, speed, pedestrian, demographic characteristics of driver, road sign and mark, environmental condition and road side elements.

Table 4.4 Drivers experience and roundabout related factors

Characteristics	Category	Number (N=120)	Percent (%)
Years of experience in driving	Less than 2 years	30	25.0
	2-10	65	54.2
	11-20	17	14.2
	Above 20 years	8	6.7
Type of vehicle	Personal	73	60.8
	Taxi	31	25.8
	Bus (20-50) passengers	7	5.8
	Truck	4	3.3
	Other	5	4.2
Frequency of crossing roundabout daily	Regularly	113	94.2
	Occasionally	6	5.0
	Rarely	1	.8
Factors affecting driving behavior at roundabout	Geometric design of roundabout	67	55.8
	Traffic congestion	18	15.0
	Light from building at night	10	8.3
	Road side elements	10	8.3
	Pedestrian	15	12.5
Does roundabout reduce delay time than other intersection?	Yes	18	15.0
	No	88	73.3
	I don't know	14	11.7

Right of priority in roundabout	The vehicle inside the roundabout	103	85.8
	The vehicle wants to cross the roundabout	17	14.2

Time is the very vital in transport. The main aim of transportation was to save the time and reach the place wanted to reach. Based on the summary of respondent, roundabout can not reduce the time of delay. 73.3% of respondents disagree that roundabout decreases the delay time. About 15% of respondents agree with the idea that roundabout decrease delay time and the left 11.75% are in a dilemma and they respond that as they did not know clearly.

When you are driving at the roundabout, if emergency vehicle was close to you, you must complete your turn and stop out of the roundabout alongside the curb exist. Drivers give different response when they asked about the emergency vehicle at roundabout. The majority of drivers knows the traffic rule at roundabout, but they did not perfectly apply at roundabout. 74.2% of respondent answered that they should move through the roundabout till receiving the required exit and then stop. 19.2% of the respondent response that he/she must go out from the next exist and stop near the curb. 6.7% respondent answered that the driver must stop inside and waiting on the roundabout till the emergency vehicle leave the roundabout.

Table 4.5 Drivers response when emergency vehicle close to them in roundabout

		Frequency	Percent
Valid	Moving through the roundabout till arriving the required exit	89	74.2
	Stopping inside the roundabout besides the curb	8	6.7
	go out from the next exit and stop beside the curb away from the roundabout	23	19.2
	Total	120	100.0

Yield Sign

Yield sign is a traffic sign which means the driver should slow and give the right of priority for pedestrian, vehicles and other road users. 75.8% of the respondents knows the meaning of yield sign, but they did not change to practical when they enter the roundabout.

Table 4.6 What does yield sign means at roundabout

		Frequency	Percent
	Keep moving at the same speed	20	16.7
	Don't stop at roundabout	7	5.8
	slow and give the right priority	91	75.8
	Increase the speed while you cross roundabout	2	1.7
	Total	120	100.0

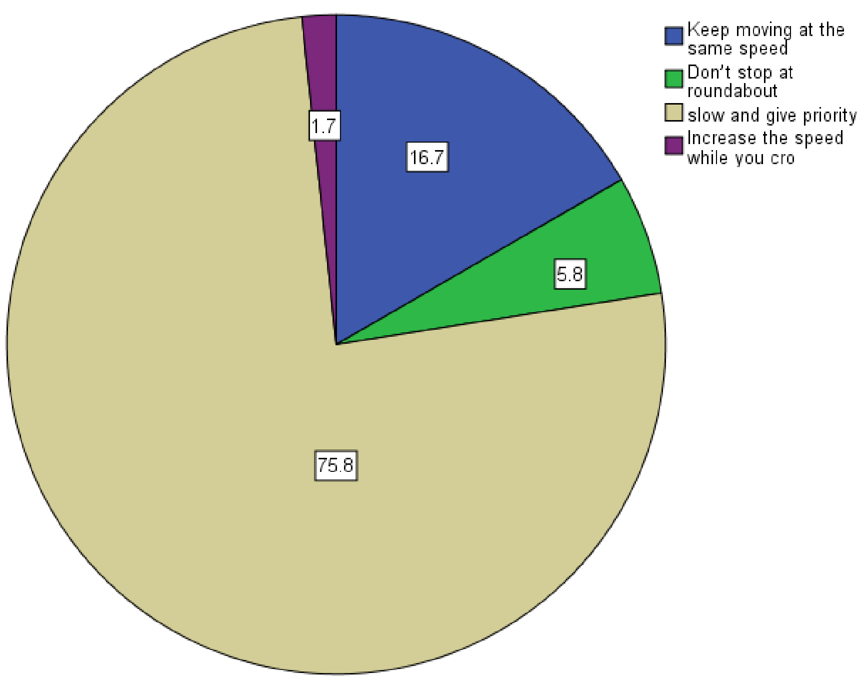

Figure 4.4 What does yield sign at roundabout

There are many problems regarding to pedestrian. Sometimes pedestrian did not respect the traffic rule. When the pedestrian cross the roundabout, they faced many conflicts. The existing vehicle and the vehicle that entering the approach were confused them. However the cross walks exist around the perimeter of the roundabout, some pedestrian cross the roundabout without road mark. This behavior affects the driver behavior and it leads to accident. Figure 4. 5 show the pedestrian crossing the roundabout without zebra line.

Figure 4. 5 Wrong crossing Pedestrian behaviors

Table 4.7 Did you slow your speed when you arriving the roundabout

		Frequency	Percent
Valid	Yes	94	78.3
	No	6	5.9
	sometimes	19	15.8
	Total	120	100.0

Table 4.8 Summary of factors that influence the priority rule at roundabout

Factors	Category	Frequency	Percent
Geometric shape of roundabout	Very High	65	54.2
	High	53	44.2
	Normal	2	1.7
Over speed	Very high	62	51.7
	High	54	45
	Normal	4	3.3
Driver carelesness	Very High	55	45.8
	High	58	48.3
	Normal	7	5.8
Ignorance of traffic law about roundabout	Very High	42	35
	High	56	46.7
	Normal	22	18.3
Traffic congestion	Very High	60	50
	High	51	42.5
	Normal	9	7.5
Low education level	Very High	13	10.8
	High	46	38.3
	Normal	51	42.5

	Low	10	8.3
Tye of vehicles	Very High	25	20.8
	High	57	47.5
	Normal	34	28.3
	Low	4	3.3
Experience	Very High	65	54.2
	High	51	42.5
	Normal	4	3.3

4.3.1 Speed from video analysis

The speed at roundabout are influenced by variety of factors, including the geometry of the roundabout and the operating speed of the approaching roadway. With regard to the sample taken, there were different speed among the drivers. Some drivers respect the roundabout rule and their speed was 30 km/h or less, but more percent of drivers (47%) did not respect the roundabout rule. Among the recorded, 230 drivers were counted and the higher percent of drivers stay at the same speed when they cross the roundabout. they did not decrease their speed and they drive beyond the permitted speed.

Table 4.9 Speed of drivers approaching to the roundabout

Speed (km/h)		Frequency	Percent
Valid	less than 35	30	13
	35-45	92	40
	Above 45	108	47
	Total	230	100.0

4.3.2 Knowlegde about Traffic laws and priority right at roundabout

The questionnaire collected from drivers shows that most of the respondents know where the vehicle must wait when bicycles and pedestrian want to cross the roundabout, they answer correctly before the stop line. From the video analysis, the majority of drivers did not respect the priority rule and some drivers close circulation lane and wait for crossing. This behavior affects the capacity of roundabout and also it is the reason for the accident. The priority is the vehicle which is in circulating and the approaching vehicle must be wait. The waiting place must be before entering the yield line, but most of the samples wait inside the circulation lane.

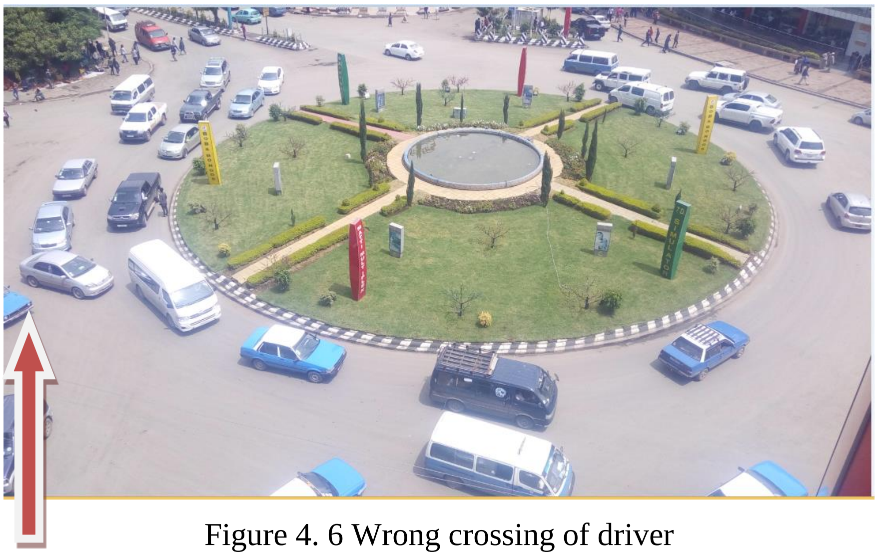

Figure 4. 6 Wrong crossing of driver

4.4 Evaluation of roundabout capacity

To get the required aim the data collected was used as input in aaSIDRA software. In addition to the collected data other information such as Gap-acceptance parameters, critical gap and follow up headway are also the recommended. In this research, the critical and follow up headway using aaSIDRA specific to roundabout geometry and flow condition besides to the collected. In this analysis, the researcher use the value of environmental factor 1 and lane utilization factors 100 has been used since heavy vehicles in the sample roundabout was very few and the most vehicle was light vehicle. The design was based on aaSIDRA input guide, June 2012.

The result of aaSIDRA capacity analysis was summarized in the the appendix c. From the analysis result, all roundabouts are under critical condition and low capacity. All the Level of Service of the roundabouts according to the HCM 2000 Manual is LOS F. for detail information the condition of roundabout was listed in appendix

4.5 General factors that decrease the capacity of roundabout and possible counter measures

After field survey and site visit was conducted, the result was compared with Highway Capacity Manual Standards. Hence the possible counter measures are suggested for the identified design problem or critical areas.

Table 4.11 Factors affecting roundabout capacity and counter measures

General problem of roundabout	Possible counter measures
Inadequacy of island diameter	Increase the diameter of island
Absence of road mark and signs	Improve road sign on the appropriate place
Absence of important geometric feature of roundabout	Add important roundabout features such as deflection, yield line and island splitter.
Over speed	Speed limit
	Speed control device
Inadequacy of entry lane width	Increase the lane width
Inadequacy of circulation lane width	Increase the width of circulation lane
Poor visibility	Improve sightlines realignment
	Remove obstacle and adjust the lights
The habit of not give priority for vehicle in circulation/pedestrian	Educate drivers as they give priority vehicles inside the roundabout and engage the traffic police at every roundabout
Pedestrian cross the road every where without crossing sine	Teaching the pedestrians as they cross the road only at crossing sign and before crossing they should be see the coming vehicles from right and left.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main objective of this research was to determine the general characteristics of driving behavior at roundabout and to analyze the factors that affect the priority rule. The data has been analyzed using aaSIDRA Version 5.1 and SPSS version 20 software and the results of the research are:

According to questionnaire analysis, the ages of the drivers 18-30 are 56.7% and that means they are youth. At this age the drivers are in hot sense and they did not care about other. They think crossing the roundabout prior to other is as a winner of competition.

Regarding to the questionnaire analysis, 85.8% of the study sample knew who has the priority right inside the roundabout, while in practical result obtained from video analysis were different, only 42% applied the priority right. The problem that enforces the drivers as they did not apply priority rule was the inadequacy of lane width, Central Island, circulation width, high pedestrian volume, driving experience, age of the driver and absence of road marks and signs.

From the questionnaire analysis, 94% of the studied sample gives response as they reduce their speed when they approach to the roundabout, while in practical result from video analysis; only 30% of drivers reduce their speed when they approach to the roundabout. This means most drivers did not reduce their speed when they approach to the roundabout due to the absence of some important geometric elements such as deflection, which forces drivers to reduce their speeds.

According to the questionnaire analysis, 73.3% of studied sample reply that a roundabout did not reduce the time of delay. By interview, most drivers response that traffic light control is preferable than roundabout to reduce time delays.

Based on actual field conditions, it was common to see that at peak hour, the traffic volume was very high and the existing roundabout cannot handle the volumes. All studied sample roundabouts were under critical condition with Level of Service F. The major problem seen in the sample roundabouts were the inadequacy of the number of entry lane, number of circulatory lane, diameter of the island, high traffic flow, high pedestrian volume and the absence of major geometric features of roundabout such as yield line, island splitters and deflection.

Safari roundabout: There was no deflection, yield line and island splitters. The entry lane number and leg number was not adequate. At night time, there was no light and the visibility was very low.

Urael roundabout: Among the most important geometric features, there was no deflection, yield line and island splitter. The central island of the roundabout was very small and even it was very difficult to rotate for heavy vehicles. The entry lane number and circulation lane number are not adequate. There was high traffic volume and high pedestrian volume.

Bole-Medhanialem roundabout: The drivers did not reduce their speed when they approach to the roundabout. The light that shine from the buildings affect the drivers at night time. Among the most important geometric features, there was no deflection, yield line and island splitter. Even if the leg number was five, there was high traffic volume at leg 1, 3, 4 and 5. There was no adequate circulation lane number and have high pedestrian volume.

5.2 Recommendations

Since the traffic volume was very increases alertly, the existing roundabout capacity cannot handle the traffic volume and the geometric elements of roundabout such as entry lane width, Central Island and circulation lane width should be revised.

Since some basic geometric element of roundabout did not exist, the AACRA should be add the basic geometric elements such as deflection, yield line and island splitters to control the speed of drivers and to reduce the accident occurred at roundabout.

It was recommended that all roundabouts should be changed to traffic light control. Since traffic light controls reduce delay time than roundabout, it was good changing roundabout to traffic light control.

Due to increase the capacity of roundabout and the safety of pedestrian, it is better to separate the pedestrians from the vehicular traffic at roundabouts where high pedestrian flows exist.

Since the traffic volume data collected for this study was limited and collected by man power, especially regarding peak hour traffic the result developed by this research is only insight on the theme of my research. In this respect, further studies should be conducted with video recording and more data collection in order to develop the result and for use in the improvement of roundabout traffic services.

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APPENDEX A

Drivers questionnaire

Part One

Put thick mark "√"on your appropriate answer.

1. Sex? A- Male ( ) B- Female ( )
2. Age? A- 18-30 ( ) B-31-40 ( ) C-41-50 ( )
   D- 41-60 ( ) E- Above 60 ( )
3. Level of education? A- High school ( ) B- Diploma ( )
   C- Degree ( ) D- Masters ( ) E- PhD ( )
4. How many years of experience do you have in driving? A- less than 2 years ( ) B- 2-10 ( ) C- 11-20 ( ) D- greater than 20 years ( )
5. What type of vehicle do you drive?
   A-Personal ( ) B-Taxi ( ) C-bus (20-50) passengers ( ) D-truck
   E- Other ( )
6. Do you understand all traffic signs? A- Yes ( ) B- No ( )
   C- Some of them ( )
7. How frequently do you cross roundabout daily? A- Regularly ( )
   B- Occasionally ( ) C- Rarely ( ) D- Never ( )
8. Did you slow your speed when you arriving the roundabout?
   A- yes ( ) B- no ( ) C- Sometimes ( )
9. What factors affect your driving behavior at roundabout?
   A- geometric design of roundabout ( ) C- Light from building at night ( )
   B- Traffic congestion ( ) D- road side elements ( ) E- Pedestrian ( )
10. Does roundabout reduce delay time than other intersection?
    A- Yes ( ) B- No ( ) C- I don't know ( )
11. Are you thinking roundabout is safer than other intersection?
    A- Yes ( ) B- No ( ) C- I don't know ( )
12. Are you thinking crossing roundabout is easy than other intersection?
    A- Yes ( ) B- No ( ) C- I don't know ( )
13. Who have the right of priority at roundabout?

A- The vehicle inside the roundabout ( ) B- The vehicle wants to cross the roundabout ( )

14. What are you going to do while you are inside the roundabout and an emergency car was closed to you?
    A- Moving through the roundabout till arriving the required exit ( )
    B- Stopping inside the roundabout beside the curb ( )
    C- go out from the next exit and stop beside the curb away from roundabout ( )
15. What does yield sign means at roundabout?
    A- Keep moving at the same speed ( ) C- Slow and give the right of priority ( )
    B- Don't stop at roundabout ( ) D- Increase the speed while you cross roundabout ( )
16. Do you give the priority right for pedestrian at roundabout?
    A-Yes ( ) B- No ( ) C- Sometimes ( )

Part II

Put thick mark "√" under your appropriate answer in this table.

1. According to your opinion, how much you are agreeing with the degree of factors that enforce drivers to ignore the priority rule at the roundabout?

Reason	Degree of contribution				
	Very high	High	Normal	Low	Very low
Geometric shape of Roundabout					
Over speed					
Driver carelessness					
Ignorance of traffic laws about roundabout					

Traffic congestion

Low education level

Type of vehicle

Experience

Age of driver

Absence of road sign and mark

APPENDIX B

Summary of traffic volume

Site: **Safari Roundabout**

		Types of vehicles					
Day	Time	Bus & Dump Truck	Truck & Trailer	Total	Light vehicle	Total traffic (pcu)	Pedestrian
Monday	7:00-8:00 am	155	14	169	3456	3716	2869
	8:00-9:00 am	45	6	51	2453	2532	2484
	9:00-10:00 am	63	9	71	2214	2326	2541
	10:00-11:00 am	34	0	34	2131	2182	2318
	11:00-12:00 am	78	2	80	2367	2488	2534
	12:00-1:00 pm	110	1	111	2670	2837	2540
	1:00-2:00 pm	96	5	101	2578	2732	2321
	2:00-3:00 pm	38	3	41	1945	2008	2437
	3:00-4:00 pm	39	0	39	1231	1289	2137
	4:00-5:00 pm	48	1	49	1673	1747	1234
	5:00-6:00 pm	102	3	105	2880	3039	2891
	6;00-7:00 pm	87	5	92	3236	3376	1874
Tuesday	7:00-8:00 am	99	4	103	3127	3283	2254
	8:00-9:00 am	64	19	83	2547	2681	2347
	9:00-10:00 am	56	12	68	2631	2739	2019
	10:00-11:00 am	78	2	80	2342	2463	2213
	11:00-12:00 am	82	9	91	2625	2766	2953

	12:00-1:00 pm	87	6	93	3115	3257	3245
	1:00-2:00 pm	93	4	97	2856	3003	2876
	2:00-3:00 pm	69	0	69	2234	2337	2342
	3:00-4:00 pm	56	3	59	2298	2388	1978
	4:00-5:00 pm	78	2	80	2347	2468	2223
	5:00-6:00 pm	92	9	101	2853	3009	2687
	6;00-7:00 pm	74	3	77	2545	2662	2316

		Types of vehicles					
Day	Time	Bus & Dump Truck	Truck & Trailer	Total	Light vehicle	Total traffic (pcu)	Pedestrian
Thursday	7:00-8:00 am	78	11	89	2551	2690	3158
	8:00-9:00 am	65	3	68	2437	2540	3054
	9:00-10:00 am	47	9	56	2314	2402	2341
	10:00-11:00 am	63	1	64	1897	1993	2237
	11:00-12:00 am	49	4	53	2105	2186	2465
	12:00-1:00 pm	97	4	101	2214	2367	3215
	1:00-2:00 pm	85	7	92	2178	2319	2657
	2:00-3:00 pm	55	9	64	2543	2643	2332
	3:00-4:00 pm	49	3	52	1896	1975	1984

	4:00-5:00 pm	67	11	78	2389	2511	2103
	5:00-6:00 pm	87	3	90	2191	2327	3587
	6;00-7:00 pm	53	5	58	1986	2066	2767
Friday	7:00-8:00 am	98	12	110	2130	2301	3253
	8:00-9:00 am	77	7	84	1893	2022	2745
	9:00-10:00 am	43	12	55	1896	1984	2312
	10:00-11:00 am	39	0	39	1654	1712	2628
	11:00-12:00 am	46	2	48	2138	2211	2543
	12:00-1:00 pm	92	1	93	1784	1924	3217
	1:00-2:00 pm	38	0	38	2341	2398	2323
	2:00-3:00 pm	54	1	55	2654	2737	1895
	3:00-4:00 pm	45	8	63	1988	2071	2319
	4:00-5:00 pm	67	5	72	1895	2005	2267
	5:00-6:00 pm	66	4	100	2774	2881	3219
	6;00-7:00 pm	53	1	54	2312	2393	2134

		Types of vehicles					
Day	Time	Bus & Dump Truck	Truck & Trailer	Total	Light vehicle	Total traffic (pcu)	Pedestrian

Saturday	7:00-8:00 am	88	8	96	3012	3160	3149
	8:00-9:00 am	72	4	76	3237	3353	3044
	9:00-10:00 am	54	6	60	3625	3718	2336
	10:00-11:00 am	63	2	67	3154	3252	2226
	11:00-12:00 am	55	3	56	3544	3632	2365
	12:00-1:00 pm	112	4	116	5086	5262	3884
	1:00-2:00 pm	80	8	88	4217	4353	2757
	2:00-3:00 pm	63	9	72	3269	3381	2432
	3:00-4:00 pm	51	4	55	2896	2980	2084
	4:00-5:00 pm	62	9	71	2389	2500	2183
	5:00-6:00 pm	91	2	93	2191	2331	3687
	6;00-7:00 pm	64	5	69	2986	3092	2867
Sunday	7:00-8:00 am	85	7	92	3681	3822	3354
	8:00-9:00 am	81	3	84	3493	3620	2842
	9:00-10:00 am	52	12	64	2996	3098	2286
	10:00-11:00 am	48	0	48	2754	2826	2722
	11:00-12:00 am	57	2	59	3638	3727	2665
	12:00-1:00 pm	89	1	90	3784	3919	3289
	1:00-2:00 pm	41	0	41	3141	3202	2396
	2:00-3:00 pm	48	3	51	2954	3032	2015
	3:00-4:00 pm	50	4	54	2288	2371	2416
	4:00-5:00 pm	72	6	78	2395	2515	2298

	5:00-6:00 pm	69	3	71	2774	2883	3305
	6;00-7:00 pm	57	2	59	2312	2401	2241

Site: Urael Roundabout

		Types of vehicles					
Day	Time	Bus & Dump Truck	Truck & Trailer	Total	Light vehicle	Total traffic (pcu)	Pedestrian
Monday	7:00-8:00 am	134	27	161	4527	4782	3189
	8:00-9:00 am	117	23	140	3262	3483	2657
	9:00-10:00 am	106	12	118	3127	3310	2114
	10:00-11:00 am	98	5	103	2131	2288	2554
	11:00-12:00 am	79	9	88	2365	2501	2234
	12:00-1:00 pm	112	8	120	3651	3835	2589
	1:00-2:00 pm	93	1	94	2985	3126	2119
	2:00-3:00 pm	98	17	115	3215	3396	2288
	3:00-4:00 pm	87	6	93	2768	2910	2314
	4:00-5:00 pm	69	4	73	3228	3339	2972
	5:00-6:00 pm	74	17	91	3574	3719	3112
	6;00-7:00 pm	58	3	61	3654	3747	2876

Tuesday	7:00-8:00 am	49	16	65	4156	4261	3583
	8:00-9:00 am	64	3	67	3678	3780	2334
	9:00-10:00 am	72	7	79	2985	3107	2234
	10:00-11:00 am	68	4	72	3345	3455	2654
	11:00-12:00 am	57	2	59	3148	3237	2465
	12:00-1:00 pm	79	9	88	3985	4121	2984
	1:00-2:00 pm	83	0	83	3423	3547	2398
	2:00-3:00 pm	74	7	81	2873	2998	2245
	3:00-4:00 pm	58	11	69	2254	2363	1897
	4:00-5:00 pm	62	4	66	2338	2439	1987
	5:00-6:00 pm	69	8	77	2958	3077	2658
	6;00-7:00 pm	49	2	51	2344	2421	2312

		Types of vehicles					
Day	Time	Bus & Dump Truck	Truck & Trailer	Total	Light vehicle	Total traffic (pcu)	Pedestrian
Thursday	7:00-8:00 am	114	18	132	3487	3694	5124
	8:00-9:00 am	99	6	105	2987	3147	4321
	9:00-10:00 am	78	9	87	2389	2524	3576

	10:00-11:00 am	63	4	67	2245	2347	3113
	11:00-12:00 am	35	3	38	2102	2160	2456
	12:00-1:00 pm	56	7	63	3242	3340	3346
	1:00-2:00 pm	54	2	56	2768	2853	2876
	2:00-3:00 pm	23	6	29	1945	1991	1867
	3:00-4:00 pm	37	0	37	2117	2172	1983
	4:00-5:00 pm	49	2	51	1981	2058	2651
	5:00-6:00 pm	74	3	77	3531	3648	3112
	6;00-7:00 pm	44	7	51	3329	3409	2143
Friday	7:00-8:00 am	63	11	74	4231	4347	4123
	8:00-9:00 am	71	11	82	3451	3579	3428
	9:00-10:00 am	46	2	48	2657	2730	3176
	10:00-11:00 am	47	6	53	2562	2644	2989
	11:00-12:00 am	51	7	58	3378	3468	2767
	12:00-1:00 pm	43	26	69	4132	4248	3746
	1:00-2:00 pm	64	4	68	2341	2445	3486
	2:00-3:00 pm	57	12	69	2563	2672	2576
	3:00-4:00 pm	49	2	51	2867	2944	2556
	4:00-5:00 pm	55	4	59	3114	3204	2233
	5:00-6:00 pm	79	17	96	3895	4047	2967
	6;00-7:00 pm	46	2	48	3243	3316	2134

		Types of vehicles					
Day	Time	Bus & Dump Truck	Truck & Trailer	Total	Light vehicle	Total traffic (pcu)	Pedestrian
Saturday	7:00-8:00 am	82	9	91	3551	3692	4875
	8:00-9:00 am	74	5	79	3437	3558	3145
	9:00-10:00 am	56	7	63	2914	3012	2412
	10:00-11:00 am	65	2	67	2897	2998	2302
	11:00-12:00 am	54	5	59	2805	2896	3869
	12:00-1:00 pm	99	6	105	3914	4074	3783
	1:00-2:00 pm	87	11	98	2978	3130	4120
	2:00-3:00 pm	54	8	66	2543	2640	2423
	3:00-4:00 pm	53	4	57	3196	3283	2085
	4:00-5:00 pm	71	7	78	2389	2509	2189
	5:00-6:00 pm	83	4	87	3191	3323	3465
	6;00-7:00 pm	51	6	57	2986	3074	2816
Sunday	7:00-8:00 am	99	9	108	3547	3713	5874
	8:00-9:00 am	75	5	80	3124	3246	2774
	9:00-10:00 am	57	8	65	2896	2997	2416
	10:00-11:00 am	46	0	46	3745	3814	2695
	11:00-12:00 am	53	3	56	4238	4323	2577

	12:00-1:00 pm	112	10	122	5387	5575	3314
	1:00-2:00 pm	48	1	49	4141	4215	2366
	2:00-3:00 pm	59	2	61	3654	3746	1945
	3:00-4:00 pm	57	8	65	3388	3489	2428
	4:00-5:00 pm	71	4	75	2895	3009	2311
	5:00-6:00 pm	63	6	69	3124	3230	3269
	6;00-7:00 pm	66	0	66	3524	3623	2425

Site: Bole-Medhanialem

		Types of vehicles					
Day	Time	Bus & Dump Truck	Truck & Trailer	Total	Light vehicle	Total traffic (pcu)	Pedestrian
Monday	7:00-8:00 am	78	16	94	5484	5633	3850
	8:00-9:00 am	64	7	71	4432	4542	3346
	9:00-10:00 am	48	3	51	3456	3534	3456
	10:00-11:00 am	53	0	53	3654	3733	3543
	11:00-12:00 am	58	4	62	3589	3684	3127
	12:00-1:00 pm	52	9	61	3515	3601	3854
	1:00-2:00 pm	43	2	45	3453	3521	3567

	2:00-3:00 pm	63	12	75	2698	2816	3236
	3:00-4:00 pm	49	4	53	2678	2759	3349
	4:00-5:00 pm	51	7	58	3127	3217	2876
	5:00-6:00 pm	46	12	58	3420	3513	3250
	6;00-7:00 pm	55	4	59	3347	3437	3114
Tuesday	7:00-8:00 am	67	3	70	3651	3757	3812
	8:00-9:00 am	51	2	53	3237	3317	3327
	9:00-10:00 am	44	5	49	3127	3203	3138
	10:00-11:00 am	39	0	39	3016	3074	3246
	11:00-12:00 am	43	4	47	3113	3185	3547
	12:00-1:00 pm	28	6	34	3357	3411	3814
	1:00-2:00 pm	67	2	69	3423	3527	3452
	2:00-3:00 pm	34	1	34	3456	3509	3431
	3:00-4:00 pm	29	3	32	2897	2946	3225
	4:00-5:00 pm	34	0	34	3226	3277	3312
	5:00-6:00 pm	47	3	50	3114	3190	3459
	6;00-7:00 pm	34	2	36	3521	3576	3951

		Types of vehicles					
		Bus & Dump	Truck & Trailer	Total	Light vehicle	Total traffic	Pedestrian

Day	Time	Truck				(pcu)	
Thursday	7:00-8:00 am	29	16	45	3658	3733	3151
	8:00-9:00 am	63	14	77	3342	3464	3089
	9:00-10:00 am	58	8	66	3421	3524	2978
	10:00-11:00 am	36	6	42	3115	3181	3125
	11:00-12:00 am	43	9	52	2987	3069	3324
	12:00-1:00 pm	52	7	59	4574	4588	3695
	1:00-2:00 pm	55	11	66	3567	3671	3298
	2:00-3:00 pm	46	7	53	3471	3554	3345
	3:00-4:00 pm	54	3	57	3344	3431	3118
	4:00-5:00 pm	34	8	42	3211	3278	3123
	5:00-6:00 pm	39	6	45	3112	3182	2987
	6;00-7:00 pm	45	13	58	2988	3081	2887
Friday	7:00-8:00 am	57	4	61	3356	3449	3659
	8:00-9:00 am	63	5	68	3547	3651	3545
	9:00-10:00 am	47	11	58	2978	3070	3564
	10:00-11:00 am	54	7	61	2341	2436	2768
	11:00-12:00 am	72	3	75	2897	3011	3426
	12:00-1:00 pm	68	13	81	3224	3352	3475
	1:00-2:00 pm	53	5	58	3324	3413	2987
	2:00-3:00 pm	45	9	54	2987	3072	3225
	3:00-4:00 pm	42	15	57	3123	3216	3651

	4:00-5:00 pm	37	1	38	2134	2191	3245
	5:00-6:00 pm	29	7	36	3104	3161	3658
	6;00-7:00 pm	34	3	37	2997	3054	2767

		Types of vehicles					
Day	Time	Bus & Dump Truck	Truck & Trailer	Total	Light vehicle	Total traffic (pcu)	Pedestrian
Saturday	7:00-8:00 am	63	7	70	4551	4659	3335
	8:00-9:00 am	81	2	83	3437	3562	3984
	9:00-10:00 am	49	6	55	3314	3399	2868
	10:00-11:00 am	53	0	53	3897	3976	2267
	11:00-12:00 am	56	6	62	4105	4201	2522
	12:00-1:00 pm	96	2	98	5818	5966	3287
	1:00-2:00 pm	88	7	95	5178	5324	2723
	2:00-3:00 pm	65	10	75	4543	4660	2457
	3:00-4:00 pm	52	5	57	3896	3984	1998
	4:00-5:00 pm	71	9	80	3389	3513	2240
	5:00-6:00 pm	82	4	86	3191	3322	3623
	6;00-7:00 pm	64	6	70	2986	3094	2811

Sunday	7:00-8:00 am	91	11	102	4130	4288	4286
	8:00-9:00 am	72	8	80	3893	4017	2768
	9:00-10:00 am	55	8	63	3796	3894	2416
	10:00-11:00 am	47	4	51	3654	3732	2672
	11:00-12:00 am	42	3	45	3138	3207	2585
	12:00-1:00 pm	95	6	101	4784	4938	3291
	1:00-2:00 pm	43	0	43	3341	3405	2417
	2:00-3:00 pm	57	1	58	3654	3741	1912
	3:00-4:00 pm	51	8	59	3988	4080	2419
	4:00-5:00 pm	69	5	74	3895	4008	2322
	5:00-6:00 pm	74	0	74	3774	3885	3319
	6;00-7:00 pm	58	1	59	3312	3401	2285

APPENDIX C

Level of service analysis output using aaSIDRA software

Safari Roundabout

Input data used for SIDRA software are:

Number of leg -3 Central island diameter -26

Number of circulating lane -2 Inscribed circle diameter -50

Number of entry for each leg -

Leg1-2

Leg2 -2

Le3 -2

Average entry lane width

Leg1 - 3.8

Leg3 – 3.3

Leg2 – 3.7

Roundabout Basic Parameters

Intersection ID: 1
Roundabout

Cent Island Diam m	Circ Width m	Insc Diam. m	Ent Rad m	Ent Ang deg	Cir Lan	Ent Lan	Av.Ent Lane Width m	Circulating/Exiting Stream: Flow veh/h	%HV	Adjust. Flow pcu/h	%Exit Incl.	Cap. Constr. Effect	O-D Factor
East: Georgis Condominium													
Environment Factor: 1.00								Entry/Circulating Flow Adjustment: Medium					
26	12	50	20	30	2	2	3.90	616	0.0	616	0	Y	0.818
North: 72													
Environment Factor: 1.00								Entry/Circulating Flow Adjustment: Medium					
26	12	50	20	30	2	2	3.85	616	0.0	616	0	Y	0.818
West: Semit													
Environment Factor: 1.00								Entry/Circulating Flow Adjustment: Medium					
26	12	50	20	30	2	2	3.65	616	0.0	616	0	Y	0.818

Roundabout Gap Acceptance Parameters

Intersection ID: 1
Roundabout

Turn	Lane No.	Lane Type	Flow Rate pcu/h	Aver Speed km/h	Aver Dist m	In-Bnch Headway sec	Prop Bunched	Critical Gap Hdwy sec	Critical Gap Dist m	Foll-up Headway sec
East: Georgis Condominium										
Environment Factor: 1.00		Entry/Circulating Flow Adjustment: Medium								
Thru	1	Subdominant	616	25.1	40.8	2.00	0.534	5.00U	34.9	3.00U
Right	2	Dominant	616	25.1	40.8	2.00	0.534	3.22	22.5	2.12
North: 72										
Environment Factor: 1.00		Entry/Circulating Flow Adjustment: Medium								
Left	1	Subdominant	616	37.5	60.9	2.00	0.534	5.00U	52.1	3.00U
Right	2	Dominant	616	37.5	60.9	2.00	0.534	3.27	34.0	2.13
West: Semit										
Environment Factor: 1.00		Entry/Circulating Flow Adjustment: Medium								
Left	1	Subdominant	616	25.1	40.8	2.00	0.534	5.00U	34.9	3.00U
Thru	2	Dominant	616	25.1	40.8	2.00	0.534	3.41	23.8	2.13

Driver Characteristics

Intersection ID: 1
Roundabout

Lane No.	Satn Speed km/h	Satn Flow veh/h	Satn Hdwy sec	Satn Spacing m	Average Queue Space m	Driver Response Time sec
East: Georgis Condominium						
1 T	30.0	1200	3.00	25.00	7.00	2.16
2 R	30.0	1696	2.12	17.69	7.00	1.28
North: 72						
1 L	25.1	1200	3.00	20.93	7.00	2.00
2 R	30.0	1691	2.13	17.74	7.00	1.29
West: Semit						
1 L	25.1	1200	3.00	20.93	7.00	2.00
2 T	30.0	1691	2.13	17.74	7.00	1.29

Lane Use and performance

Safari Roundabout
Roundabout

Lane Use and Performance

	Demand Flows L veh/h	Demand Flows T veh/h	Demand Flows R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m
East: Georgis Condominium												
Lane 1	0	975	0	975	0.0	517	1.886	100	412.3	LOS F	162.6	1138.4
Lane 2	0	0	1165	1165	0.0	866	1.346	100	167.6	LOS F	114.4	800.8
Approach	0	975	1165	2140	0.0		1.886		279.1	LOS F	162.6	1138.4
North: 72												
Lane 1	970	0	0	970	0.0	517	1.875	100	412.1	LOS F	160.9	1126.3
Lane 2	0	0	1043	1043	0.0	859	1.214	100	111.1	LOS F	78.9	552.0
Approach	970	0	1043	2013	0.0		1.875		256.1	LOS F	160.9	1126.3
West: Semit												
Lane 1	906	0	0	906	0.0	517	1.753	100	357.4	LOS F	140.2	981.7
Lane 2	0	1041	0	1041	0.0	844	1.233	100	119.3	LOS F	82.9	580.4
Approach	906	1041	0	1947	0.0		1.753		230.1	LOS F	140.2	981.7
Intersection				6100	0.0		1.886		255.9	LOS F	162.6	1138.4

Urael Roundabout

Input data used for SIDRA software are:

Number of leg -4

Central island diameter -21

Number of circulating lane -3

Inscribed circle diameter -45

Number of entry for each leg:

Leg_1-2

Leg_3 -2

Leg_2 -3

Leg_4 -2

Average entry lane width

Leg_1 - 3.3

Leg_3 -4.2

Leg_2 – 3.6

Leg_4- 3.4

Roundabout Basic Parameters

```
Intersection ID: 1
Roundabout

-------------------------------------------------------------------------------
                                            Circulating/Exiting Stream
 Cent  Circ  Insc  Ent Ent Cir Ent Av.Ent ---------------------------------------
Island Width Diam. Rad Ang Lan Lan Lane   Flow %HV Adjust. %Exit  Cap.    O-D
 Diam                              Width            Flow   Incl. Constr. Factor
   m     m     m    m  deg            m   veh/h      pcu/h         Effect
-------------------------------------------------------------------------------
South: Kesanchis
  Environment Factor: 1.00   Entry/Circulating Flow Adjustment: Medium
  21    12    45   20  30   2   2   3.60 1180  4.0  1181     0      Y     0.724
-------------------------------------------------------------------------------
East: Stadium
  Environment Factor: 1.00   Entry/Circulating Flow Adjustment: Medium
  21    12    45   20  30   2   2   3.30 1065  4.0  1066     0      Y     0.807
-------------------------------------------------------------------------------
North: Bole Atlas
  Environment Factor: 1.00   Entry/Circulating Flow Adjustment: Medium
  21    12    45   20  30   2   2   4.20  976  4.0   977     0      Y     0.796
-------------------------------------------------------------------------------
West: 22
  Environment Factor: 1.00   Entry/Circulating Flow Adjustment: Medium
  21    12    45   20  30   2   2   3.40  877  4.0   878     0      Y     0.842
-------------------------------------------------------------------------------
```

Roundabout Gap Acceptance Parameters

```
Intersection ID: 1
Roundabout

-------------------------------------------------------------------------------
Turn Lane   Lane    ---- Circulating/Exiting Stream ---   Critical Gap
      No.   Type     Flow  Aver    Aver In-Bnch  Prop     ------------  Foll-up
                     Rate  Speed   Dist Headway Bunched   Hdwy    Dist  Headway
                    pcu/h  km/h     m     sec              sec     m      sec
-------------------------------------------------------------------------------
South: Kesanchis
  Environment Factor: 1.00   Entry/Circulating Flow Adjustment: Medium
Left  1 Subdominant 1181   28.3    23.9  1.42   0.659    5.00U   39.3    3.00U
Thru  2 Dominant    1181   28.3    23.9  1.42   0.659    3.00    23.5    1.99
Right 2 Dominant    1181   28.3    23.9  1.42   0.659    3.00    23.5    1.99
-------------------------------------------------------------------------------
East: Stadium
  Environment Factor: 1.00   Entry/Circulating Flow Adjustment: Medium
Left  1 Dominant    1066   27.2    25.5  1.43   0.619    3.31    25.0    2.03
Thru  1 Dominant    1066   27.2    25.5  1.43   0.619    3.31    25.0    2.03
      2 Subdominant 1066   27.2    25.5  1.43   0.619    4.02    30.4    2.47
Right 2 Subdominant 1066   27.2    25.5  1.43   0.619    5.00U   37.8    3.00U
-------------------------------------------------------------------------------
North: Bole Atlas
  Environment Factor: 1.00   Entry/Circulating Flow Adjustment: Medium
Left  1 Subdominant  977   27.8    28.4  1.89   0.698    5.00U   38.6    3.00U
Thru  1 Subdominant  977   27.8    28.4  1.89   0.698    5.00U   38.6    3.00U
      2 Dominant     977   27.8    28.4  1.89   0.698    5.00U   38.6    3.00U
Right 2 Dominant     977   27.8    28.4  1.89   0.698    2.76    21.3    2.07
-------------------------------------------------------------------------------
West: 22
  Environment Factor: 1.00   Entry/Circulating Flow Adjustment: Medium
Left  1 Subdominant  878   27.4    31.2  1.52   0.565    3.91    29.7    2.40
Thru  1 Subdominant  878   27.4    31.2  1.52   0.565    3.91    29.7    2.40
      2 Dominant     878   27.4    31.2  1.52   0.565    3.42    26.0    2.10
Right 2 Dominant     878   27.4    31.2  1.52   0.565    3.42    26.0    2.10
-------------------------------------------------------------------------------
```

Driver Characteristics

```
Intersection ID: 1
Roundabout

--------------------------------------------------------
                                         Average  Driver
 Lane   Satn    Satn    Satn    Satn     Queue   Response
 No.    Speed   Flow    Hdwy    Spacing  Space    Time
        km/h    veh/h   sec      m        m       sec
--------------------------------------------------------
 South: Kesanchis
 1 L     23.7   1199    3.00    19.77     7.24    1.90
 2 TR    30.0   1809    1.99    16.58     7.24    1.12
--------------------------------------------------------
 East: Stadium
 1 LT    29.4   1771    2.03    16.60     7.24    1.15
 2 TR    29.5   1203    2.99    24.52     7.24    2.11
--------------------------------------------------------
 North: Bole Atlas
 1 LT    26.8   1199    3.00    22.32     7.24    2.03
 2 TR    30.0   1489    2.42    20.15     7.24    1.55
--------------------------------------------------------
 West: 22
 1 LT    26.9   1500    2.40    17.96     7.24    1.43
 2 TR    30.0   1711    2.10    17.53     7.24    1.23
--------------------------------------------------------
```

Lane use and performance

Urael Roundabout
Roundabout

Lane Use and Performance

	Demand Flows L veh/h	Demand Flows T veh/h	Demand Flows R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m
South: Kesanchis												
Lane 1	518	0	0	518	4.0	287	1.809	100	391.9	LOS F	85.2	616.5
Lane 2	0	504	444	948	4.0	606	1.565	86 [5]	267.9	LOS F	122.5	886.9
Approach	518	504	444	1466	4.0		1.809		311.8	LOS F	122.5	886.9
East: Stadium												
Lane 1	448	442	0	890	4.0	682	1.304	100	155.8	LOS F	80.9	585.8
Lane 2	0	9	460	469	4.0	359	1.304	100	165.0	LOS F	46.1	334.0
Approach	448	451	460	1359	4.0		1.304		159.0	LOS F	80.9	585.8
North: Bole Atlas												
Lane 1	498	182	0	679	4.0	345	1.966	100	462.1	LOS F	121.0	876.3
Lane 2	0	370	615	984	4.0	501	1.966	100	453.2	LOS F	170.3	1232.9
Approach	498	551	615	1663	4.0		1.966		456.8	LOS F	170.3	1232.9
West: 22												
Lane 1	528	207	0	734	4.0	636	1.156	100	94.9	LOS F	47.7	345.3
Lane 2	0	337	553	890	4.0	770	1.156	100	89.2	LOS F	56.0	405.2
Approach	528	544	553	1625	4.0		1.156		91.8	LOS F	56.0	405.2
Intersection				6113	4.0		1.966		258.8	LOS F	170.3	1232.9

Bole-Medhanialem Roundabout

Input data used for SIDRA software are:

Number of leg -5 Central island- 36

Number of circulating lane -3 Inscribed Circle diameter- 66

Number of entry for each leg -

Leg_1-2 Le_3 -2

Leg_2 -3 Leg_4 -2

Leg_5 -2

Average entry lane width

Leg_1 - 3.3 Leg_3 – 4.5

Leg_2 – 3.3 Leg_4 – 4.5

Leg_5 – 4.3

Roundabout Basic Parameters

```
Intersection ID: 1
Roundabout

-------------------------------------------------------------------------------
                                            Circulating/Exiting Stream
 Cent  Circ  Insc  Ent Ent Cir Ent Av.Ent ----------------------------------
Island Width Diam. Rad Ang Lan Lan Lane   Flow %HV Adjust. %Exit  Cap.    O-D
 Diam                              Width           Flow   Incl. Constr. Factor
  m     m     m     m  deg           m   veh/h      pcu/h         Effect
-------------------------------------------------------------------------------
South: Ureal
  Environment Factor: 1.00   Entry/Circulating Flow Adjustment: Medium
  36    15    66   20  30   2   2   4.25 1204  0.0  1204     0     Y     0.779
-------------------------------------------------------------------------------
East: Atlas
  Environment Factor: 1.00   Entry/Circulating Flow Adjustment: Medium
  36    15    66   20  30   2   2   4.25 1003  0.0  1003     0     Y     0.798
-------------------------------------------------------------------------------
North: Air port
  Environment Factor: 1.00   Entry/Circulating Flow Adjustment: Medium
  36    15    66   20  30   3   2   4.15 1388  0.0  1388     0     Y     0.674
-------------------------------------------------------------------------------
NorthWest: Moyenco
  Environment Factor: 1.00   Entry/Circulating Flow Adjustment: Medium
  36    15    66   20  30   2   2   3.65 2186  0.0  2186     0     Y     0.736
-------------------------------------------------------------------------------
West: Hayahulet
  Environment Factor: 1.00   Entry/Circulating Flow Adjustment: Medium
  36    15    66   20  30   2   2   3.65 1608  0.0  1608     0     Y     0.826
-------------------------------------------------------------------------------
```

Roundabout Gap Acceptance Parameters

Turn	Lane No.	Lane Type	Circulating/Exiting Stream: Flow Rate pcu/h	Aver Speed km/h	Aver Dist m	In-Bnch Headway sec	Prop Bunched	Critical Gap: Hdwy sec	Critical Gap: Dist m	Foll-up Headway sec
South: Ureal										
Environment Factor: 1.00 Entry/Circulating Flow Adjustment: Medium										
Left	1	Subdominant	1204	31.6	26.2	1.56	0.705	5.00U	43.9	3.00U
Thru	2	Dominant	1204	31.6	26.2	1.56	0.705	2.25	19.8	1.76
Right	2	Dominant	1204	31.6	26.2	1.56	0.705	2.25	19.8	1.76
East: Atlas										
Environment Factor: 1.00 Entry/Circulating Flow Adjustment: Medium										
Left	1	Subdominant	1003	32.6	32.5	1.34	0.568	2.94	26.6	2.24
Thru	1	Subdominant	1003	32.6	32.5	1.34	0.568	2.94	26.6	2.24
	2	Dominant	1003	32.6	32.5	1.34	0.568	2.41	21.8	1.83
Right	2	Dominant	1003	32.6	32.5	1.34	0.568	2.41	21.8	1.83
North: Air port										
Environment Factor: 1.00 Entry/Circulating Flow Adjustment: Medium										
Left	1	Subdominant	1388	32.5	23.4	1.39	0.716	5.00U	45.1	3.00U
Thru	1	Subdominant	1388	32.5	23.4	1.39	0.716	2.82	25.4	2.56
	2	Dominant	1388	32.5	23.4	1.39	0.716	2.24	20.2	2.04
Right	2	Dominant	1388	32.5	23.4	1.39	0.716	2.24	20.2	2.04
NorthWest: Moyenco										
Environment Factor: 1.00 Entry/Circulating Flow Adjustment: Medium										
Left	1	Dominant	2186	33.6	15.4	1.35	0.900	2.01	18.7	1.39
Right	2	Subdominant	2186	33.6	15.4	1.35	0.900	2.85	26.6	1.97
West: Hayahulet										
Environment Factor: 1.00 Entry/Circulating Flow Adjustment: Medium										
Left	1	Subdominant	1608	31.8	19.8	1.40	0.785	3.00	26.6	2.08
Thru	1	Subdominant	1608	31.8	19.8	1.40	0.785	3.00	26.6	2.08
	2	Dominant	1608	31.8	19.8	1.40	0.785	2.32	20.5	1.60
Right	2	Dominant	1608	31.8	19.8	1.40	0.785	2.32	20.5	1.60

Intersection ID: 1
Roundabout

Lane No.	Satn Speed km/h	Satn Flow veh/h	Satn Hdwy sec	Satn Spacing m	Average Queue Space m	Driver Response Time sec
South: Ureal						
1 L	28.1	1200	3.00	23.44	7.00	2.10
2 TR	30.0	2051	1.76	14.63	7.00	0.92
East: Atlas						
1 LT	30.0	1610	2.24	18.64	7.00	1.40
2 TR	30.0	1966	1.83	15.26	7.00	0.99
North: Air port						
1 LT	30.0	1229	2.93	24.42	7.00	2.09
2 TR	30.0	1767	2.04	16.97	7.00	1.20
NorthWest: Moyenco						
1 L	28.1	2593	1.39	10.85	7.00	0.49
2 R	30.0	1827	1.97	16.42	7.00	1.13
West: Hayahulet						
1 LT	30.0	1734	2.08	17.30	7.00	1.24
2 TR	30.0	2243	1.60	13.37	7.00	0.76

Lane use and performance

Bole Medhanialem
Roundabout

Lane Use and Performance

	Demand Flows L veh/h	Demand Flows T veh/h	Demand Flows R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m
South: Ureal												
Lane 1	519	0	0	519	0.0	289	1.797	100	389.8	LOS F	85.2	596.6
Lane 2	0	538	577	1115	0.0	784	1.423	79[5]	204.1	LOS F	120.9	846.6
Approach	519	538	577	1635	0.0		1.797		263.1	LOS F	120.9	846.6
East: Atlas												
Lane 1	707	153	0	860	0.0	719	1.196	100	104.5	LOS F	58.2	407.3
Lane 2	0	455	671	1126	0.0	941	1.196	100	99.0	LOS F	73.7	515.6
Approach	707	608	671	1985	0.0		1.196		101.4	LOS F	73.7	515.6
North: Air port												
Lane 1	381	72	0	453	0.0	236	1.923	100	445.0	LOS F	80.2	561.7
Lane 2	0	523	559	1082	0.0	563	1.923	100	425.6	LOS F	177.6	1243.1
Approach	381	595	559	1535	0.0		1.923		431.4	LOS F	177.6	1243.1
North West: Moyenco												
Lane 1	317	0	0	317	0.0	338	0.938	100	87.6	LOS F	15.9	111.5
Lane 2	0	0	286	286	0.0	193	1.477	100	283.3	LOS F	40.3	281.9
Approach	317	0	286	603	0.0		1.477		180.3	LOS F	40.3	281.9
West: Hayahulet												
Lane 1	420	143	0	563	0.0	452	1.247	100	147.4	LOS F	49.1	343.7
Lane 2	0	298	528	826	0.0	662	1.247	100	139.3	LOS F	69.4	485.7
Approach	420	442	528	1389	0.0		1.247		142.6	LOS F	69.4	485.7
Intersection				7147	0.0		1.923		223.9	LOS F	177.6	1243.1