Jimma University
School of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Highway Engineering Stream

CAPACITY ESTIMATION FOR ROUNDABOUTS USING GAP ACCEPTANCE METHOD: A CASE STUDY ON ADDIS ABABA

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)

By: Safi Kaso

February, 2020

Jimma, Ethiopia

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DECLARATION

I, the under signed, declare that this thesis entitled "**Capacity Estimation for Roundabouts Using Gap Acceptance Method: A Case Study on Addis Ababa**". This thesis is my original work, and has not been presented for a degree in this or any other University.

Name: **Safi Kaso**

Signature:________________ Date ___________

CERTIFICATION

I, the signers, confirm that I read and here by recommend for the receipt by the Jimma University a paper entitled: "**Capacity Estimation for Roundabouts Using Gap Acceptance Method: A Case Study on Addis Ababa**" in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Civil Engineering (Highway Engineering).

Advisor: Dr Ing. Fikadu Fufa

Signature:________________ Date ____________

Co-advisor: Eng. Mesfin Dinku (MSc)

Signature:__________________Date ___________

ABSTRACT

Capacity of roundabout depends on several factors which include the high traffic volume of vehicle, geometry of roundabout, high pedestrian volume. The main emphasis of this study was focused on the most important element of operational performance of roundabout traffic intersections in Addis Ababa: capacity analysis. The relation between a roundabout performances measure and capacity is often expressed in terms of degree of saturation (Demand volume – Capacity ratio).

Capacity estimation is done based on empirical gap – acceptance method that is accepted by aaSIDRA software. The essential geometric data for the analysis (average entry width, circulatory road width, number of entry and circulatory lanes, and island diameter), traffic movement data with vehicle characteristics and pedestrians volume were gathered from 6 roundabouts. These 6 roundabouts represent for different sizes of inscribed circle diameters of roundabouts, which are directly connected to their approach leg numbers (3 leg, 4 legs, 5 legs and 6 legs).

aaSIDRA software capacity estimation results indicated that out of 6 roundabouts 4 of them have greater than 0.85 degree of saturation. This 0.85 value is recommended by evaluation process of some model countries such as Australia, Germany, United Kingdom and U.S.A. whose roundabouts were planned to operate at no more than 85 percent of their estimated capacity. Approach entry capacity has been analyzed for all 6 roundabouts at their legs and with curve – fitting techniques. Effective capacity versus geometric parameter relationship have been developed in order to find out the causes of their over saturation ($v/c > 0.85$) and the results indicate that number of entry lanes, number of circulatory lanes, high traffic volumes are the major causes of over saturation.

Moreover, the chart is developed using the parameters number of entry lanes, number of circulatory lanes and opposing circulatory flows, which can assist in designing of roundabouts and forecasting their capacity.

Keywords: Capacity, Level of Service (LOS), Degree of Saturation, Over Saturation, aaSIDRA

ACKNOWLEGEMENT

First and foremost, I would like to thank the Almighty God for giving me strength to endure the challenges in my quest to complete this thesis.

Secondly, I would like to express my gratefulness to my advisor Dr Ing. Fikadu Fufa and my co adviser Eng. Mesfin Dinku (MSc) who offered me excellent academic guidance to improve and shape my thesis. I appreciate your patience and diligence in reading and commenting on the paper at each step.

Also, I would like to thank the Ethiopian Road Authority, ERA for its kind, being sponsorship of my study program for the Msc, and to all my lecturers who have thought me in Jimma University, Jimma Institute of Technology, thank you for all the knowledge and guidance.

Finally I would like to thank to my beloved family members and friends. Their support was instrumental for the successful of this research.

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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
RTA	Road Traffic Accident

CHAPTER ONE

1. INTRODUCTION

1.1 Background of Study

Roundabouts are popular in recent years, according to statistics; there are over 2000 roundabouts in the US and Canada [16]. And more and more scholars have paid their attention to roundabouts from different views, such as capacity, safety, and performance. Capacity may be expressed in terms of persons or vehicles. Roadway conditions refer to the geometric characteristics of the facility, such as the number of lanes, lane widths, shoulder widths, and free flow speeds. The rate used is for the peak 15-minutes of the peak hour. Capacity is the maximum possible through of the traffic facility and it is a determinant parameter for other performance actions, such as delay and queue [25].

These facilities were introduced in order to solve the problems of presented 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 [10].

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].

Conflict point is a point where paths of two vehicles diverge, merge or cross. As roundabouts have become more favorable, more roundabouts have been built on or near main highways with high truck volume roundabout is very important since it is directly related to delay, level of service, accident, operation cost, and environmental issues. For more than four decades modern roundabouts have been used successfully throughout the world as an intersection control device. Addis Ababa also has its share of roundabouts. There are three legs; four legs; five legs and six legs roundabouts in Addis Ababa. Since little attention has been paid to the design and capacity evaluation of the roundabouts, nobody knows their capacities or level of services.

Therefore, road authorities and other concerned bodies need to conduct comprehensive capacity and delay study of every roundabout so that they can come up with solutions for the traffic congestions, traffic delays, and level of services, accidents and operating costs.

1.2 Statement of the problem

In Addis Ababa City, increasing traffic volumes and congestions are two quickly developing problems facing the society. Now-a-days, it is common to see traffic congestion at junctions at peak hours in the morning and Afternoon. Hence, the traffic police need to intervene in the situation to regulate the traffic flow by over-riding the traffic control devices. Otherwise, it would be practically impossible to have normal traffic flows, especially at roundabout intersections, which is more dependent on driver behavior and balanced traffic flow between the approaches. Poor road planning and sub-standard geometric conditions of roundabouts have a significant effect on roundabout capacity and traffic congestion.

Therefore, it is vital to evaluate the capacity of roundabout for proper traffic operation and to give a clear picture for the planners and traffic engineers involved in highway capacity design and traffic operation tasks.

Some of the problems related to capacity of roundabouts are as follows:

A. Necessarily geometric features of roundabouts such as flare and apron do not exist.
B. In some roundabouts, there are visibilities problems caused by plants or elevated masonry. This causes the entering driver to hesitate on entering the circulating traffic, affecting the capacities of the roundabouts.
C. Roundabouts central islands are accessed by pedestrians.
D. Absence of road markings, signings and lightings.

These and other problems related factors 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 capacity of roundabout in Addis Ababa city and if possible to establish \basis for further studies.

1.3 Research Question

1. How to collect geometric and traffic data used for capacity of roundabout?
2. What are factor affect capacities of roundabout?
3. How to determine level of service of roundabout?
4. What are the methods used to evaluate the capacity of roundabout?

1.4 Objective of the Study

1.4.1 General objective

- The main objective of this research was to evaluate the capacity of roundabout in Addis Ababa City.

1.4.2 Specific objective

- To determine the geometric and traffic data used for capacity of roundabout
- To analysis factors that affect the capacity of roundabout and possible counter measures
- To determine level of service of roundabout
- To evaluate Capacity of roundabout.

1.5 Significance of the study

The research study assessed the capacity of roundabout and factors affecting the capacity. 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 the capacity of roundabout and factors that affect capacity of roundabout.

Even though the study is foreseen to specific area in the Addis Ababa, 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 geometric features of roundabout. This study is help full for further research studies on geometric features of roundabout in other areas of Ethiopia. For the road construction companies in Ethiopia, this research study gives guidelines and an overview on factors that affect and reduce the capacity of roundabout.

1.6 Scope of the study

The scope of this study was focused on Six roundabouts that are founds in Addis Ababa namely Adwa-Aboare, Mexico, Pissa-Degol, Gorgis-Woizron,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 Addis Ababa, 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 Poor road planning and sub-standard geometric conditions of roundabout.

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. .

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, which discusses the basic concepts of roundabouts and the methodologies of roundabout capacity analysis. The third chapter discuses the gathering of data sets (data collection). The fourth chapter deals with capacity analyses for different approach leg numbers, and finally chapter five, a conclusion and recommendation are derived from results and discuss.

CHAPTER TWO

2. LITERATURE REVEIW

2.1 Meaning and Basic Concepts of Roundabout

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 [1].

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 [13]. 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.

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 [10].

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.

2.5 Major Geometric Features of 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 [22] of roundabouts are described as follows and these features are given in figure 2.1 [11].

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.

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.

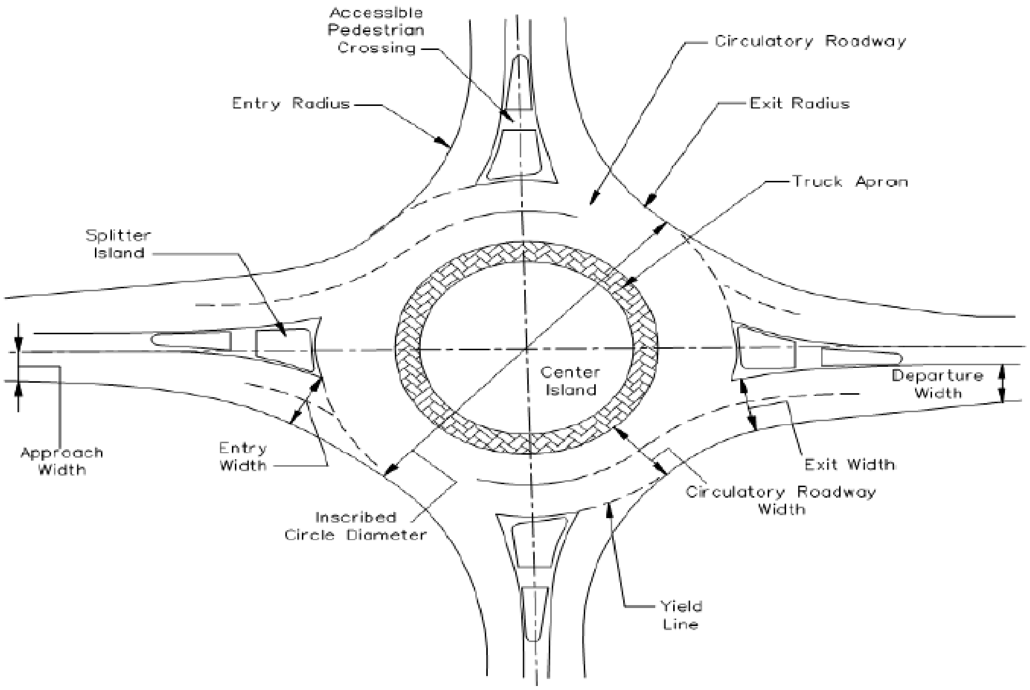

Figure 2.1: Basic geometric elements of roundabout [11]

2.6 Appropriate Sites for Roundabouts

1. Heavy holdup on minor road.
2. Traffic signals result in greater holdup.
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 inattention. 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 [22].

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.

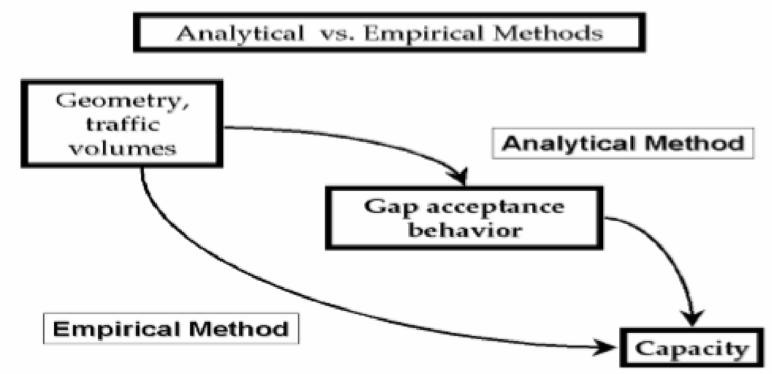

Figure 2.2: Analytical Verses Empirical method

2.9.1 Empirical 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].

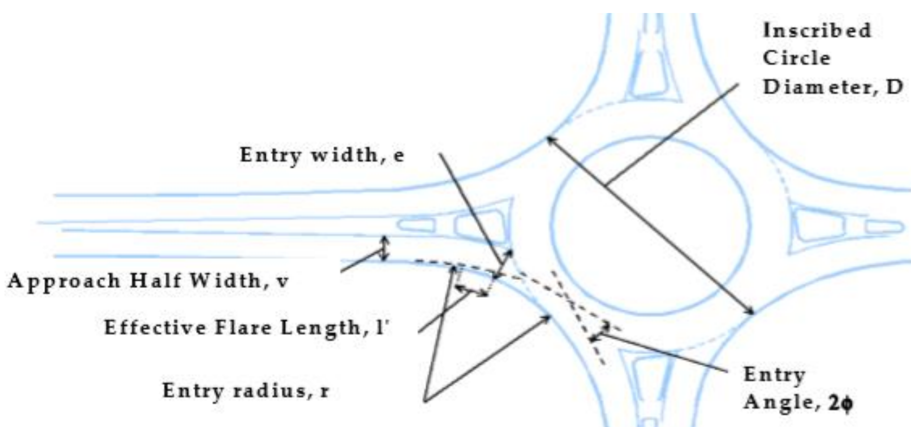

Figure 2.3: (UK- 6 Geometric Parameters used for Capacity Analysis)

Qe = F – fc * Qc………………………………… (2-1)

Where;

Qe = Entering capacity (veh/h)

Qc = Circulating flow (veh/h)

F, fc = 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

$Qe = k (F-fc Qc)$………………………………….. (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 30^0, 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).

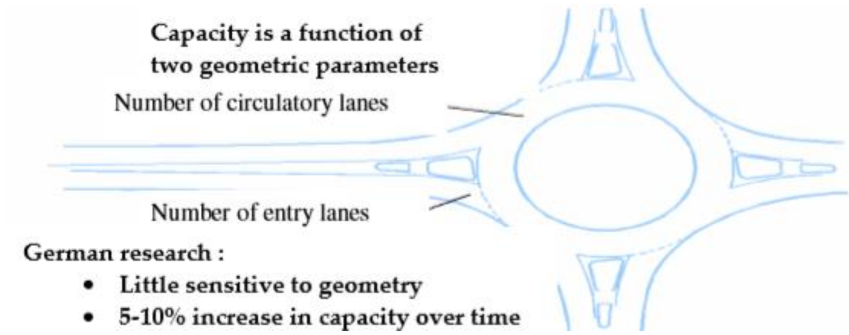

Figure 2.4: (Germany's -Geometric parameters)

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 (Brilon1990)

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.

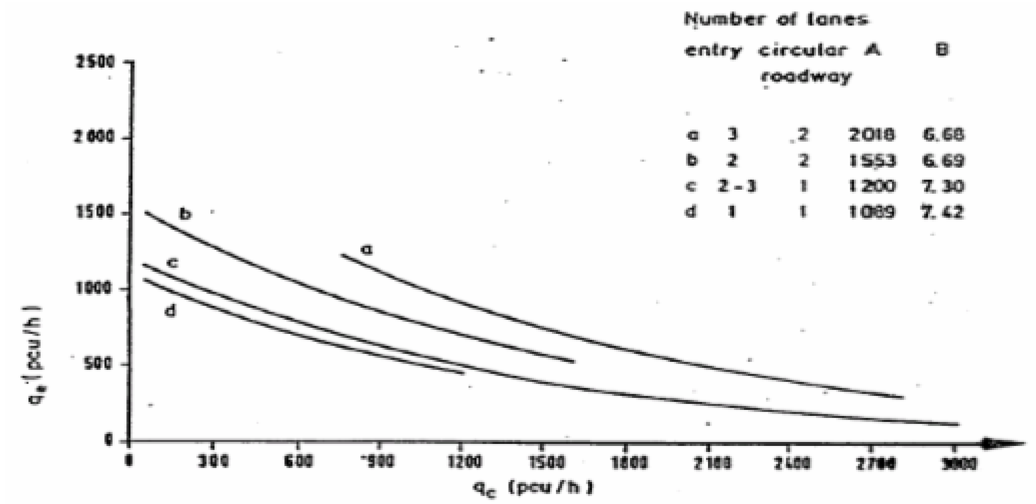

Figure 2.5: Parameters for Exponential Analysis (Brilon 1990)

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 given in eq (2.10)

Qe = C+ DQc …………………………….. 2.10

Qe = Entering Capacity (vph)

Qc = Circulatory flow (vph)

F, f c = Parameters defined by roundabout geometry

Where C and D are as shown in the Table 2.2

Table 2.2: Parameters for linear regression (Brilon 1997)

Number of lanes Entry/ Circle	C	D	N (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

2.9.2 Analytical Method

The empirical formulation has some drawback, 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)
The development of gap acceptance capacity formula was fundamentally based on Tanner's capacity equation (2.9.2.1) for priority intersection. The equation has been adjusted in order to relate with data observed in the field. Australia has adapted Tanner's equation with modifications for use in Australia.

To a great extent, all model input parameters related to intersection geometry and driver behavior are important for calibrating the traffic model to represent particular intersection conditions. For roundabouts, gap-acceptance parameters (especially follow up headway and critical gap) are key parameters to represent driver behavior. The overall roundabout geometry (configuration of approach roads, number of approach and circulating road lanes, and allocation of lanes to movement) affects the capacity and performance directly. The gap-acceptance parameters as well as the overall approach and circulating road lane use are affected by roundabout geometry as well as the overall demand flow levels and patterns, which in turn affects capacity and performance significantly (Akcelik, 2005).

Another important component of Akcelik's formulation is the identification of the dominant and subdominant entry lanes based on their flows. The dominant lane has the highest flow rate, and all others are subdominant. The purpose of this component is that dominant and subdominant entry lanes can have different critical gap and follow up times. The distinction between dominant and subdominant lanes appears to be quite important because vehicles using the left most entry lane must find a gap in both circulating lanes, as opposed to the right entry lane, which must only deal with traffic in the outer most circulating lane.

In the aaSIDRA equation (2.9.2.2) an empirical gap-acceptance method has been used to model roundabout capacity and performance. The aaSIDRA model includes the effect of both roundabout geometry and driver behavior, and it incorporates effects of priority reversal (low critical gaps at higher circulating flows), priority emphasis (unbalanced O-D patterns), and unequal lane use (both approach and circulating lanes). Capacity can be measured as service rate for each traffic lane in under saturated conditions (v/c ratio less than 1) according to the Highway Capacity Manual (HCM) definition of capacity under prevailing conditions. This is in contrast to measuring approach capacity in over saturated conditions [21].

Many of the additional elements in aaSIDRA are parameters used to enhance its basic gap acceptance theory. The parameters that deal with the entering traffic stream include the inscribed diameter, average entry lane width, the number of circulating and entry lanes, the entry capacity (based on the circulating flow rate), and the ratio of the entry flow to the circulating flow. These additional model elements demonstrate the detailed nature of the aaSIDRA. Akcelik (ARR 321, 1998) contends that, while Kimber objects to the "simple gap acceptance method", the model presented for use in the aaSIDRA software package goes beyond the simple approach. One main addition to Akcelik's gap acceptance approach is the modeling of the roundabout, based on approach lane use. Furthermore, Akcelik writes that the method presented in his report improves capacity prediction during heavy flow conditions and especially for multilane roundabouts with uneven approach demands.

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:

$Q = s\ u = (3600/\beta)\ u$………………………….. (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 = 3.0 means 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. (23)

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, 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, and 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 bunch (or free) in the circulating stream I determined from the following formula (this replace the exponential model used in earlier version of aaSIDRA):

$\phi = (1 - \Delta\, qc) / [1 - (1 - Kd)\, \Delta\, qc]$…………………………… (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)

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

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

2.9.2.3 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.

I. 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 (SB, NB, EB….)

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)

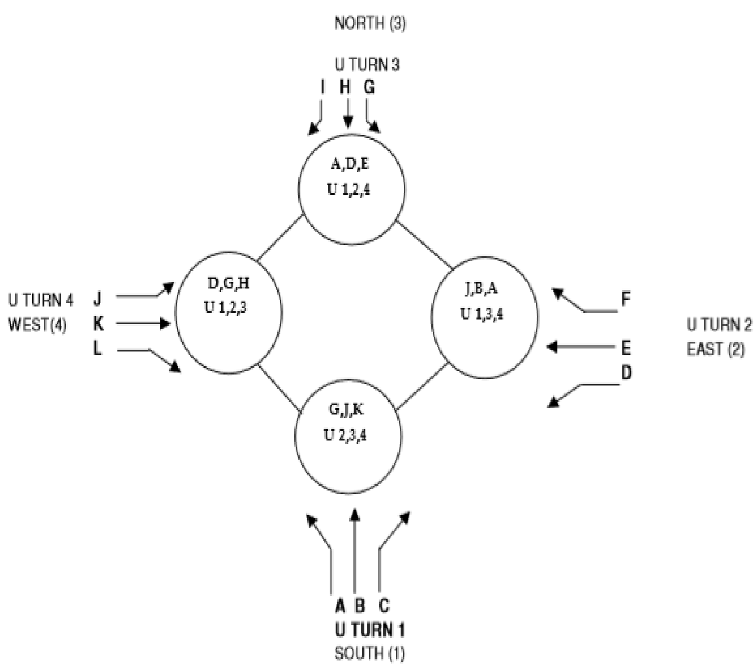

Figure 2.6: shows circulating volume at entry for 4-leg and 2-lane roundabouts.

For instance, for the vehicles that will pass by the north bound approach include the south bound left (g), the east bound left (j) and through (k), and the U-turns from the westbound (2), south bound (3) and east bound (4) approaches. Each movement that passes an approach is an adjusted circulating volume (VOL'c) for that approach.

II. Lane Utilization Factor

The utilization of circulating road lanes is important in determining the capacity entry lane giving way (yielding) to the circulating stream in front of it. The calibration effort should aim to replicate the observed lane flow it allows the user to specify lane utilization factors in order to allow for lane underutilization (unequal lane utilization) observed in the field (Akcelik, 2005). The circulating flow at entry for a given approach lane is calculated using equations 2-18 and 2-19.

$$q_{cr} = \Sigma_d VOL'_c * P_c * \Psi \quad \text{(2-18)}$$

$$q_{cl} = \Sigma_d VOL'_c * \Psi \quad \text{(2-19)}$$

Where,

VOL'c = Adjusted circulating flow at a given approach (pce/h)

Pc = Circulating split (proportion of vehicles in the outside lane)

qcr = Circulating flow at entry for the right lane (pce/h)

qcl = Circulating flow at entry for the left lane (pce/h)

Ψ = Factor based on driver familiarity

d = Direction of approach (NB, SB, EB...)

The driver familiarity parameter (Ψ) affects the total circulating volume, which ultimately affects the capacity of an entry lane. The value of this parameter should decrease as driver familiarity increases, eventually having no effect on the circulating traffic when drivers are comfortable. Recommended values range from about 1.20 for uncomfortable drivers to 1.00 once drivers become acclimatized to the facility. Location near an airport or tourist attraction where motorists are more likely to be unfamiliar with the facility value of 1.2 might also apply. The most appropriate method would be to calibrate this parameter based on field data.

The circulating (or outside) split variable (Pc) measures the proportion of circulating vehicles that occupy the outside lane. This parameter is a user controllable parameter that can range from 0.5 to 1.00. The latter should be used for roundabouts with low capacities or with a single circulating lane. The lower limit of 0.5 assumes that at capacity the inside lane would be fully utilized.

Unless there are extraordinary circumstances (a crash or stalled vehicle in the outside lane), this lane should not have more traffic than the outside lane. The recommended default value is 0.8, representing that 80% of the traffic travels in the outside lane.

The steps and equations in this section have now produced the necessary variables for the capacity model.

Determining capacity of each entry lane as stated previously, the gap acceptance capacity model (Equation 2-14), as presented in ARR 321 by Akcelik,. (Equation 2-20) shows this equation with minor alterations so that qc is represented in the equation as passenger car equivalents per second. Dividing the circulating flow by 3600, the number of seconds in an hour makes this adjustment.

$$Q_e = \left(\frac{3600}{\beta} * \left(\left(1 - \frac{\Delta c * qc}{3600}\right) + \left(\frac{\beta * \Phi * qc}{2 * 3600}\right)\right) * e^{-\lambda * (\alpha - \Delta c)}\right.$$

Equation 2-20: Adjusted Base Capacity Equation

Where,

Qe = Capacity of a single entry lane (pce/hour)

β = Follow up headway (seconds/vehicle)

α = Critical gap (seconds/vehicle)

Δc = Intrabunch headway (seconds/vehicle)

qc = Circulating flow at entry (pce/hour)

Φc = Proportion of unbunched vehicles in the circulating stream

λ = Parameter in the exponential arrival headway

This equation is used to find the capacity of each entry lane of a given approach. Different values for some of the parameters are used for the different entry lanes. Critical gap and follow up headway will have lower values for the right entry lane than the left, as it will take a vehicle longer to get into the inside lane. The other alterable variable, the circulating flow at entry, will differ based on the particular lane.

The critical gap, α is defined as the minimum time interval in the major-street traffic stream that allows intersection entry for minor-street vehicle. Thus, the driver's critical gap is the minimum gap that would be acceptable. A particular driver would reject any gap less than the critical gap and would accept gaps greater than or equal to the critical gap. Estimation of critical gap can be made on the basis of observations of the largest rejected and the smallest acceptable gap for a given intersection. The time between the departure of one vehicle from the minor street and the departure of the next vehicle using the same major -street gap, under a condition of continuous queuing on the minor street, is called the follow-up time, tf. Thus, tf is headway that defines the saturation flow rate for the approach if there were no conflicting vehicle on movement of higher rank (HCM, 2000).

The recommended values for α (tc) and ß(tf) are 3.5 and 3 for the right entering lane, and 4.5 and 3.5 for the left entering lane. All of these values are in seconds per vehicle. The user could change these if necessary, based on observed data or for situation specific cases, but the right entry lane shall always have lower values for these variables than the left entry.

CHAPTER THREE

3. MATERIAL AND METHOLOGY

Based on the literature reviewed, different countries have their own methods of Capacity Analysis, which is forwarded by different researchers, but we can categorize them into totally Roundabout Geometry dependent approach that is the Empirical Method. Gap acceptance approach that incorporate driver behavior and familiarity, type of vehicle, the circulating and entering splits and conflicting circulating flow are included in Analytical Method. aaSIDRA was not applied purely analytical method to analyses the roundabout capacity. It is semi Empirical-Analytical approach since it uses some geometric elements for the analyses.

Using driving (Traffic) rules and Geometric features, it is possible to distinguish the rotary and traffic circles from modern roundabouts. The driving or traffic rules for modern roundabouts are priority to circulating vehicles, no pedestrian access, no parking and one direction circulation. The geometric features are yield line, approach flare, deflection and splitter island (not for small roundabouts).

Which Methods or formulas forwarded by different researchers or different countries practice are appropriate for Addis Ababa?

Since the regression or Empirical method totally depends on the geometric elements of the roundabout, it is sometimes difficult to find the necessary geometric features (elements) on Addis Ababa roundabouts, which may be a problem during evaluation. Besides, the analytical method is more realistic than empirical method since it includes the traffic environment. Therefore, the Analytic method is preferred for this thesis using aaSIDRA software with some geometric elements. In fact, AACRA also recommend aaSIDR software for capacity analysis, which is developed by using Analytic method with some geometric elements.

Roundabout's, geometric and traffic data (peak hour) were required in order to achieve the objective of this thesis. As much as possible, the traffic data collected should indicate the existing peak hour traffic conditions. Even if the Addis Ababa Road Authority Traffic Engineering Department has established a computerized database system for traffic data, the data collected does not relate to peak hour traffic and it does not show the turning movements on the junction. Only the Average Annual Daily Traffic (AADT) along some of Addis Ababa's major and minor roads was stored in the database.

Therefore, it was found necessary to collect this data using skilled persons and by assigning them at the roundabouts. And yet, since it was not easy to get skilled manpower for the task, the researcher finally decided to train high school graduates at reasonable expense.

As a result, after being skillfully trained, the trainees were able how to count the turning movement of traffic around the roundabout junction, how to fill the general information on appropriate forms for traffic volume and pedestrian counts and how to measure geometric elements of the roundabouts.

3.1 Description of Study area

After the training, the necessary geometric and peak hour traffic data were collected at six roundabouts. These six roundabouts were chosen based on the principle of possible representative of the target population of roundabouts in terms of size and numbers. There are around thirty roundabouts in Addis Ababa, and their size more or less is related to their leg numbers. Clearly in terms of number, six roundabouts can represent the thirty roundabouts. The study area selected for this research was Addis Ababa, which have business centers.

Six roundabouts in Addis Ababa city, which have different legs and sizes that can represent other was selected and the chosen roundabouts have three legs, four legs, five legs and six legs in order to fully represent the size of the roundabouts.

Actually, most of these roundabouts were built before 30 years ago when rotary and traffic circles were popular but now the drivers have to operate in accordance to modern roundabout traffic rules, even if some geometric elements of modern roundabouts do not exist; and also on few roundabouts, Parking for buses is allowed. Since aaSIDRA does not totally depend on geometric elements, but they are more dependent on traffic rules so that by collecting traffic data and by observing some geometric features it is possible to carry out the capacity analysis.

The chosen roundabout names are as follows (the name being adopted from the area or publicly declared by the government).

Table 3.1: The selected roundabout names and legs

No	**Roundabout name**	**Number of legs**
1	Adwa-Aboare	Three-legs
2	Ureal	Four-legs

3	Tewodros	Five-legs
4	Gorgis-woizron	Four-legs
5	Pizzia-Degol	Four-legs
6	Mexico	Six-legs

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, pedestrian, accident data, Addis Ababa traffic commission and Roundabout geometry**.**

3.4 Research approach

The research approach in this thesis involve quantitative approache. Quantitative data 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. 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.

However, in this research the selected site was different 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.

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 Intersection software.

3.5 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.

3.6 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.

3.7 Data collection techniques and Equipment

The researcher used skillman power to count the vehicle that cross each leg. 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. 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. 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. Quantitative data were utilized based on the necessary input parameters for the analysis by comparing with Highway Capacity Manual. 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 2010, and finally the results from software out puts were compared with Standard Specification.

Figure 3.1: Interview of traffic police before collecting traffic flow

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 capacity and level of service.

The primary traffic flow and geometric data collection techniques used were

1. field measurements
2. Manual traffic volume count

3.7.1 field measurements

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 degree of saturation (v/c) and level of service going to be determind.

3.7.2 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. 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.

3.8 Study variables

3.8.1 Dependent variable

- Capacity of roundabout

3.8.2 Independent variable

- Geometry of roundabout
- Road side element
- Pedestrian volume
- Traffic flow
- Level of service

3.9 Software and Instruments

The following software and instruments were used for this study:

aaSIDRA, Microsoft excel, Meter tape, Digital Camera for documentation.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 General

Taking in to consideration all the above summarized data, we can proceed to the capacity analysis using aaSIDRA for all roundabouts. However, some additional information is required to represent driver behavior.

Gap-acceptance parameters, critical gap and follow up headway were not measured during the traffic flow count. These data were collected later. Actually to have a better result, it is good to do it simultaneously with the traffic count since it expresses the existing geometric and traffic conditions.

When it is measured with the traffic count, even on different legs at the same roundabout, different results of critical and follow up headway can be observed. In the case of this research, we can have critical and follow up headway using aaSIDRA specific to roundabout geometry and flow conditions besides to the collected critical and follow up data.

Environmental factor-1 and lane utilization factors 100 have been used in this analysis, except for the Urael roundabout which has higher heavy vehicle volume, and for roundabouts that have higher pedestrian volumes (Gorgis- woizor and Mexico). Environmental factor represents the general roundabout environment in terms of roundabout design type, visibility, significant grades, operating speeds, size of light and heavy vehicles, driver aggressiveness and alertness (driver response times), pedestrians, heavy vehicle activity and parking turn over (aaSIDRA Input guide, September 2004). Lane Utilization factor is a saturation flow adjustment factor for modeling unequal lane utilization at entry. When there is a parking facility near to entry of roundabout the lane utilization factor may reduce. aaSIDRA does not directly include the effects of pedestrian volume in the capacity analysis of roundabouts.

4.1 Methods of data analysis

4.1.1 Geometric Data

As per the requirement of both aaSIDRA and Akcelik's base capacity formula, the collected geometric data include: island diameter, circulatory width, number of circulatory lanes, entry lane number and average lane width at entry and also data collection format was prepared in excel document and processed using micro soft excel like table, graph. These data are measured with a tap meter or observed on the roundabout existing sites. The collected geometric data are summarized as shown in Table 4.1

Please see the roundabouts geometry in the Appendix – B

Table 4.1: Summary of Roundabout geometry

No	Roundabout name	No of legs	No of circulatory lanes	Island Diametry (m)	Circulatory road width (m)	Inscribe circle Diametry (m)
1	Adwa-Aboare	3	2	15	11	37
2	Ureal	4	3	21	12	45
3	Tewodros	5	3	40	25	90
4	Gorgis-woizron	4	2	22	10	42
5	Piassa-Degol	4	2	15	7	29
6	Mexico	6	3	65	12	89

From the summarized geometric data we can see that the island diameter of the roundabouts ranges from 15m to 65m. When we add their circulatory width, the range becomes 29m to 90m, which can be categorized from mini roundabouts to urban multilane roundabouts according to Roundabout Information Guide.

As shown in Figure 4-1, when the central island diameter increases the circulatory lane numbers also increases. Out of 6 roundabouts, 3 of them have 3 circulatory lanes, the rest have 2 lanes. For 2 circulatory lanes it is possible to use aaSIDRA and Akcelik's Base Capacity formulas for roundabout capacity analysis. But for 3 lanes circulatory roundabouts the analysis will be carried out only using aaSIDRA; since Ackelik's Base Capacity formula allows calibration only for two lanes circulatory roundabouts. So that the capacity analysis of this thesis will be on the basis of aaSIDRA, results only for comparison and references the Akcelik's analysis results for two circulatory lanes will be attached to the appendix B

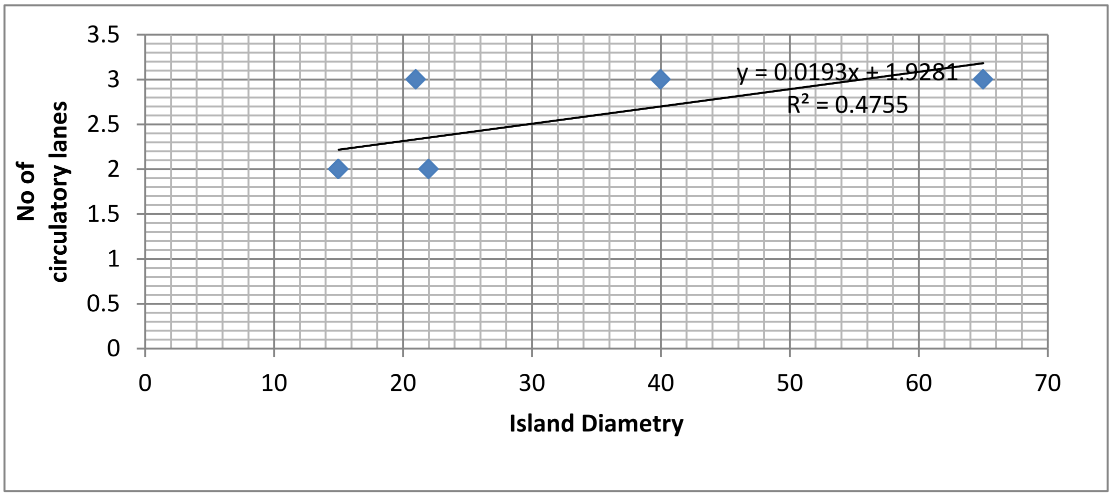

Figure 4.1: Island Diameter Vs Number of Circulatory Lane

Number of legs at junction and island diameters relationships is established by curve fitting techniques as shown on Figure 4-2 and it shows that there is a linear relationship with good R mean square results which is 0.894. The island diameter linearly increases with the approaches leg numbers. Therefore, it is a justified representative (chosen) sample, which is based on leg numbers.

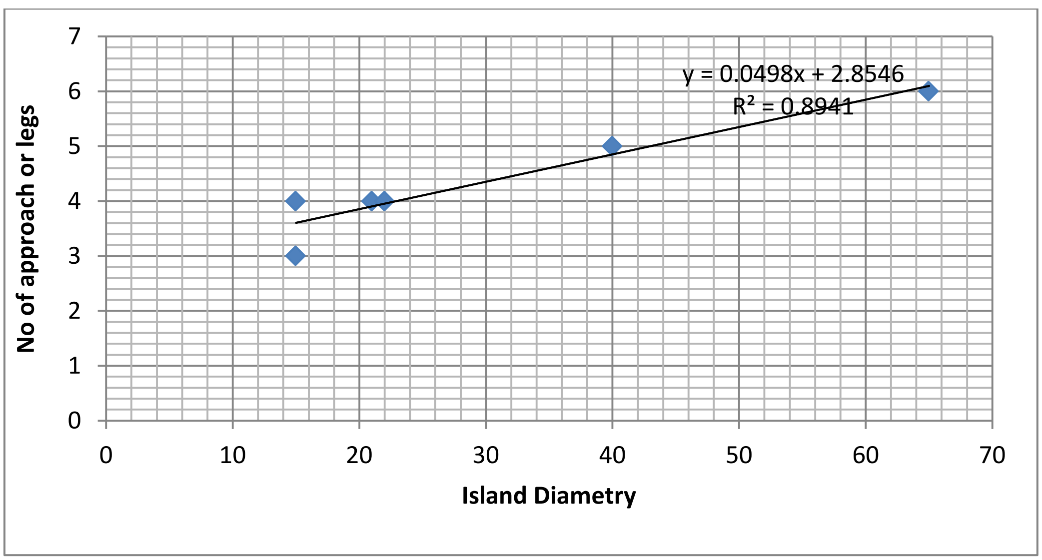

Figure 4.2: Island Diameter Vs Number of Legs

As discussed above, other important parameters for the analysis are number of entry lanes and average lane width. These two parameters are carefully measured from the roundabouts approach site, summarized and are presented in Table 4.2 below. The roundabouts approach legs have between 1 and 4 entry lane numbers and their average widths were measured also between 3m and 6m.

Table 4.2: Summery of legs or approaches Geometry

No	Roundabouts	Leg No.	No. of entry lane	Average lane width (m)
1	Adwa-Aboare	1	1	4.5
		2	1	4.5
		3	3	3
2	Urael	1	2	3.3
		2	3	3.6
		3	2	4.2
		4	2	3.4
3	Tewodros	1	4	3
		2	1	6
		3	2	4
		4	1	6
		5	1	6
4	Gorgis-woizron	1	2	4.5
		2	2	3.6
		3	1	5.8
		4	2	4.5
5	Piassa-Degol	1	1	5
		2	1	6
		3	1	6
		4	3	4
6	Mexico	1	3	3.1
		2	3	3
		3	2	4.5
		4	3	4
		5	3	3
		6	2	4.5

4.1.2 Traffic Data

Traffic movements of vehicle and vehicles' volume classification are important parameters for capacity analysis using aaSIDRA. High pedestrian volume also has a significant effect on capacity. Because of this, vehicle and pedestrian volume data were collected at peak hours with their direction of movements. The vehicles and pedestrians counted are summarized as shown in Table 4.3. The data is collected for one hour or 60 minutes duration. For detailed information on the movement of vehicles, please see Appendix A.

Figure 4.3 and Figure 4.4 clearly shows the maximum and the minimum numbers of vehicle and pedestrian traffic at surveyed junctions. For the most part when there is increased traffic volume, there are more pedestrians. The reason for this can mostly be attributed to land use. And the maximum numbers of vehicles and pedestrians traffic exist at Gorgis-woizron, Piassa-Degol and Mexico, that are located at the central part of Addis Ababa. The minimum numbers of vehicle and pedestrian traffic were counted at Adwa-Aboare roundabout, which is relatively far from the center of the city.

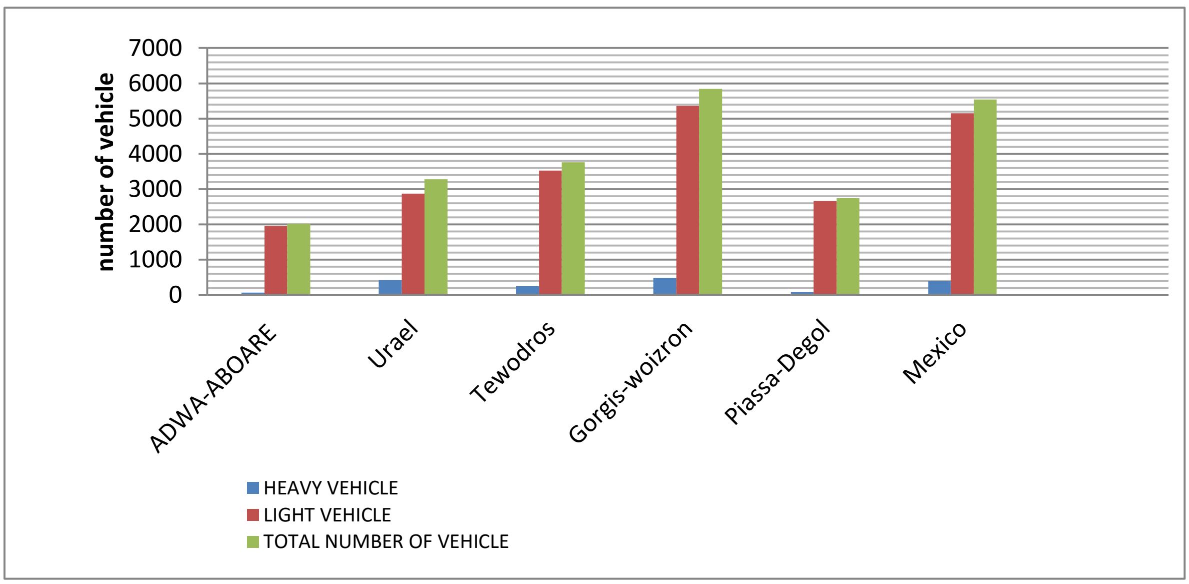

Figure 4.3:Maximum Peak Hour Vehicles Volume Distribution On Intersections

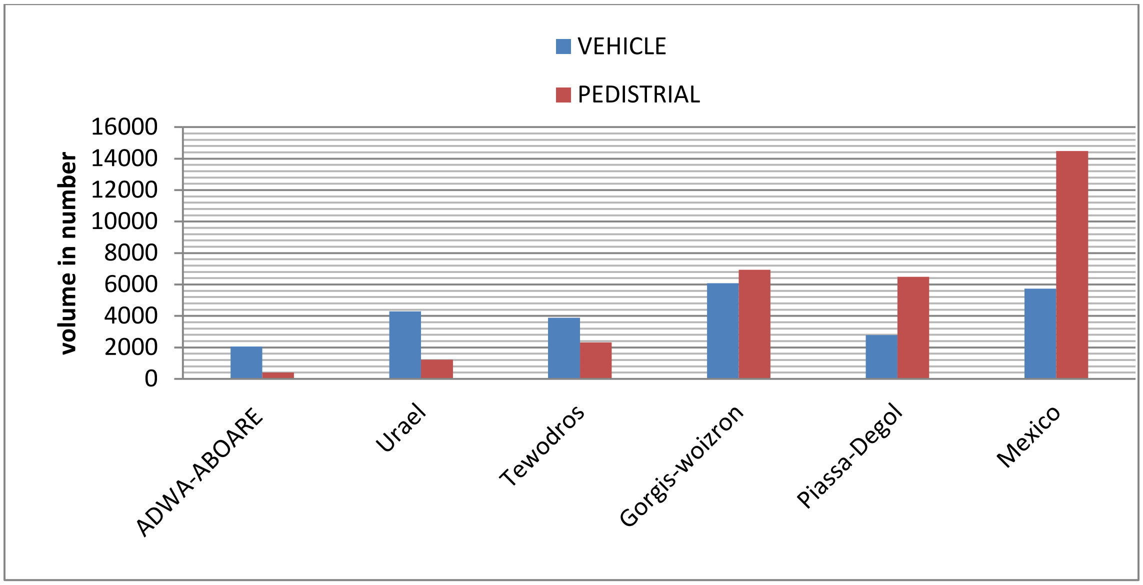

Figure 4.4 Pedestrians Vs Vehicles Volume at Junctions

The percentage of heavy vehicles at the majority of the intersection does not exceed 10% as shown in table 4.3. Only Urael has 10% of heavy vehicles, out of the total number ofvehicles counted at that junction. This junction is a link between ring road and a collector road, mostly these heavy vehicles travel along the ring road.

Table 4.3: Summarized vehicles and pedestrians volume at intersections at peak hour (8:00 to 9:00 AM) or (5:00 to 6:00 PM) (60min or 1 hour)

no	Roundabout	Bus and Dump Truck	Truck and Trailer	Total Heavy vehicl	Light vehicl	Total No of Vehicle	Total Traffic (PCU)	Percentage of Heavy Vehicles	Pedestrian Number
1	Adwa-Aboare	60	0	60	1954	2014	2044	3	409
2	Urael	401	2	403	3676	4079	4281	10	1222
3	Tewodros	241	1	243	3519	3762	3884	6	2309
4	Gorgis-	477	3	480	5357	5837	6078	8	6940

	woizron								
5	Piassa-Degol	78	0	78	2660	2738	2777	3	6488
6	Mexico	389	0	389	5149	5538	5732	7	14484

The traffic movement on the approaches or legs and the traffic volume in passenger car unit are also necessary data for the analysis. As explained in the literature review, the passenger car equivalent factors are used to convert the number of heavy vehicles to passenger car equivalent. The summarized entry traffic flow data on legs are shown in Table 4.4. The traffic movement data with detailed information is available in the Appendix A.

From Table 4.4, it is observed that there is unbalanced traffic flow at legs or Approaches at most roundabouts. However, it is not recommended to build roundabouts as traffic control devices when there is unbalanced traffic on the legs (FHWA-RD-00-067).

Table 4.4: Summarized entry traffic flow on roundabout approach legs

Roundabout	Leg no	Entry traffic on Leg (pcu)	Percentage of traffic share
Adwa-Aboare	1	149	7
	2	591	29
	3	1304	64
Urael	1	1922	45
	2	734	17
	3	814	19
	4	811	19
Tewodros	1	1508	39
	2	338	9
	3	1597	41
	4	350	9
	5	91	2
Gorgis-woizron	1	796	13
	2	709	12
	3	561	9

	4	4012	66
Piassa-degol	1 2 3 4	573 941 179 1084	21 34 6 39
Mexico	1 2 3 4 5 6	1142 681 861 1197 1022 835	20 12 15 21 18 15

4.2 Evaluation and Analysis of roundabout capacity

4.2.1 Analysis Result

aaSIDRA capacity analysis produced the following results. The capacity analysis results for the roundabout intersections are summarized in Table 4-5. The performance is measured with v/c ratio or degree of saturation and level of service also applied according to HCM manual. Detailed analysis results of aaSIDRA and Acklick base formula are available in Appendix-B.

From Table 4-5, it is seen that 4 roundabouts have very low effective capacity compared to their entry flow. They are within the range of E to F LOS. Actually the intersection performance or capacity depends on the approaches or legs performance and always their v/c ratio is taken from the maximum v/c ratio of the legs. Below Figure 4-5 also shown peak flow or entry flow verses effective capacity.

Table 4.5: Summarized capacity analysis results on the intersections

Roundabout	Total vehicle Flow	Effective capacity	Deg.saturation (V/C)	LOS
Adwa-Aboare	2046	4092	0.500	A
Urael	4281	4311	0.993	E
Tewodros	3887	5699	0.682	B

Gorgis-woizron	6081	2810	2.164	F
Piassa-degol	2777	2326	1.194	F
Mexico	5740	3910	1.468	F

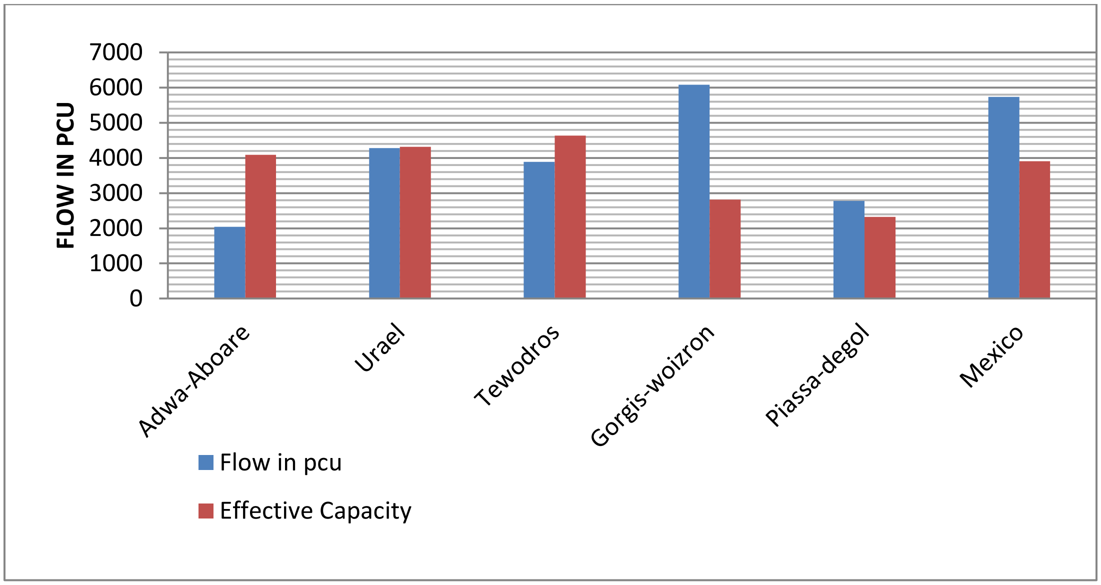

Figure 4.5: Peak Flow Vs Effective Capacity

To give a clear picture of the result Figure 4-6 also presents degree of saturation with 0.85 being the recommended limit by HCM.

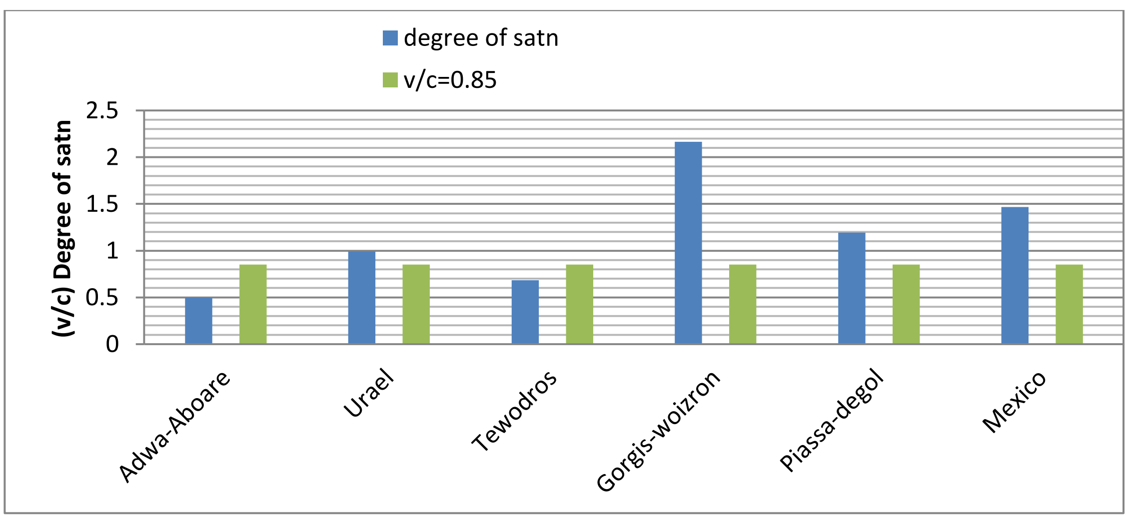

Figure 4-6: Degree of Saturation at Intersections

To have a clear picture the input parameters and the capacity analysis results (v/c) relationships has to be developed and carefully observed.

There is a linear relationship between total entry flow at intersection and degree of saturation (v/c). Figure 4-7 clearly shows this relationship with a reasonable R-squared or coefficient of determination, which is 0.735

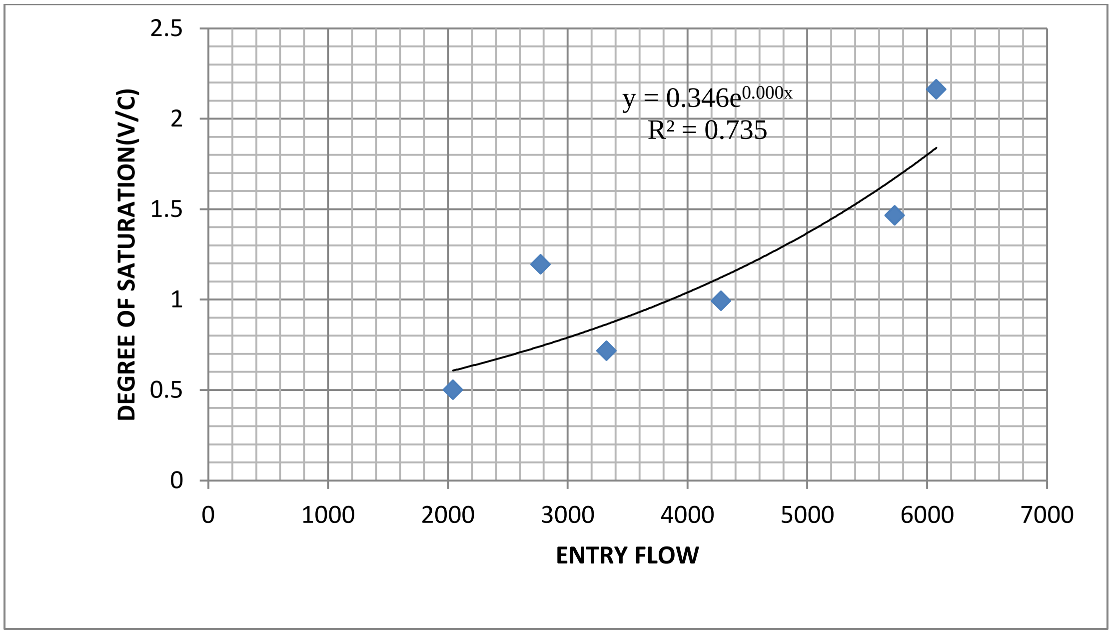

Figure 4.7: Entry Flow Vs Degree of Saturation for the Intersection

Mexico and Georgis-Woizron have higher entry flow at their intersection more than 5000 and their v/c ratio is also very high; more than 1. From this, it is observed that their higher traffic flow may lead to higher (v/c) ratio but it is too early to decide without observing other parameters and legs capacity analyses results. For all junctions, lane-by-lane capacity has been carried out and capacity at legs, degree of saturation and opposing flow have been summarized as shown in Table 4-6.

Table 4-6 Summarized capacity analysis results on the approach or legs.

Roundabout	Leg no	Traffic count at legs	Opposing circulatory flow	Degree of saturation(V/C)	Capacity at leg	(V/C)>0.85
Adwa-aboare	1	149	1231	0.341	437	-0.509
	2	591	24	0.495	1194	-0.355
	3	1304	47	0.5	2608	-0.35
Urael	1	1922	610	0.396	4854	-0.454

	2	734	893	0.694	1058	-0.156
	3	814	1831	0.407	2000	-0.443
	4	811	784	0.993	817	0.143
Tewodros	1	1508	449	0.314	4803	-0.536
	2	338	1594	0.619	546	-0.231
	3	1597	398	0.469	3405	-0.381
	4	350	1722	0.682	513	-0.168
	5	91	1759	0.194	469	-0.656
Gorgis-woizron	1	796	687	0.557	1429	-0.293
	2	709	1164	1.219	582	0.369
	3	561	1811	2.164	259	1.314
	4	4012	148	1.603	2503	0.753
Piassa-degol	1	573	1266	1.197	479	0.347
	2	941	721	1	941	0.15
	3	179	948	0.287	624	-0.563
	4	1084	182	0.282	3844	-0.568
Mexico	1	1142	2124	1.468	778	0.618
	2	681	1945	0.91	748	0.06
	3	861	1424	0.552	1560	-0.298
	4	1197	1690	0.882	1357	0.032
	5	1022	1264	0.56	1825	-0.29
	6	835	2176	1.116	748	0.266

By observing the v/c >0.85 column from Table 4-6 which is based on HCM (Capacity Manual of Highway), we can easily identify the legs which are in a critical condition.

Table 4.7: Legs with Critical Condition (V/C>0.85)

Roundabout	No. of legs(v/c)>0.85
Urael	1
Gorgis-woizron	3
Piassa-degol	2

Mexico	4

A total of 10 legs are in critical condition.

Before we investigate the reason for their inadequacy, it is better to see the assumption on the theory in respect of direct relationships of capacity at legs and opposing circulatory flow, and number of circulatory lane and circulatory flow. Capacity at legs is influenced by average entry lane width and number of entry lane.

Again, it is better to develop capacity versus these parameters using curve fittings techniques; it is easy to observe the relationships or the influences. Accordingly, since it was first developed considering opposing circulatory flows versus capacity at legs relationship as it was mentioned using curve Fitting techniques.

The curve fitting techniques result shows not a linear relationship but a polynomial one. The polynomial curve root mean square (coefficient of determination) does not have significant result which is 0.197. Even if the curve does not fit from the distribution of the values, we can observe that there is a tendency of reducing the capacity when the circulating flow increases. Since there are other factors that affect capacity at legs, exact curve fitting is not expected.

The developed relationship is shown in figure 4-8 below.

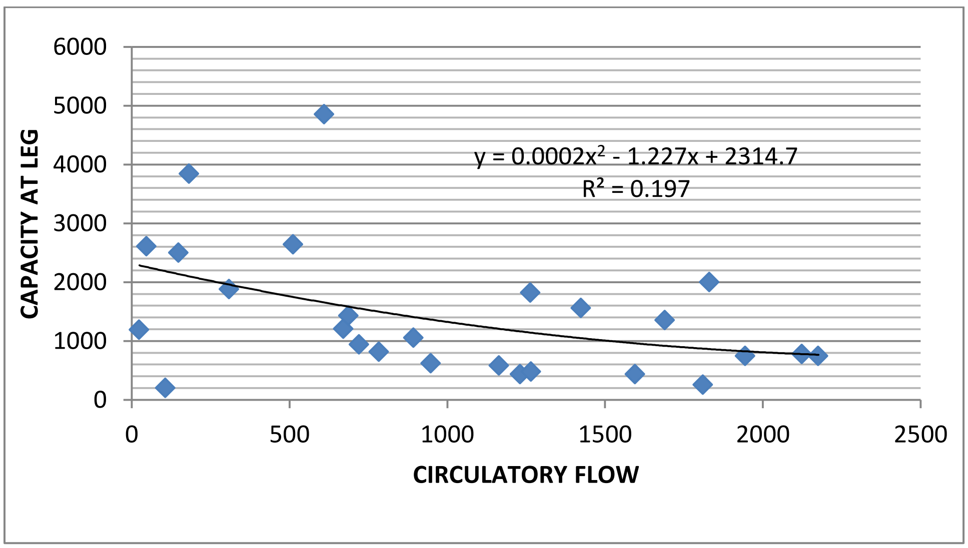

Figure 4.8: Opposing Circulatory Flows Vs Capacity at Legs

Next, groups were created in order to observe the influence of the remaining parameters and to rearrange the data in Table 4-6. Table 4-8 below shows the groups and the variables used for creating the groups. Number of entry lane and number of circulatory lane were the variables' or the bases for creating groups. All roundabout approaches with one entry lane and two circulatory lanes are grouped together, and two entry lanes and two circulatory lanes were grouped together, and so on. Again Table 4-8 clearly shows the created groups.

Table 4-8 Leg Groups Based On Number of Circulatory and Entry Lanes

Group	No of entry lanes	No of circulatory lanes
1	1	2
2	2	2
3	3	2
4	1	3
5	2	3
6	3	3

Table 4-9: the rearranged table from table 4-6 using numbers of circulatory and entry lanes.

Roundabout	Leg no	Number of Entry Lane	No. of Circulatory Lane	Traffic count on legs	circulatory flow	Capacity at leg	(v/c)
Adwa-aboare	1	1	2	149	1231	437	0.341
Adwa-aboare	2	1	2	591	24	1194	0.495
Piassa-degol	1	1	2	573	1266	479	1.197
Piassa-degol	2	1	2	941	721	941	1.000
Piassa-degol	3	1	2	179	948	624	0.287
Gorgis-woizron	3	1	2	561	1811	259	2.164
Gorgis-woizron	2	2	2	709	1164	582	1.219
Gorgis-woizron	4	2	2	4012	148	2503	1.603
Piassa -degol	4	3	2	1084	182	3844	0.282
Urael	4	1	3	811	784	817	0.993
Tewodros	2	1	3	338	1594	546	0.619
Tewodros	4	1	3	350	1722	513	0.682
Tewodros	5	1	3	91	1759	469	0.194

Urael	2	2	3	734	893	1803	0.407
Urael	3	2	3	814	1831	1173	0.694
Mexico	3	2	3	861	1424	1560	0.552
Mexico	6	2	3	836	2176	749	1.116
Mexico	1	3	3	1142	2158	778	1.468
Mexico	2	3	3	681	2150	748	0.91
Mexico	4	3	3	1197	1762	1357	0.882
Mexico	5	3	3	1022	1265	1825	0.56
Urael	1	4	3	1922	610	4854	0.396
Tewodros	1	4	3	1508	449	4803	0.314

Using curve-fitting techniques in table 4-9 for all 6 groups, opposing circulating flow versus capacity or effective capacity curve was created. The created curves are shown below in figure 4-9. The curves show >= 0.941 R- mean square (coefficient of determination) for all linear relationships which is acceptable.

Figure 4-9 clearly shows the relationship between the parameters (number of entry and circulatory lanes) and (capacity at leg and opposing circulation flow).

As the number of entry lanes increases without changing the circulation lane number, capacity at entry increases and circulation flow is adversely affected meaning that the maximum circulation flow that the intersection can handle decreases. If the number of circulatory lanes increases without changing the number of entry lanes the circulation flow increases and the maximum effective capacity at entry decreases.

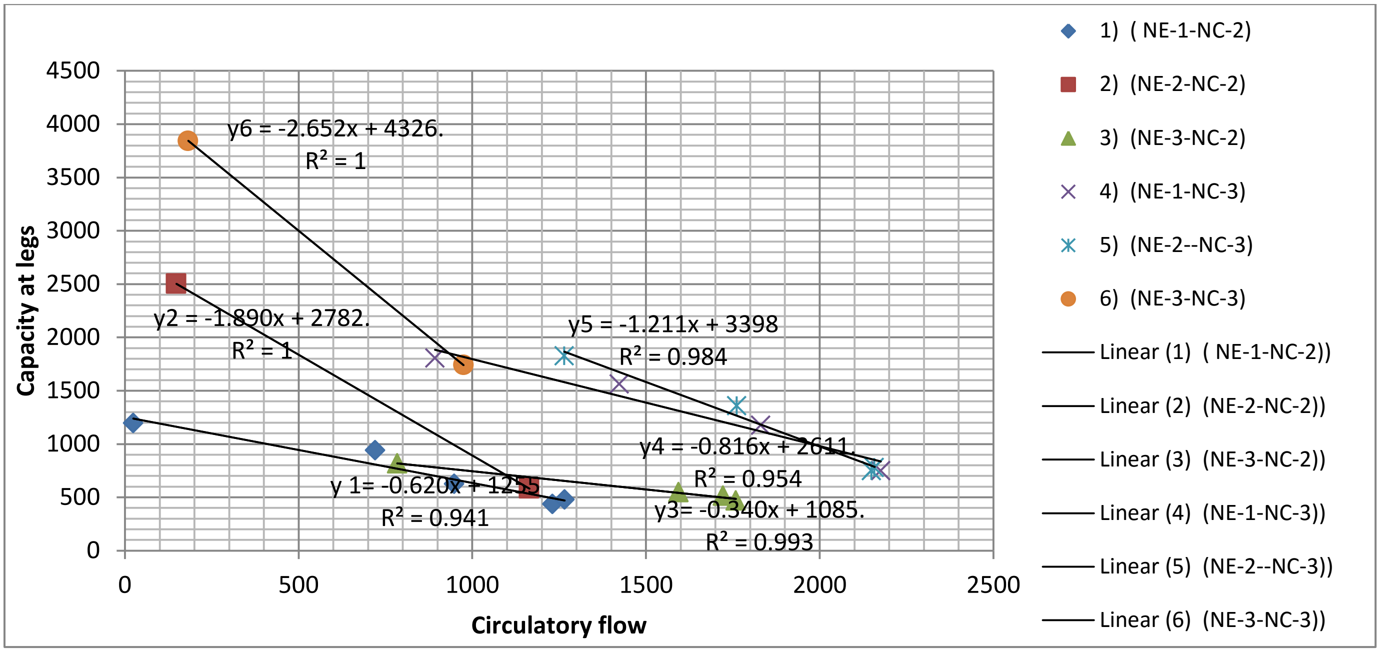

Figure 4-9 Circulatory Flow Vs Capacity At Leg For Different Value Of Number Entry And Circulatory Lanes

Observing figure 4-9 carefully, it is possible to come up with the idea of making the figure into a design and capacity analysis chart. The lines represent number of circulating and entry lanes. The first bottom line represents two circulatory and one entry lanes. The legend on the figure shows which line represents the group.

NE – Number of Entry lanes

NC – Number of circulatory lanes

The bottom line represented by NE-1-NC-2.

Since the lines representations are clear, it is easy to use the charts to know the effective entry capacity of the legs using the parameters of number of entry and circulatory lanes and traffic volume of opposing circulation flow.

Figure 4-9 or chart can be used for roundabout capacity forecasting.

4.3 Condition of Roundabouts

It is possible to identify the problem of the approach using Table 4-6 which shows v/c > 0.85, traffic volume of entry flow at legs and traffic volume of circulatory flow, entry and circulation lane numbers and Figure 4-9 or charts.

Table 4-10: Summery of the condition of the roundabouts using the figure 4-9 or chart

Roundabout	Leg no	problem
Piazza-Degol	1	Circulation lane number not adequate
Piazza-Degol	2	Entry lane number not adequate
Gorgis-Woizron	2	Circulation lane number not adequate
Gorgis-Woizron	3	Circulation lane number not adequate
Gorgis-Woizron	4	There is high traffic even if the circulatory lane number is 3 which means that it cannot handle the traffic
Ureal	4	Entry lane number not adequate
Mexico	1	There is high traffic even if the circulatory lane number is 3 which mean that it cannot handle the traffic but has narrow circulatory road width.
Mexico	2	There is high traffic even if the circulatory lane number is 3 which mean that it cannot handle the traffic but has narrow circulatory road width.
Mexico	4	There is high traffic even if the circulatory lane number is 3 which mean that it cannot handle the traffic but has narrow circulatory road width.
Mexico	6	There is high traffic even if the circulatory lane number is 3 which mean that it cannot handle the traffic but has narrow circulatory road width.

4.3.1 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 count measure**
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

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Samples of the Addis Ababa roundabouts capacity analysis results indicate that most of the roundabouts are in serious problems or over saturation. Based on observed actual field conditions, it is common to see that at peak hours, the traffic police have to regulate the traffic at these roundabouts since traffic control devices cannot function or regulate the traffic. As the study revealed, the major problems are related to inadequacy of number of entry lanes, number of circulatory lanes, high traffic flow, high volume of pedestrians and unbalanced traffic on the approaches which, in fact, are not recommended for roundabouts. Besides, most of the roundabouts were built more than 40 years ago with unknown service limits.

Even if modern roundabouts driving (traffic) rules are to be applied to Addis Ababa roundabouts, some of the important Geometric elements don't exist at some roundabouts, such as deflection and island splitters. Deflection is the most important geometric feature, which forces drivers to reduce their speeds and to avoid collision between neighboring leg entering vehicles. The aprons of the central islands also are not properly mounted to serve heavy vehicles.

All the Geometric elements used as input parameters for empirical method capacity analysis do not exist at Addis Ababa Roundabouts; thus, only analytical method was the option to carry out the capacity analysis with some geometric elements using aaSIDRA.

High traffic entry flows at Gorgis-Woizron and Mexico roundabouts were found to be more than 5000. This traffic is very high to be accommodated by the roundabouts. In addition, there are also high traffic flows at legs at Giorgis-Woizron and Mexico that show high percentage of traffic volume share, which is not recommended for roundabouts.

Regarding the traffic volumes of the pedestrians at some roundabout intersections, it is more than expected, adversely affecting normal traffic flow and endangering their safety. According to modern roundabout traffic rules the central island should not be accessed by the pedestrians. However, the central islands are accessed by pedestrians almost all roundabouts in Addis Ababa.

5.2 Recommendations

The Geometric elements of all Addis Ababa roundabouts should be revised and built properly as stated in design manuals of modern roundabouts since they are very helpful to have reasonable capacity and traffic safety.

The collected traffic data of the roundabout at peak hours have high and unbalanced traffic flow and many legs of the roundabout are found to be over saturation of traffic flow. It is recommended to increase the number of entry lanes, the number of circulatory lanes and the width the entry lanes

It is better to separate the pedestrians from vehicular traffic at the roundabouts where high pedestrian flows were observed since they affect normal traffic flows and the capacities of the roundabouts. Besides, this action is necessary for the safety of the pedestrians.

Since the collected data for the analysis was limited, especially regarding peak hour traffic the chart developed by this researches only insight on the premise of my research. In this respect, further study is recommended with more data collection in order to refine the chart and for use in the improvement of roundabout traffic services. The refined chart can assist the Addis Ababa City Road Authority when taking measures to improve roundabout capacity.

They can also use it in forecasting traffic capacity pertaining to land use. Thus, if more traffic is generated because of new land use, the charts can be used to easily forecast traffic in respect of each roundabout.

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APPENDIX -A

(SUMMERIZED TRAFFIC DATA)

SUMMERY OF NUMBER OF PEDISTRIANS

ADWA

Morning from 8:00 - 9:00	
Leg	number of pedestrians
1	120
2	235
3	54
Total	409

Afternoon from 8:00 - 9:00	
Leg	number of pedestrians
1	125
2	285
3	75
Total	485

URAEL

Morning from 8:00 - 9:00	
Leg	number of pedestrians
1	176
2	653
3	253
4	150
Total	1222

Afternoon from 8:00 - 9:00	
Leg	number of pedestrians
1	1155
2	1480
3	240
4	1265
Total	3140

GORGIS

Morning from 8:00 - 9:00	
Leg	number of pedestrians
1	1115
2	1150
3	644
4	3283
Total	6192

Afternoon from 8:00 - 9:00	
Leg	number of pedestrians
1	1255
2	2079
3	2210
4	1396
Total	6940

PIASSA-DEGOL

Morning from 8:00 - 9:00	
Leg	number of pedestrians
1	615
2	1610
3	510
4	620
Total	3355

Afternoon from 8:00 - 9:00	
Leg	number of pedestrians
1	1483
2	1405
3	2270
4	1330
Total	6488

TEWODROS

Morning from 8:00 - 9:00	
Leg	number of pedestrians
1	240
2	405
3	475
4	944
5	245
Total	2309

Afternoon from 8:00 - 9:00	
Leg	number of pedestrians
1	285
2	625
3	440
4	1483
5	520
Total	3353

MEXICO

Morning from 8:00 - 9:00	
Leg	number of pedestrians
1	3285
2	1430
3	950
4	2092
5	2257
6	4470
Total	14484

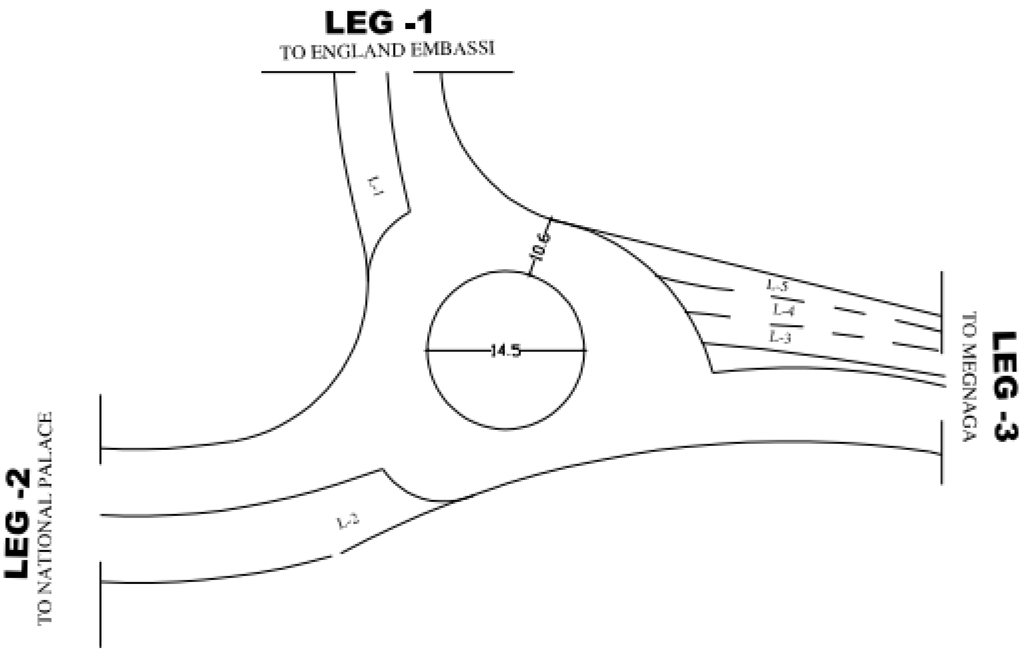
Afternoon from 8:00 - 9:00	
Leg	number of pedestrians
1	3970
2	2695
3	3631
4	1240

5	2198
6	5925
Total	19659

APPENDIX –B

(GEOMETRIC DATA AND aaSIDRA & ACKLICK'S BASE ANALYSIS)

LEVEL OF SERVICE ANALYSIS OUTPUT USING SIDRA INTERSECTION SOFTWARE



Adwa-Aboare Roundabout

Input data used for SIDRA software are:

Number of approach or legs-3

Number of circulating lane -2

Circulatory width- 11

Central island diameter -15m

Inscribed circle diameter -37m

Number of entry for each leg-

	Leg1	Leg2	Leg3	Leg4	Leg5	Leg6
Number of entry lane	1	1	3			
Average of entry width	4.5m	4.5m	3m			

Adwa-Aboare Roundabout

aaSIDRA output

ADWA-ABOARAY ROUNDABOUT
3-LEGS OR APPROACH
Intersection ID: *Ro-01* Roundabout

Table R.0 - ROUNDABOUT BASIC PARAMETERS

Cent Island Diam (m)	Circ Width (m)	Insc Diam. (m)	No. of Circ. Lanes	No. of Entry Lanes	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: East(MEGNAGA) LEG-3											
15	11	26	2	3	3.00	47	0.0	47	0	N	0.998
NorthWest: NW (ENGLAND EMB.) LEG-1											
15	11	26	2	1	4.50	1231	0.0	1231	0	N	0.912
SouthWest: SW (NATIONAL PAL.) LEG-2											
15	11	26	2	1	4.50	24	0.0	24	0	N	0.996

Table R.1 - 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 (s)	Prop Bunched	Critical Gap Hdwy (s)	Critical Gap Dist (m)	Foll-up Headway (s)
East: East(MEGNAGA) LEG-3										
Left	1	Subdominant	47	21.5	458.4	2.00	0.056	5.45	32.6	2.72
Thru	1	Subdominant	47	21.5	458.4	2.00	0.056	5.45	32.6	2.72
	2	Dominant	47	21.5	458.4	2.00	0.056	5.00	29.9	2.50
Right	3	Subdominant	47	21.5	458.4	2.00	0.056	8.00	47.9	4.23
NorthWest: NW (ENGLAND EMB.) LEG-1										
Left	1	Dominant	1231	21.5	17.5	1.04	0.549	3.97	23.8	3.33
Right	1	Dominant	1231	21.5	17.5	1.04	0.549	3.97	23.8	3.33
SouthWest: SW (NATIONAL PAL.) LEG-2										
Left	1	Dominant	24	21.5	897.8	2.00	0.029	4.40	26.3	2.93
Thru	1	Dominant	24	21.5	897.8	2.00	0.029	4.40	26.3	2.93

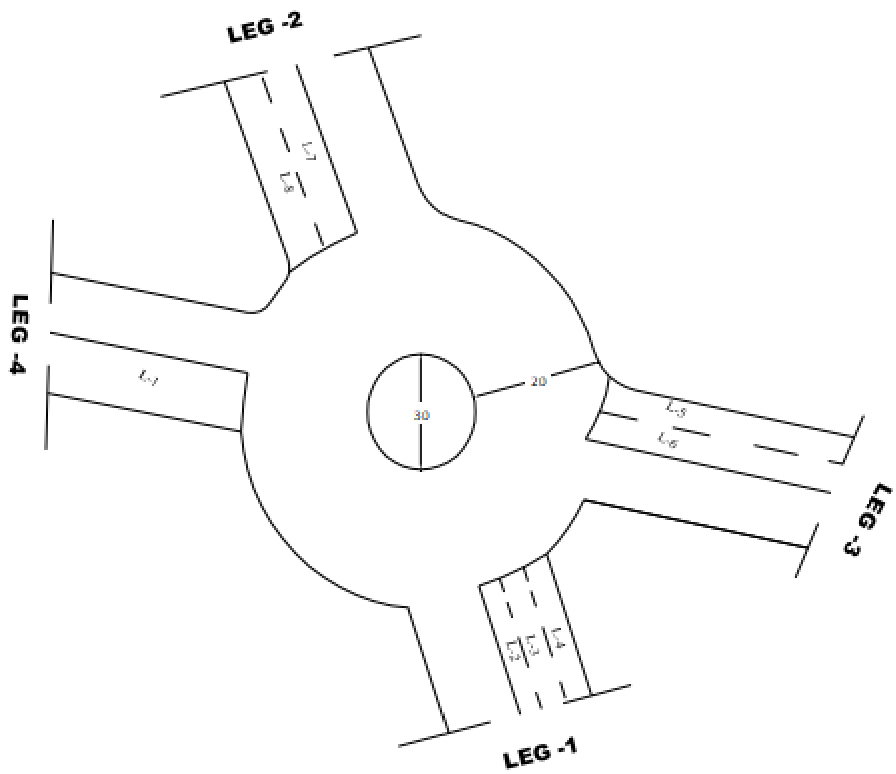
Table S.6 - INTERSECTION PERFORMANCE

Total Flow (veh/h)	Deg. Satn x	Total Delay (veh-h/h)	Total Delay (pers-h/h)	Aver. Delay (sec)	Prop. Queued	Eff. Stop Rate	Longest Queue (m)	Perf. Index	Aver. Speed (km/h)
East: East(MEGNAGA) LEG-3									
1305	0.500	1.15	1.73	3.2	0.26	0.39	32	24.53	27.8
NorthWest: NW (ENGLAND EMB.) LEG-1									
150	0.341	0.52	0.77	12.4	0.69	0.88	11	3.55	37.4
SouthWest: SW (NATIONAL PAL.) LEG-2									
591	0.495	0.94	1.40	5.7	0.16	0.48	29	10.81	42.5
ALL VEHICLES:									
2046	0.500	2.60	3.90	4.6	0.26	0.45	32	38.89	33.1
INTERSECTION (persons):									
3069	0.500		3.90	4.6	0.26	0.45		38.89	33.1

Queue values in this table are 95% back of queue (metres).

Table S.15 - CAPACITY AND LEVEL OF SERVICE

Mov No.	Mov Typ	Total Flow (veh /h)	Total Cap. (veh /h)	Deg. of Satn (v/c)	Aver. Delay (sec)	LOS	Longest Queue 95% Back (vehs)	(m)
East: East(MEGNAGA) LEG-3								
5	T	1221	2617	0.467	3.3	A	4.6	32
6	R	82	787	0.104	0.6	A	0.6	4
7	L	2	4	0.500*	4.7	A	4.6	32
		1305		0.500		A	4.6	32
NorthWest: NW (ENGLAND EMB.) LEG-1								
28	L	22	65	0.338	9.5	A	1.6	11
27	R	128	375	0.341	12.9	A	1.6	11
		150		0.341		A	1.6	11
SouthWest: SW (NATIONAL PAL.) LEG-2								
31	L	46	93	0.495	3.7	A	4.1	29
30	T	545	1105	0.493	5.9	A	4.1	29
		591		0.495		A	4.1	29
ALL VEHICLES:		2046		0.500		A	4.6	32



Urael Roundabout

Input data used for SIDRA software are:

Number of approach or legs-4

Number of circulating lane -3

Central island diameter -30m

Circulatory width -20

Inscribed circle diameter -70m

Number of entry for each leg-

	Leg1	Leg2	Leg3	Leg4	Leg5	Leg6
Number of entry lane	2	3	2	2		
Average of entry width	3.3m	3.6m	4.2m	3.4m		

Urael Roundabout

4-legs or approaches
Intersection ID: Ro-02 Roundabout

Table R.0 - ROUNDABOUT BASIC PARAMETERS

Cent Island Diam (m)	Circ Width (m)	Insc Diam. (m)	No. of Circ. Lanes	No. of Entry Lanes	Av. Ent Lane Width (m)	Circulating/Exiting Stream: Flow (veh/h)	%HV	Adjust. Flow (pcu/h)	%Exit Incl.	Cap. Constr. Effect	O-D Factor
South: nouth(kesanchis)LEG-1											
30	20	70	3	4	3.10	610	0.0	610	0	N	0.857
East: East(stadium)LEG-3											
30	20	70	3	2	3.80	1831	0.0	1831	0	N	0.645
North: North (B.atlas) LEG-2											
30	20	70	3	2	3.65	893	0.0	893	0	N	0.828
West: West (22) LEG-4											
30	20	70	3	1	3.15	784	0.0	784	0	N	0.876

Table R.1 - 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 (s)	Prop Bunched	Critical Gap: Hdwy (s)	Critical Gap: Dist (m)	Foll-up Headway (s)
South: nouth(kesanchis)LEG-1										
Left	1	Subdominant	610	29.2	47.9	2.00	0.530	2.81	22.8	1.86
Thru	1	Subdominant	610	29.2	47.9	2.00	0.530	2.81	22.8	1.86
	2	Subdominant	610	29.2	47.9	2.00	0.530	2.81	22.8	1.86
	3	Dominant	610	29.2	47.9	2.00	0.530	2.14	17.3	1.41
	4	Subdominant	610	29.2	47.9	2.00	0.530	2.81	22.8	1.86
Right	4	Subdominant	610	29.2	47.9	2.00	0.530	2.81	22.8	1.86
East: East(stadium)LEG-3										
Left	1	Subdominant	1831	29.6	16.2	0.94N	0.667	2.25	18.5	2.04
Thru	1	Subdominant	1831	29.6	16.2	0.94N	0.667	2.25	18.5	2.04
	2	Dominant	1831	29.6	16.2	0.94N	0.667	2.00*	16.4	1.67
Right	2	Dominant	1831	29.6	16.2	0.94N	0.667	2.00*	16.4	1.67
North: North (B.atlas) LEG-2										
Left	1	Subdominant	893	29.2	32.7	1.27	0.504	2.79	22.6	2.22
Thru	1	Subdominant	893	29.2	32.7	1.27	0.504	2.79	22.6	2.22
	2	Dominant	893	29.2	32.7	1.27	0.504	2.51	20.3	1.99
Right	2	Dominant	893	29.2	32.7	1.27	0.504	2.51	20.3	1.99
West: West (22) LEG-4										
Left	1	Dominant	784	29.3	37.4	1.15	0.424	3.43	28.0	2.36
Thru	1	Dominant	784	29.3	37.4	1.15	0.424	3.43	28.0	2.36
Right	1	Dominant	784	29.3	37.4	1.15	0.424	3.43	28.0	2.36

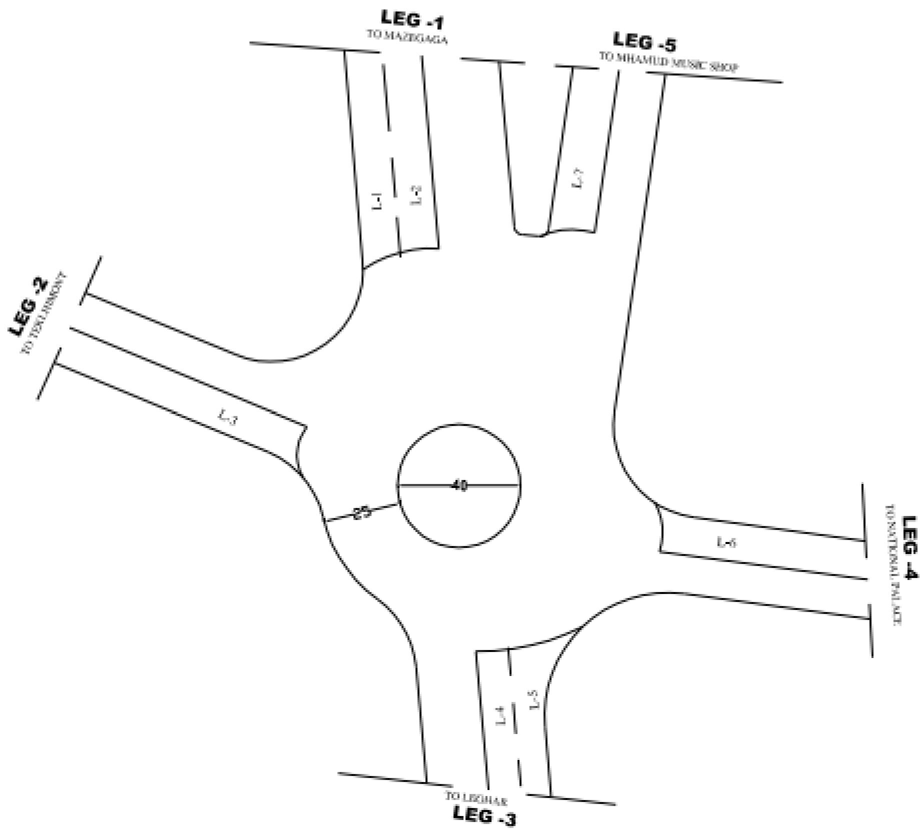
Table S.6 - INTERSECTION PERFORMANCE

Total Flow (veh/h)	Deg. Satn x	Total Delay (veh-h/h)	Total Delay (pers-h/h)	Aver. Delay (sec)	Prop. Queued	Eff. Stop Rate	Longest Queue (m)	Perf. Index	Aver. Speed (km/h)
South: nouth(kesanchis)LEG-1									
1922	0.396	1.30	1.95	2.4	0.78	0.43	32	36.76	27.5
East: East(stadium)LEG-3									
814	0.694	1.77	2.66	7.8	0.90	1.11	43	21.42	25.8
North: North (B.atlas) LEG-2									
734	0.407	0.56	0.83	2.7	0.71	0.50	21	14.24	27.7
West: West (22) LEG-4									
811	0.993	9.85	14.77	43.7	1.00	3.20	251	48.74	15.7
ALL VEHICLES:									
4281	0.993	13.48	20.22	11.3	0.83	1.10	251	121.16	23.8
INTERSECTION (persons):									
6422	0.993		20.22	11.3	0.83	1.10		121.16	23.8

Table S.15 - CAPACITY AND LEVEL OF SERVICE

Mov No.	Mov Typ	Total Flow (veh /h)	Total Cap. (veh /h)	Deg. of Satn (v/c)	Aver. Delay (sec)	LOS	Longest Queue 95% Back (vehs)	Longest Queue 95% Back (m)
South: nouth(kesanchis)LEG-1								
20	L	213	539	0.395	3.7	A	3.9	27
2	T	1504	3803	0.395	2.3	A	4.5	32
3	R	205	518	0.396	2.5	A	3.9	27
		1922		0.396		A	4.5	32
East: East(stadium)LEG-3								
21	L	109	157	0.694	9.3	B	5.4	38
5	T	571	823	0.694	7.7	B	6.2	43
6	R	134	193	0.694	7.3	B	6.2	43
		814		0.694		B	6.2	43
North: North (B.atlas) LEG-2								
22	L	112	276	0.406	4.0	A	2.8	20
8	T	561	1381	0.406	2.5	A	2.9	21
9	R	61	150	0.407	2.3	A	2.9	21
		734		0.407		A	2.9	21
West: West (22) LEG-4								
10	LTR	811	817	0.993*	43.7	E	35.8	251
		811		0.993		E	35.8	251
ALL VEHICLES:		4281		0.993		E	35.8	251

Level of Service calculations are based on v/c ratio.



Tewodros Roundabout

Input data used for SIDRA software are:

Number of approach or legs-5

Number of circulating lane -3

Circulatory width -20

Central island diameter -40 m

Inscribed circle diameter -90 m

Number of entry for each leg-

	Leg1	Leg2	Leg3	Leg4	Leg5	Leg6
Number of entry lane	4	1	2	1	1	
Average of entry width	3m	6m	4m	6m	6m	

Tewodros Roundabout

5-LEGS OR APPROACHS
Intersection ID: Ro-03 Roundabout

Table R.0 - ROUNDABOUT BASIC PARAMETERS

Cent Island Diam (m)	Circ Width (m)	Insc Diam. (m)	No.of Circ. Lanes	No.of Entry Lanes	Av.Ent Lane Width (m)	Circulating/Exiting Stream Flow (veh/h)	%HV	Adjust. Flow (pcu/h)	%Exit Incl.	Cap. Constr. Effect	O-D Factor
South: South (LEGHAR) LEG-3											
40	20	80	3	3	4.00	398	0.0	398	0	N	0.950
East: East (N.PALACE) LEG-4											
40	20	80	3	1	6.00	1722	0.0	1722	0	N	0.761
NorthEast: North(MHAMUD SHOP)LEG-5											
40	20	80	3	1	6.00	1759	0.0	1759	0	N	0.798
North: North (CITY HHALL)LEG-1											
40	20	80	3	4	3.00	449	0.0	449	0	N	0.955
West: West (TEKLHIMANOT)LEG-2											
40	20	80	3	1	6.00	1594	0.0	1594	0	N	0.765

Table R.1 - 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 (s)	Prop Bunched	Critical Gap: Hdwy (s)	Dist (m)	Foll-up Headway (s)
South: South (LEGHAR) LEG-3										
Left	1	Subdominant	398	29.9	75.1	2.00	0.384	3.19	26.5	2.52
Thru	1	Subdominant	398	29.9	75.1	2.00	0.384	3.19	26.5	2.52
	2	Dominant	398	29.9	75.1	2.00	0.384	2.68	22.3	2.12
	3	Subdominant	398	29.9	75.1	2.00	0.384	3.19	26.5	2.52
Right	3	Subdominant	398	29.9	75.1	2.00	0.384	3.19	26.5	2.52
East: East (N.PALACE) LEG-4										
Left	1	Dominant	1722	30.0	17.4	0.93	0.637	2.63	21.9	2.39
Thru	1	Dominant	1722	30.0	17.4	0.93	0.637	2.63	21.9	2.39
Right	1	Dominant	1722	30.0	17.4	0.93	0.637	2.63	21.9	2.39
NorthEast: North(MHAMUD SHOP)LEG-5										
Left	1	Dominant	1759	30.0	17.0	1.12	0.728	2.61	21.8	2.38
Thru	1	Dominant	1759	30.0	17.0	1.12	0.728	2.61	21.8	2.38
Right	1	Dominant	1759	30.0	17.0	1.12	0.728	2.61	21.8	2.38
North: North (CITY HHALL)LEG-1										
Left	1	Subdominant	449	29.9	66.6	2.00	0.422	3.55	29.5	2.24
Thru	1	Subdominant	449	29.9	66.6	2.00	0.422	3.55	29.5	2.24
	2	Subdominant	449	29.9	66.6	2.00	0.422	3.55	29.5	2.24
	3	Dominant	449	29.9	66.6	2.00	0.422	2.69	22.4	1.69
	4	Subdominant	449	29.9	66.6	2.00	0.422	3.55	29.5	2.24
Right	4	Subdominant	449	29.9	66.6	2.00	0.422	3.55	29.5	2.24
West: West (TEKLHIMANOT)LEG-2										
Left	1	Dominant	1594	30.0	18.8	0.96N	0.621	2.69	22.4	2.44
Thru	1	Dominant	1594	30.0	18.8	0.96N	0.621	2.69	22.4	2.44
Right	1	Dominant	1594	30.0	18.8	0.96N	0.621	2.69	22.4	2.44

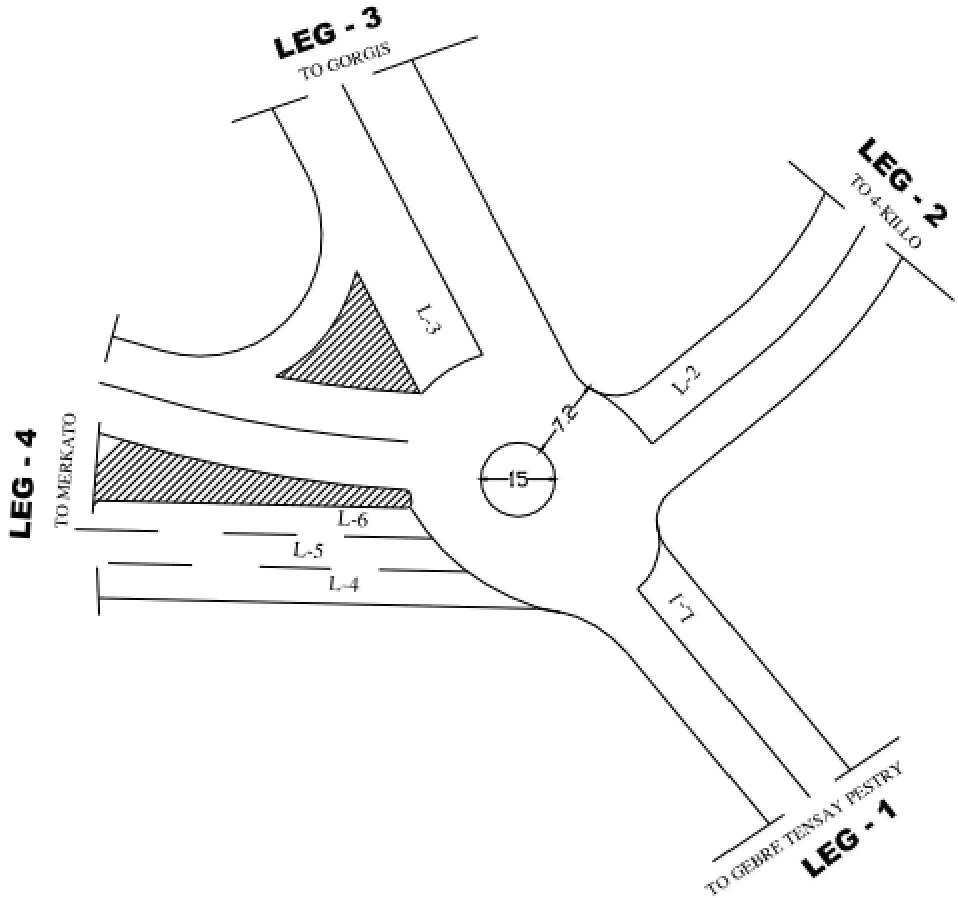
Table S.6 - INTERSECTION PERFORMANCE

Total Flow (veh/h)	Deg. Satn x	Total Delay (veh-h/h)	Total Delay (pers-h/h)	Aver. Delay (sec)	Prop. Queued	Eff. Stop Rate	Longest Queue (m)	Perf. Index	Aver. Speed (km/h)
South: South (LEGHAR) LEG-3									
1597	0.469	0.72	1.08	1.6	0.55	0.29	25	33.23	28.6
East: East (N.PALACE) LEG-4									
351	0.682	1.29	1.94	13.3	0.86	1.05	34	9.27	36.5
NorthEast: North(MHAMUD SHOP)LEG-5									
92	0.194	0.18	0.26	6.9	0.73	0.76	7	2.34	29.6
North: North (CITY HHALL)LEG-1									
1519	0.314	0.77	1.15	1.8	0.57	0.33	19	31.99	28.5
West: West (TEKLHIMANOT)LEG-2									
328	0.619	0.98	1.47	10.8	0.82	0.99	29	8.56	34.6
ALL VEHICLES:									
3887	0.682	3.93	5.90	3.6	0.61	0.45	34	85.39	29.8
INTERSECTION (persons):									
5831	0.682		5.90	3.6	0.61	0.45		85.39	29.8

Table S.15 - CAPACITY AND LEVEL OF SERVICE

Mov No.	Mov Typ	Total Flow (veh /h)	Total Cap. (veh /h)	Deg. of Satn (v/c)	Aver. Delay (sec)	LOS	Longest Queue 95% Back (vehs)	Longest Queue 95% Back (m)
South: South (LEGHAR) LEG-3								
20	L	149	318	0.469	1.8	A	3.3	23
2	T	1442	3078	0.468	1.6	A	3.6	25
3	R	6	13	0.462	1.7	A	3.3	23
		1597		0.469		A	3.6	25
East: East (N.PALACE) LEG-4								
21	L	58	85	0.682*	8.6	B	4.8	34
4	TR	293	430	0.681	14.2	B	4.8	34
		351		0.682		B	4.8	34
NorthEast: North(MHAMUD SHOP)LEG-5								
22	L	75	387	0.194	5.9	A	1.0	7
24	TR	17	88	0.193	11.5	A	1.0	7
		92		0.194		A	1.0	7
North: North (CITY HHALL)LEG-1								
23	L	105	335	0.313	2.1	A	2.4	17
8	T	1356	4323	0.314	1.8	A	2.7	19
9	R	58	185	0.314	2.0	A	2.4	17
		1519		0.314		A	2.7	19
West: West (TEKLHIMANOT)LEG-2								
25	L	120	194	0.619	7.2	B	4.2	29
10	TR	208	336	0.619	12.8	B	4.2	29
		328		0.619		B	4.2	29
ALL VEHICLES:		3887		0.682		B	4.8	34

Level of Service calculations are based on v/c ratio.



Piassa-Degol Roundabout

Input data used for SIDRA software are:

Number of approach or legs-4

Number of circulating lane -2

Circulatory width- 7.2

Central island diameter -29.1m

Inscribed circle diameter -14.7m

Number of entry for each leg-

	Leg1	Leg2	Leg3	Leg4	Leg5	Leg6
Number of entry lane	1	1	1	2		
Average of entry width	5m	6m	6m	4m		

Piassa-Degol Roundabout

4-LEG OR APPROACH

Intersection ID: Ro-04 Roundabout

Table R.0 - ROUNDABOUT BASIC PARAMETERS

Cent Island Diam (m)	Circ Width (m)	Insc Diam. (m)	No.of Circ. Lanes	No.of Entry Lanes	Av.Ent Lane Width (m)	Circulating/Exiting Stream: Flow (veh/h)	%HV	Adjust. Flow (pcu/h)	%Exit Incl.	Cap. Constr. Effect	O-D Factor
South: South (LEG-1)											
15	7	29	1	1	5.00	1266	0.0	1266	0	N	0.831
East: East(4-KILLO)LEG-2											
15	7	29	1	1	6.00	721	0.0	721	0	Y	0.892
North: North (GORGIS) LEG-3											
15	7	29	1	1	6.00	948	0.0	948	0	Y	0.692
West: West(MERKATO)LEG-4											
15	7	29	1	3	4.00	182	0.0	182	0	N	0.962

Table R.1 - 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 (s)	Prop Bunched	Critical Gap: Hdwy (s)	Critical Gap: Dist (m)	Foll-up Headway (s)
South: South (LEG-1)										
Left	1	Dominant	1266	26.5	20.9	2.00N	0.839	2.57	18.9	1.98
Thru	1	Dominant	1266	26.5	20.9	2.00N	0.839	2.57	18.9	1.98
Right	1	Dominant	1266	26.5	20.9	2.00N	0.839	2.57	18.9	1.98
East: East(4-KILLO)LEG-2										
Left	1	Dominant	721	23.2	32.2	2.00	0.595	2.37	15.3	2.16
Thru	1	Dominant	721	23.2	32.2	2.00	0.595	2.37	15.3	2.16
Right	1	Dominant	721	23.2	32.2	2.00	0.595	2.37	15.3	2.16
North: North (GORGIS) LEG-3										
Left	1	Dominant	948	28.7	30.3	2.00	0.710	2.29	18.3	2.08
Thru	1	Dominant	948	28.7	30.3	2.00	0.710	2.29	18.3	2.08
Right	1	Dominant	948	28.7	30.3	2.00	0.710	2.29	18.3	2.08
West: West(MERKATO)LEG-4										
Left	1	Subdominant	182	20.4	112.3	2.00	0.198	3.84	21.8	2.02
Thru	1	Subdominant	182	20.4	112.3	2.00	0.198	3.84	21.8	2.02
	2	Dominant	182	20.4	112.3	2.00	0.198	3.17	18.0	1.67
	3	Subdominant	182	20.4	112.3	2.00	0.198	4.14	23.5	2.19
Right	3	Subdominant	182	20.4	112.3	2.00	0.198	4.14	23.5	2.19

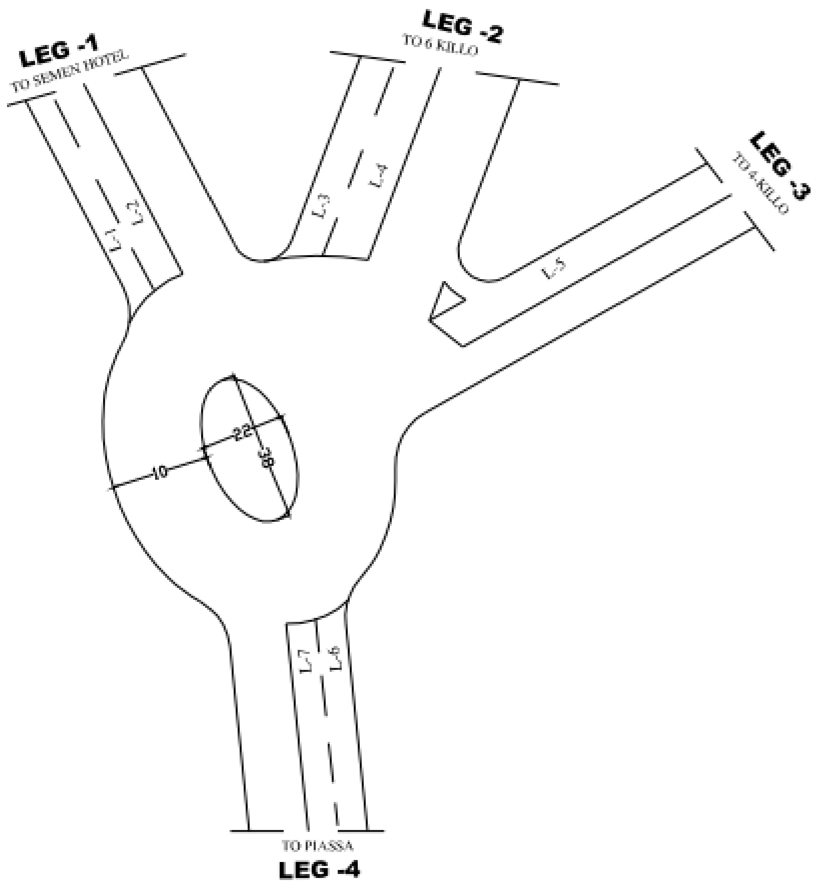
Table S.6 - INTERSECTION PERFORMANCE

Total Flow (veh/h)	Deg. Satn x	Total Delay (veh-h/h)	Total Delay (pers-h/h)	Aver. Delay (sec)	Prop. Queued	Eff. Stop Rate	Longest Queue (m)	Perf. Index	Aver. Speed (km/h)
South: South (LEG-1)									
573	1.197	67.18	100.77	422.1	1.00	7.34	998	154.96	4.9
East: East(4-KILLO)LEG-2									
943	1.000	10.46	15.70	39.9	1.00	2.00	257	45.97	27.6
North: North (GORGIS) LEG-3									
181	0.287	0.44	0.66	8.8	0.89	0.88	18	4.57	25.5
West: West(MERKATO)LEG-4									
1087	0.282	1.75	2.62	5.8	0.41	0.52	19	20.95	38.4
ALL VEHICLES:									
2784	1.197	79.83	119.75	103.2	0.76	2.45	998	226.45	15.0
INTERSECTION (persons):									
4176	1.197		119.75	103.2	0.76	2.45		226.45	15.0

Table S.15 - CAPACITY AND LEVEL OF SERVICE

Mov No.	Mov Typ	Total Flow (veh /h)	Total Cap. (veh /h)	Deg. of Satn (v/c)	Aver. Delay (sec)	LOS	Longest Queue 95% Back (vehs)	(m)
South: South (LEG-1)								
2	L	146	122	1.197*	420.3	F	142.5	998
1	TR	427	357	1.196	422.7	F	142.5	998
		573		1.197		F	142.5	998
East: East(4-KILLO)LEG-2								
5	L	2	2	1.000	38.2	E	36.7	257
4	TR	941	970	0.970	39.9	E	36.7	257
		943		1.000		E	36.7	257
North: North (GORGIS) LEG-3								
8	L	179	623	0.287	8.8	A	2.6	18
7	TR	2	7	0.286	10.8	A	2.6	18
		181		0.287		A	2.6	18
West: West(MERKATO)LEG-4								
11	L	284	1007	0.282	4.4	A	2.6	18
10	TR	803	2847	0.282	6.3	A	2.7	19
		1087		0.282		A	2.7	19
ALL VEHICLES:		2784		1.197		F	142.5	998

Level of Service calculations are based on v/c ratio.



Gorgis-woizron Roundabout

Input data used for SIDRA software are:

Number of approach or legs-4

Number of circulating lane -2

Circulatory width- 10

Central island diameter -22m

Inscribed circle diameter -42m

Number of entry for each leg-

	Leg1	Leg2	Leg3	Leg4	Leg5	Leg6
Number of entry lane	2	2	1	2		
Average of entry width	4.5m	3.6m	5.8m	4.5m		

Gorgis-woizron Roundabout

4-LEGS OR APPROACH

Intersection ID: *Ro-05* Roundabout

Table R.0 - ROUNDABOUT BASIC PARAMETERS

Cent Island Diam (m)	Circ Width (m)	Insc Diam. (m)	No.of Circ. Lanes	No.of Entry Lanes	Av.Ent Lane Width (m)	Circulating/Exiting Stream: Flow (veh/h)	%HV	Adjust. Flow (pcu/h)	%Exit Incl.	Cap. Constr. Effect	O-D Factor
South: South (PIASSA)LEG-4											
22	10	42	2	2	4.50	148	0.0	148	0	Y	0.972
East: East (4-KILLO)LEG-3											
22	10	42	2	1	5.80	1811	0.0	1811	0	Y	0.528
NorthEast: N,East (6-KILLO)LEG-2											
22	10	42	2	2	3.60	1164	0.0	1164	0	Y	0.733
North: North (SEMEN HOTEL)LEG-1											
22	10	42	2	2	4.50	687	0.0	687	0	Y	0.835

Table R.1 - 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 (s)	Prop Bunched	Critical Gap: Hdwy (s)	Critical Gap: Dist (m)	Foll-up Headway (s)
South: South (PIASSA)LEG-4										
Left	1	Subdominant	148	23.5	159.0	2.00	0.165	3.89	25.4	2.67
Thru	1	Subdominant	148	23.5	159.0	2.00	0.165	3.89	25.4	2.67
	2	Dominant	148	23.5	159.0	2.00	0.165	3.48	22.7	2.39
Right	2	Dominant	148	23.5	159.0	2.00	0.165	3.48	22.7	2.39
East: East (4-KILLO)LEG-3										
Left	1	Dominant	1811	29.8	16.5	1.25	0.788	2.61	21.7	2.38
Right	1	Dominant	1811	29.8	16.5	1.25	0.788	2.61	21.7	2.38
NorthEast: N,East (6-KILLO)LEG-2										
Left	1	Dominant	1164	29.1	25.0	1.41	0.649	3.37	27.2	2.24
Right	2	Subdominant	1164	29.1	25.0	1.41	0.649	4.70	37.9	3.11
North: North (SEMEN HOTEL)LEG-1										
Left	1	Subdominant	687	23.5	34.3	2.00	0.576	3.49	22.8	2.69
Thru	1	Subdominant	687	23.5	34.3	2.00	0.576	3.49	22.8	2.69
	2	Dominant	687	23.5	34.3	2.00	0.576	3.15	20.6	2.43

Table S.6 - INTERSECTION PERFORMANCE

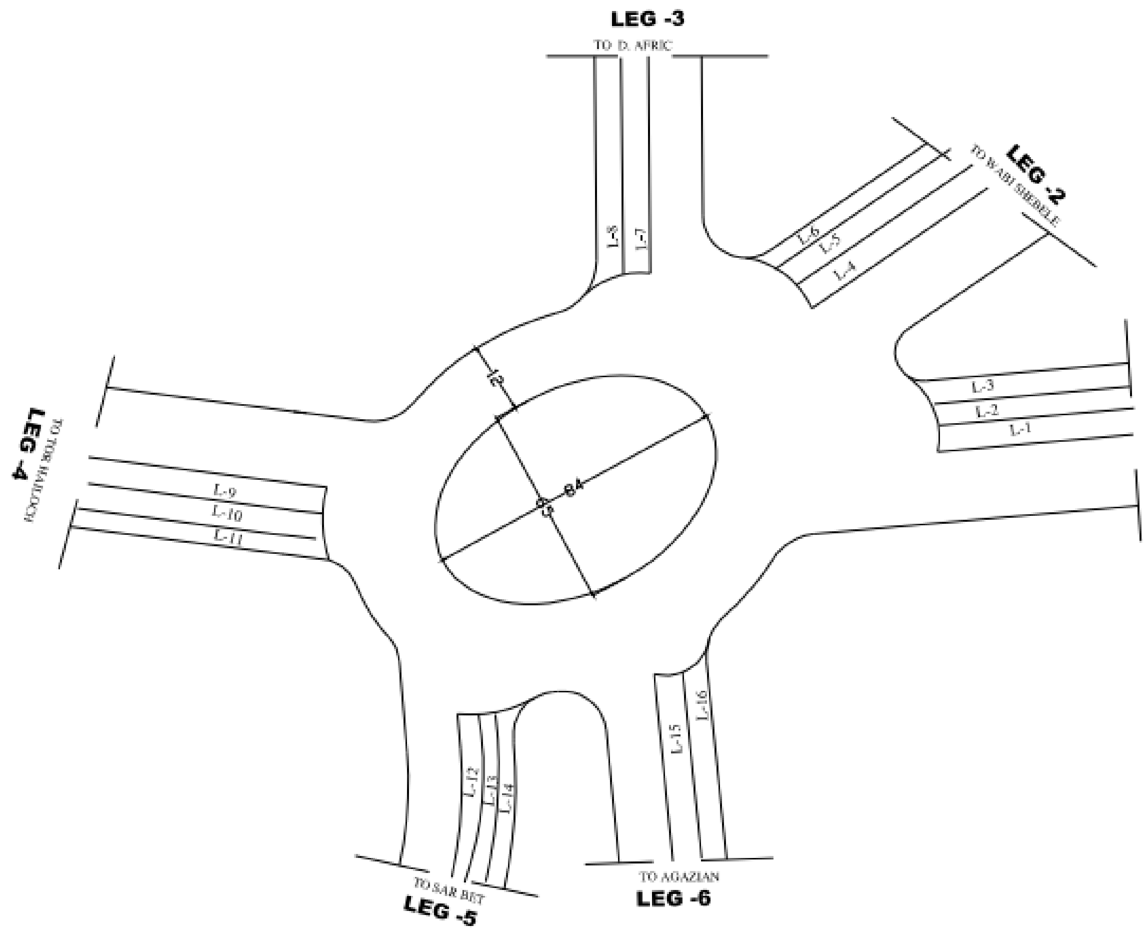
Total Flow (veh/h)	Deg. Satn x	Total Delay (veh-h/h)	Total Delay (pers-h/h)	Aver. Delay (sec)	Prop. Queued	Eff. Stop Rate	Longest Queue (m)	Perf. Index	Aver. Speed (km/h)
South: South (PIASSA)LEG-4									
4013	1.603	1213.61	1820.41	1088.7	1.00	21.92	7332	2546.41	1.3
East: East (4-KILLO)LEG-3									
584	2.164	344.84	517.27	2125.8	1.00	17.18	2850	571.92	1.0
NorthEast: N,East (6-KILLO)LEG-2									
688	1.219	74.76	112.14	391.2	0.99	11.57	1112	194.27	4.0
North: North (SEMEN HOTEL)LEG-1									
796	0.557	1.37	2.05	6.2	0.84	0.94	39	22.40	27.2
ALL VEHICLES:									
6081	2.164	1634.58	2451.88	967.7	0.98	17.55	7332	3335.00	1.6
INTERSECTION (persons):									
9122	2.164		2451.88	967.7	0.98	17.55		3335.00	1.6

Queue values in this table are 95% back of queue (metres).

Table S.15 - CAPACITY AND LEVEL OF SERVICE

Mov No.	Mov Typ	Total Flow (veh/h)	Total Cap. (veh/h)	Deg. of Satn (v/c)	Aver. Delay (sec)	LOS	Longest Queue 95% Back (vehs)	Longest Queue 95% Back (m)
South: South (PIASSA)LEG-4								
2	T	2834	1768	1.603	1088.8	F	1047.4	7332
3	R	1165	727	1.602	1088.5	F	1047.4	7332
10	L	14	9	1.556	1092.6	F	929.3	6505
		4013		1.603		F	1047.4	7332
East: East (4-KILLO)LEG-3								
11	L	333	154	2.162	2124.5	F	407.2	2850
4	R	251	116	2.164*	2127.4	F	407.2	2850
		584		2.164		F	407.2	2850
NorthEast: N,East (6-KILLO)LEG-2								
12	L	640	525	1.219	419.8	F	158.9	1112
26	R	48	307	0.156	9.3	A	0.9	6
		688		1.219		F	158.9	1112
North: North (SEMEN HOTEL)LEG-1								
13	L	137	246	0.557	9.0	A	5.3	37
8	T	659	1184	0.557	5.6	A	5.6	39
		796		0.557		A	5.6	39
ALL VEHICLES:		6081		2.164		F	1047.4	7332

Level of Service calculations are based on v/c ratio.



Mexico Roundabout

Input data used for SIDRA software are:

Number of approach or legs-6 Circulatory width -12

Number of circulating lane -3 Central island diameter -65m

Inscribed circle diameter -89m

Number of entry for each leg-

	Leg1	Leg2	Leg3	Leg4	Leg5	Leg6
Number of entry lane	3	3	2	3	3	2
Average of entry width	3.0m	4.5m	4m	3m	4.5m	4.5m

Mexico Roundabout

6-legs or approachs
Intersection ID: *Ro-06* Roundabout

Table R.0 - ROUNDABOUT BASIC PARAMETERS

Cent Island Diam (m)	Circ Width (m)	Insc Diam. (m)	No.of Circ. Lanes	No.of Entry Lanes	Av.Ent Lane Width (m)	Circulating/Exiting Stream Flow (veh/h)	%HV	Adjust. Flow (pcu/h)	%Exit Incl.	Cap. Constr. Effect	O-D Factor
South: South (SARBET) LEG-5											
65	12	89	3	3	3.00	1264	0.0	1264	0	Y	0.719
SouthEast: S.EAST (AGAZIAN)LEG-6											
65	12	89	3	2	4.50	2176	0.0	2176	0	N	0.773
East: East (LEGHAR) LEG-1											
65	12	89	3	3	3.10	2124	0.0	2124	0	Y	0.796
NorthEast: N.East (W.SHEBELE)LEG-2											
65	12	89	3	3	3.00	1945	0.0	1945	0	Y	0.749
North: North (D.AFRIC)LEG-3											
65	12	89	3	2	4.50	1424	0.0	1424	0	Y	0.813
West: West (TOR HAILOCH)LEG-4											
65	12	89	3	3	4.00	1690	0.0	1690	0	Y	0.791

Table R.1 - 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 (s)	Prop Bunched	Critical Gap Hdwy (s)	Critical Gap Dist (m)	Foll-up Headway (s)
South: South (SARBET) LEG-5										
Left	1	Dominant	1264	30.0	23.7	1.01	0.546	2.00*	16.7	1.40
Thru	2	Subdominant	1264	30.0	23.7	1.01	0.546	2.45	20.4	1.73
	3	Subdominant	1264	30.0	23.7	1.01	0.546	2.45	20.4	1.73
Right	3	Subdominant	1264	30.0	23.7	1.01	0.546	2.45	20.4	1.73
SouthEast: S.EAST (AGAZIAN)LEG-6										
Left	1	Subdominant	2176	30.0	13.8	1.20	0.855	2.00	16.7	1.82
Thru	1	Subdominant	2176	30.0	13.8	1.20	0.855	2.00	16.7	1.82
Right	2	Dominant	2176	30.0	13.8	1.20	0.855	2.00*	16.7	1.42
East: East (LEGHAR) LEG-1										
Left	1	Dominant	2124	30.0	14.1	1.40	0.914	2.00*	16.7	1.11
Thru	2	Subdominant	2124	30.0	14.1	1.40	0.914	2.00*	16.7	1.44
Right	3	Subdominant	2124	30.0	14.1	1.40	0.914	2.26	18.8	1.67
NorthEast: N.East (W.SHEBELE)LEG-2										
Left	1	Dominant	1945	30.0	15.4	1.48	0.898	2.00*	16.7	1.17
Thru	2	Subdominant	1945	30.0	15.4	1.48	0.898	2.00*	16.7	1.32
	3	Subdominant	1945	30.0	15.4	1.48	0.898	2.00*	16.7	1.32
Right	3	Subdominant	1945	30.0	15.4	1.48	0.898	2.00*	16.7	1.32
North: North (D.AFRIC)LEG-3										
Left	1	Subdominant	1424	30.0	21.1	1.30	0.698	2.23	18.6	2.03
Thru	1	Subdominant	1424	30.0	21.1	1.30	0.698	2.23	18.6	2.03
	2	Dominant	1424	30.0	21.1	1.30	0.698	2.00*	16.7	1.68
Right	2	Dominant	1424	30.0	21.1	1.30	0.698	2.00*	16.7	1.68
West: West (TOR HAILOCH)LEG-4										
Left	1	Dominant	1690	30.0	17.8	1.54	0.850	2.00*	16.7	1.25
Thru	2	Subdominant	1690	30.0	17.8	1.54	0.850	2.00*	16.7	1.67
	3	Subdominant	1690	30.0	17.8	1.54	0.850	2.00*	16.7	1.67
Right	3	Subdominant	1690	30.0	17.8	1.54	0.850	2.00*	16.7	1.67

Table S.6 - INTERSECTION PERFORMANCE

Total Flow (veh/h)	Deg. Satn x	Total Delay (veh-h/h)	Total Delay (pers-h/h)	Aver. Delay (sec)	Prop. Queued	Eff. Stop Rate	Longest Queue (m)	Perf. Index	Aver. Speed (km/h)
South: South (SARBET) LEG-5									
1022	0.560	0.85	1.28	3.0	0.84	0.60	39	24.22	27.9
SouthEast: S.EAST (AGAZIAN)LEG-6									
836	1.116	45.02	67.54	193.9	0.98	6.20	673	128.17	7.1
East: East (LEGHAR) LEG-1									
1143	1.468	170.14	255.21	535.9	1.00	8.71	1280	369.17	3.0
NorthEast: N.East (W.SHEBELE)LEG-2									
681	0.910	15.60	23.39	82.4	1.00	2.42	211	49.48	12.6
North: North (D.AFRIC)LEG-3									
861	0.552	1.52	2.28	6.4	0.85	1.01	37	23.87	27.1
West: West (TOR HAILOCH)LEG-4									
1197	0.882	13.79	20.69	41.5	1.00	2.06	186	62.10	17.7
ALL VEHICLES:									
5740	1.468	246.93	370.39	154.9	0.95	3.61	1280	657.01	8.4
INTERSECTION (persons):									
8610	1.468		370.39	154.9	0.95	3.61		657.01	8.4

Table 5.15 - CAPACITY AND LEVEL OF SERVICE

Mov No.	Mov Typ	Total Flow (veh /h)	Total Cap. (veh /h)	Deg. of Satn (v/c)	Aver. Delay (sec)	LOS	Longest Queue 95% Back (vehs)	(m)
South:	South (SARBET) LEG-5							
1	L	615	1099	0.560	3.3	A	5.5	39
2	T	369	1493	0.247	2.5	A	1.8	12
3	R	38	154	0.247	2.5	A	1.8	12
		1022		0.560		A	5.5	39
SouthEast:	S.EAST (AGAZIAN)LEG-6							
21	L	5	8	0.625	21.1	B	6.2	43
22	T	265	409	0.648	21.1	B	6.2	43
23	R	566	507	1.116	276.3	F	96.1	673
		836		1.116		F	96.1	673
East:	East (LEGHAR) LEG-1							
4	L	504	432	1.167	436.5	F	121.9	853
5	T	222	346	0.642	47.5	B	8.6	60
6	R	417	284	1.468*	915.9	F	182.8	1280
		1143		1.468		F	182.8	1280
NorthEast:	N.East (W.SHEBELE)LEG-2							
24	L	424	466	0.910	122.6	D	30.2	211
25	T	222	725	0.306	16.1	A	3.3	23
26	R	35	114	0.307	16.1	A	3.3	23
		681		0.910		D	30.2	211
North:	North (D.AFRIC)LEG-3							
7	L	208	377	0.552	6.7	A	4.6	32
8	T	625	1134	0.551	6.3	A	5.2	37
9	R	28	51	0.549	6.1	A	5.2	37
		861		0.552		A	5.2	37
West:	West (TOR HAILOCH)LEG-4							
10	L	576	653	0.882	64.2	C	26.6	186
11	T	369	609	0.606	20.4	B	7.3	51
12	R	252	416	0.606	20.4	B	7.3	51
		1197		0.882		C	26.6	186
ALL VEHICLES:		5740		1.468		F	182.8	1280

Level of Service calculations are based on v/c ratio.