Capacity Evaluation of Roundabout Junctions

In Addis Ababa

A thesis submitted to School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

(Road and Transport Engineering)

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ABSTRACT

This thesis addresses the most important element of operational performance of roundabout traffic intersections in Addis Ababa: capacity analysis. The relation between a roundabout performance measure and capacity is often expressed in terms of degree of saturation (Demand volume – Capacity ratio).

The capacity analysis is done based on empirical gap – acceptance method that is adopted by aaSIDRA software. The necessary 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 collected from 10 roundabouts. These 10 roundabouts represent different sizes of inscribed circle diameters of roundabouts, which are directly related to their approach leg numbers (3 leg, 4 legs, 5 legs and 6 legs).

aaSIDRA software capacity analysis results indicated that out of 10 roundabouts 6 of them have greater than 0.85 degree of saturation. This 0.85 value is recommended by analysis procedure of some model countries such as Australia, Germany, United Kingdom and U.S.A. Whose roundabouts are designed to operate at no more than 85 percents of their estimated capacity.

Approach entry capacity has been analyzed for all 10 roundabouts at their legs and with curve –fitting techniques. Effective capacity verses geometric parameters relationship have been developed in order to find out the causes of their over Saturation (v/c ratio greater than 0.85) And the result indicates; number of entry lanes, number of circulatory lanes, high traffic flow and pedestrian volumes are the major causes of their over saturation.

Furthermore, 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.

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1. Introduction

Evaluation of junction capacity is very important since it is directly related to delay, level of service, accident, operation cost, and environmental issues. For more than three decades modern roundabouts have been used successfully throughout the world as a junction 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, and most of them have served more than 30 years. 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 a 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.

1.1 Definition of the Problem

Now days, it is common to see traffic congestion at junctions in Addis Ababa 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 junctions, which is more dependent on driver behavior and balanced traffic flow between the approaches. This problem will continue and it may worsen in the future due to the rapid growth of population and vehicle numbers in Addis Ababa.

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 roundabouts for proper traffic operation, and to give a clear picture for the planners and traffic engineers involved in highway junction design and traffic operation tasks.

Some of the problems related to capacity of roundabouts are:

i. Necessarily geometric features of roundabouts such as flare and apron do not exist.
ii. In some roundabouts, there are visibility 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.
iii. Roundabouts' central islands are accessed by pedestrians.
iv. Absence of road marking signs and lights.

These and other inadequacies of the junctions result in a low level of capacities leading to traffic congestion. This study is carried out to evaluate the capacities of roundabouts in Addis Ababa and if possible to establish bases for further studies.

1.2 Objectives

The specific objectives of this research are:

i. To compile available information regarding capacity analysis of roundabouts through critical literature review;
ii. To select the appropriate methodology for evaluating the capacity of roundabouts in Addis Ababa;
iii. To evaluate the capacities of roundabout junctions in Addis Ababa; and

iv. Based on the results of the analyses, to draw conclusions and recommendations for possible future considerations during roundabout designs in Addis Ababa and elsewhere in Ethiopia.

1.3 Organization of the Thesis

This thesis consists of five chapters. The first chapter is introduction, which discusses the problem, objectives and approaches of the research work. Chapter 2 is the literature review, which discusses the basic concepts of roundabouts and the methodologies of roundabout capacity analysis. Chapter 3 discuses the gathering of data sets (data collection), Chapter 4 deals with capacity analyses for different approach leg numbers, and finally Chapter 5 presents conclusions and recommendations.

2. Literature Review

Transport Research Laboratory of England first introduced modern roundabout facilities in the early 1960s , United Kingdom (Mark 2003). These facilities were introduced in order to solve the problems of the existing rotaries and traffic circles; using the principle that entering traffic yields to circulating traffic, or the "give way" rule. And almost all city planners soon accepted it. Above all, improvement in safety is the most distinct advantage of roundabouts; most areas that implement roundabouts rules experience an impressive impact on their accident numbers. Because of this reputation, some countries have converted many ordinary intersections into roundabouts. Norway and Ireland were the first countries to follow England; the first roundabout in Norway was built in 1971. For instance, France is building almost 1500 roundabouts a year (Thaweesak, 1998). In the Netherlands, since the late 1980s, approximately 400 roundabouts have been built over a period of only six years (Thaweesak, 1998).

Since 1960, many different types of methodologies have been developed in order to determine roundabout capacity. This literature review will discuss most of the different approaches or theories upon which these methodologies are based. However, it is necessary to look at the basic concepts of roundabout and some definitions.

2.1 Basic Concepts of Roundabouts and Definitions

A roundabout is a channelised intersection at which all traffic moves anticlockwise around a central traffic island. (AACRA Geometric Design Manual, 2003). This definition can be used for traffic circles also because it doesn't mention priority.

Roundabouts are intersections 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 make a 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 (FHWA-RD-00-067, 2000).

Roundabouts are often confused with traffic circles or rotaries and it is important to be able to distinguish between them. According to FHWA-2000 information guide, roundabouts have five main characteristics that identify them when compared to traffic circles:

i. **Traffic control:** Yield control is used on 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. 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. A case in point can be in countries like In

United Kingdom, Japan, India, Australia, New Zealand, South Africa, Kenya, Uganda, Tanzania, Zambia, Zimbabwe, and Malawi.

Besides to those five mentioned above, Thaweesak (1998) included additional features of roundabout, which distinguish them from other traffic circles.

Approach Flare: Most roundabout approaches flare out at the entries and allow more vehicles to enter the circulating roadway at a more obtuse angle. This improves capacity, and allows entering vehicles to enter at similar speeds as the circulating vehicles unless a queue has developed at the entry. The size and angle of the flare is generally controlled by a raised traffic island that separates the entering and exiting traffic at an approach. This island also gives pedestrians a safe location to cross the approach in two stages. This is the old English principle and gives high capacity, but low safety due to high speed in some countries.

Deflection: This characteristic is the geometry of the facility that requires vehicles to slow down as they maneuver through the roundabout. The size of the Center Island and angle of approach determine the deflection and potential speeds of entering and circulating vehicles.

Generally, the effect of the roundabout is that traffic is required to slow down to negotiate the curve around the central island, but unlike full stop and signal controlled intersections, vehicles entering a roundabout are not required to stop completely. This makes the facility more efficient under a wide range of traffic volumes, as motorists only need to find an acceptable gap for entrance.

2.1.1 Major Geometric Features of a Modern Roundabouts

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

- **Design of vehicles**
- **Design speed**
- **Sight distance**
- **Deflection**
- **Central island**
- **Circulating width**
- **Inscribed circle diameter**
- **Entry and exit design**
- **Splitter island**
- **Superelevation and drainage**
- **Pavement markings**
- **Signage**
- **Lighting**
- **Landscaping**

2.1.2 Some Description on Basic Elements of Roundabouts

Central Island: A raised, nonmountable curb usually delineates the central island, and its size is determined by the width of the circulatory roadway and the diameter of the inscribed circle.

Truck Apron: A truck apron is a traversable portion of the raised center island to accommodate the wheel path of oversized vehicles.

Splitter Island: The splitter island is placed within the leg of a roundabout to separate entering and exiting traffic and provide vehicle deflection prior to entering the roundabout.

Bypass Lane: A bypass lane may be warranted for heavy right turn vehicles as it allows traffic to bypass the roundabout.

Approach Width: The approach width refers to the width of the entering lanes before flaring or any other influence from the roundabout.

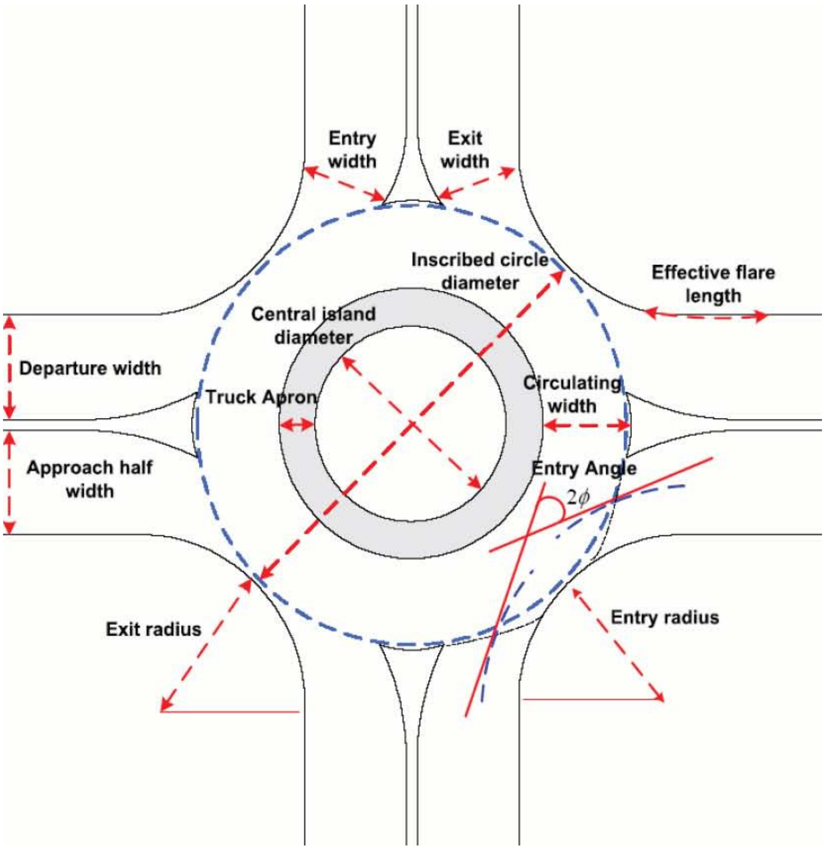

Figure 2-1 Major Geometric Features of Modern Roundabout

Exit Width: The exit width is the perpendicular distance from the right curb line of the exit to the intersection of the left edge line and the inscribed circle.

Departure Width: The departure width refers to the width of the lanes departing from the roundabout at a point where the width is no longer influenced by the roundabout.

Effective Flare Length: A flare may be used to increase the entry width and capacity of a roundabout by providing additional lanes at the entry. The effective flare length is equal to the distance from the entry width to a point where the approach width is equal to half the sum of the entry width and the approach traveled way width prior to influence from the roundabout.

Entry Radius: The entry radius is the minimum radius of curvature for the compound curve measured along the right curb at entry beginning before the yield line.

Approach Stopping Sight Distance: The approach stopping sight distance is the minimum stopping sight distance to the back of queue or yield line at the roundabout entry.

Circulating Roadway Width: The width of the circulatory roadway depends mainly on the number of entry lanes and the radius of vehicle paths.

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

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

(i) The empirical method, and

(ii) The analytical or gap acceptance based method.

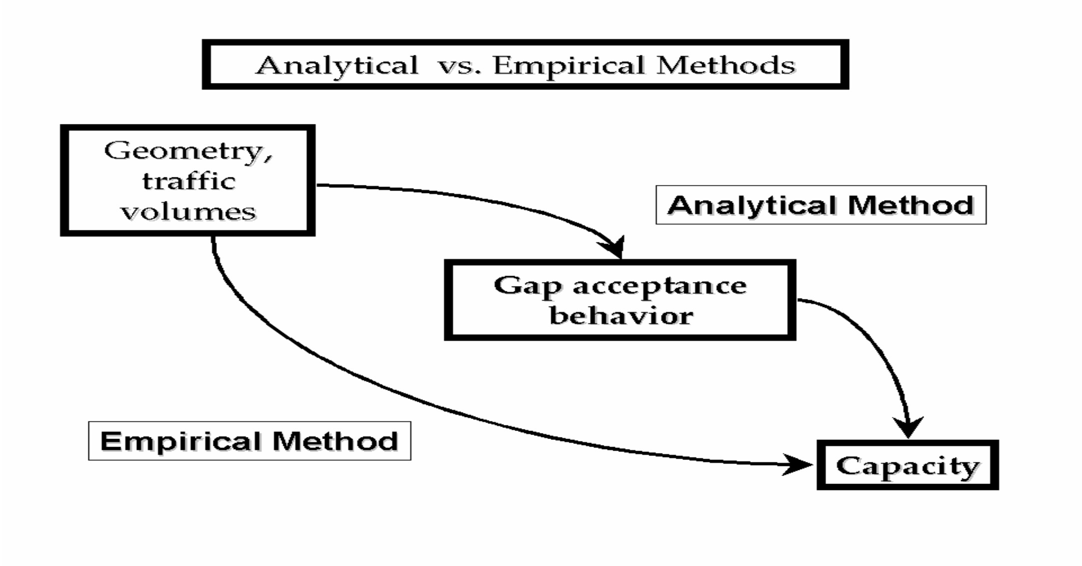

Figure 2-2 Analytical Verses Empirical methods

2.2.1 Empirical Method

2.2.1.1 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. (Thaweesak , 1998)

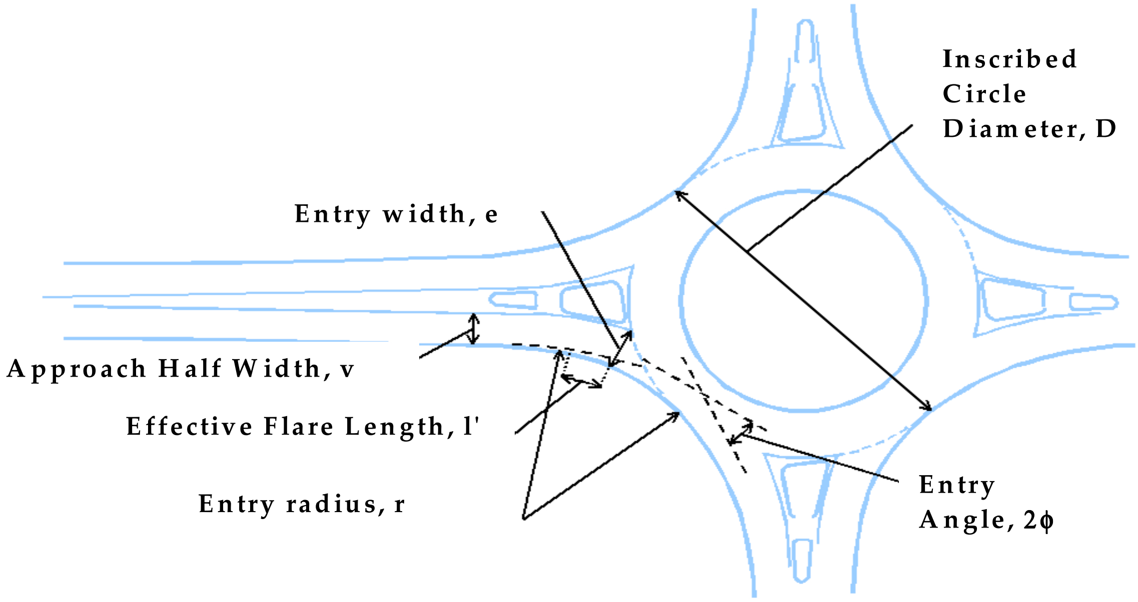

Figure 2-3 (UK- 6 Geometric Parameters used for Capacity Analysis)

Kimber's capacity formula is:

Qe = F- fc Qc (2-1)

where Q e = Entering Capacity (vph)

Q c = Circulating Flow (vph)

F, f c = Parameters defined by roundabout geometry

Kimber's equation could be used for both large and small roundabouts. Kimber used a number of parameters to describe the geometry, as defined in figure 2-2 which are the entry width, the circulation width, the inscribed diameter, the effective length, the approach road half width, the entry radius, the angle of entry, the width of the weaving section and the length of the weaving section.

$\mathbf{S = (e- v)/\mathit{l} \text{ or } S = 1.6(\mathit{e}\text{-}v)/\mathit{l}'}$ (2-2)

Where:

S = the sharpness of the flare

e= entry width

v = the approach road half width (m)

l, l'= the effective length

The ranges of the geometric parameters in the tested database were

e : 3.6 m - 16.5 m

v : 1.9 m - 12.5 m

l': 1- ∝ m

S : 0-2.9m

D : 13.5 m - 171.6 m

ϕ :0° - 77°

r: 3.4m - ∞ m

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

Kimber regressed the number of entry lanes, n, with the effective entry width, $\boldsymbol{X_2}$, given by the equation:

$$X_2 = v + ((e-v)/ (1+2S)) \qquad (2\text{-}3)$$

He then sought equations for the slope and intercept of the entry/circulation flow formula by linear regression of F and as a 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, *f*c, decreased as the diameter increased and accordingly, a factor, *t*d, was included in the equation for fc to account for this effect. In addition, Kimber established the following equations:

$$fc = 0.210\ (1 + 0.2\ x2)\ td \qquad (2\text{-}4)$$

for the slope, and the equation

$$F = 303x_2 \qquad (2\text{-}5)$$

for the intercept, where

$$t_d = 1 + 0.5/[1 + e^{((D-60)/10}] \qquad (2\text{-}6)$$

Values of *td* were equal to 1.0 for large diameters and 1.5 for very small diameters. For all but the largest roundabouts (D>30 m) *td* can be set to 1.48.

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

$$Qe = k\ (F - fcQc) \qquad (2\text{-}7)$$

Where $k = 1.151 - 0.00347\phi - 0.978/r$ **(2-8)**

r = the entry radius (m)

ϕ= the angle of entry (degree)

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

Kimber tested for linearity, concluding that a parabolic function 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* = 1300 pcu/h or so is about 200 pcu/h or about 15 percent of the entry capacity.

2.2.1.2 Germany's Capacity Formula

In Germany, they use an approach similar to that of the UK. German 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. (Thaweesak , 1998)

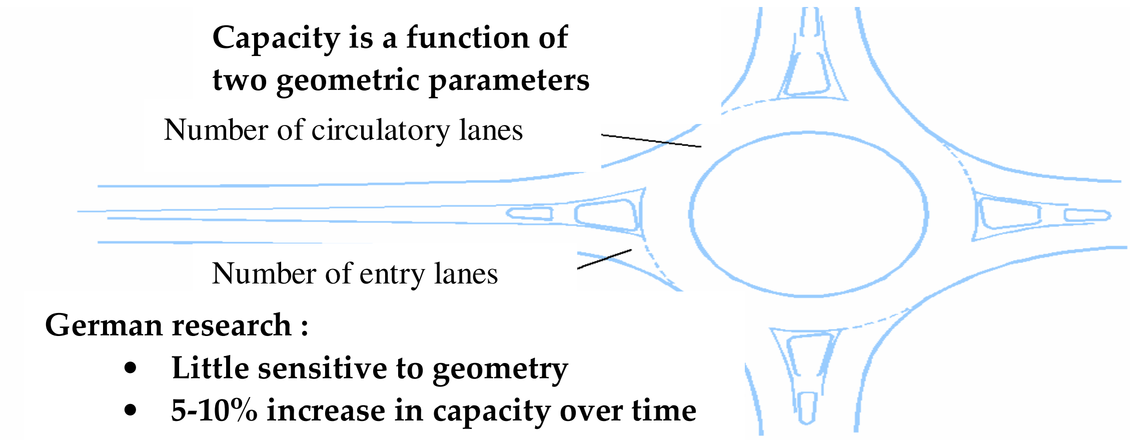

Figure 2-4 (Germany's -Geometric parameters)

Germany's formula:

$$Qe = A * e^{(-BQc/1000)} \qquad \textbf{(2-9)}$$

Where:

$Q\ e$ = entering capacity (vph)

$Q\ c$ = circulating flow (vph)

A, B = defined parameters

Several types of roundabouts were investigated. The parameters A and B in this equation have been determined separately from the measurements by regression calculation for different number of entries. The values of A and B are shown in Table 2-2 and also the regression curve are shown in Figure 2-4

Table 2-1: Formula for Calculating Roundabout Capacity *(Brilon 1990)*

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

The German results are between 0.7 and 0.8 of the English values. In Birgit Stuwe's opinion (*Stuwe 1991*), this difference can be explained by different driver 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.

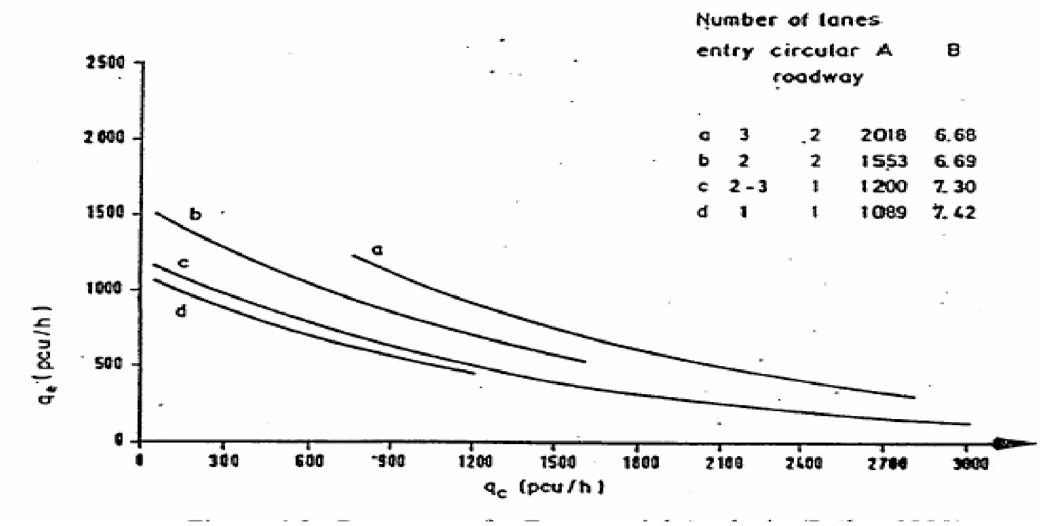

Figure 2-5 : Parameters for Exponential Analysis *(Brilon 1990)*

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 Bondzio 1997*). The new capacity formula is:

$$Qe=C + DQc \qquad (2\text{-}10)$$

Where C and D are as shown in the Table below

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*
½ or 1/3	*1250*	*-0.53*	*879*
2/2	*1380*	*-0.50*	*4574*
2/3	*1409*	*-0.42*	*295*

*no. of observed 1-minute intervals

2.2.2 Analytical Method

The empirical formulation has some drawbacks, for example, data has to be collected at over saturated flow (or at capacity) level. It is a painstaking task to collect enough amounts of data to ensure reliability of results, and this method is sometimes inflexible under unfamiliar circumstances, for example, when the value is far out of the range of regressed data. Consequently, researchers looked for other reliable methods of determining roundabout capacity. Many researchers agree that a gap acceptance theory (Analytical Method) is a 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 interactions at roundabouts with the availability of gap in the traffic streams (Thaweesak , 1998).

The development of gap acceptance capacity formula was fundamentally based on Tanner’s capacity equation (2.2.2.1) 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, 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 (2.2.2.2) 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 (Akcelik, 2005).

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.

2.2.2.1 *Tanner's* Basic Capacity Equation

Tanner (1962) analyzed the delays at an intersection of two streams in which the major stream had priority. He assumed that both major and minor stream arrival are random, but that a major stream vehicle cannot enter the intersection sooner than Δ 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 T_0 seconds. Tanner's equation (Taekratok 1998) would then be:

$$q_e = q_c(1-\Delta q_c)e^{q_c(T-\Delta)} / \; 1-e^{-q_c T_0} \qquad \textbf{(2-11)}$$

where

q_e **= Entering Capacity (veh/sec)**

q_c **= Circulating flow (veh/sec)**

T **= Critical gap**

T_0 **= Follow-up time**

Δ = Minimum headway

2.2.2.2 aaSIDRA Gap-Acceptance Method

In aaSIDRA, the roundabout capacity is estimated from:

$$Q = s\, u = (3600 / \beta)\, u \qquad (2\text{-}12)$$

Where s = 3600 / β is the saturation flow rate (veh/h), β is 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 s means a maximum capacity of 3600/3.0 = 1200 veh/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 predict decreased capacity with increased circulating flow. In gap-acceptance modeling, this is due to the b*locked periods* that result when the approach vehicles cannot find an acceptable gap in the circulating stream. *Unblocked periods occur* when queued or unqueued 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. (Akcelik, 1997)

Many different forms of the roundabout capacity formula based on gap-acceptance method that exist, including the HCM capacity formula, can be explained in terms of the concept expressed by (equation 2-12). aaSIDRA uses this concept directly to calculate the gap-acceptance capacity. In aaSIDRA version 2.1, the gap-acceptance capacity, Qe incorporates the following effects:

i. Critical gap and follow-up headway of the entry stream depend on the roundabout geometry (inscribed diameter, number of entry lanes, average entry lane width and number of circulating lanes), the type of lane (dominant or subdominant) as well as the circulating flow and arrival (demand) flow rates and an *environment factor* for local conditions;
ii. At low circulating flow rates, critical gap and follow-up headway decrease with increasing *ratio of demand flow rate to circulating flow rate* (a calibration factor is available for determining an appropriate level of the effect of this factor);
iii. Heavy vehicles in the circulating stream increase the effective circulating rate.
iv. Heavy vehicles 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 time, average gap-acceptance cyc1e time and the unblocked time ratio;
vi. Minimum intrabunch 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 circulating lanes in front of each approach determines the values of intrabunch 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 intrabunch 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 origin-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

a. The proportion bunched (or free) in the circulating stream is determined from the following formula (this replaces the exponential model used in earlier versions of aaSIDRA):

$$\varphi = (1 - \Delta\, q_c) / [1 - (l - k_d)\, \Delta\, q_c] \quad \textbf{(2-13)}$$

subject to $\varphi >= 0.001$

Where

φ =proportional unbunched (free) in the circulating stream,

Δ =minimum intrabunch headway in the circulating stream (seconds)

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

k_d =bunching delay parameter (a constant) kd=2.2 for roundabout circulating streams.

2.2.2.3 Akcelik Base Capacity Equation

This Analytical method of capacity analysis is carried out by lane-by-lane analysis. According to Akcelik, (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 a 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 (Akcelik 1994). Several additional equations will be required in order to create inputs to this Equation.

$$Q_e = (\tfrac{3600}{\beta}) * ((1 - \Delta_c * q_c) + (0.5 * \beta * \Phi_c * q_c)) * e^{-\lambda*(\alpha - \Delta_c)} \qquad (2\text{-}14)$$

Where,

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

β = Follow up headway (seconds/vehicle)

α = Critical gap (seconds/vehicle)

Δ_c = Intrabunch headway (seconds/vehicle)

q_c = Circulating flow at entry (pce/hour)

Φ_c = Proportion of unbunched vehicles in the circulating stream

λ = Parameter in the 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 equations. 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 adopted from The U.S DOT's Roundabout Guide (2000))

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.

$$VOL' = VOL*P_t*2 + VOL*P_r*1.5 + VOL*(100-(P_t + P_r)) \quad (2\text{-}15)$$

Where,

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

VOL = Turning movement volume (vehicles/hour)

P_t = Proportion of vehicles that are tractor-trailers

P_r = 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 volumes 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 (P_{ed}) 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.

$$q_{ar} = \Sigma_d \, VOL'_e * P_{ed} \qquad \textbf{(2-16)}$$

$$q_{al} = \Sigma_d \, VOL'_e *(1- P_{ed}) \qquad \textbf{(2-17)}$$

Where,

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

P_{ed} = Entering split (proportion in right lane) for direction for approach 'd'

q_{ar} = Arrival flow rate for the right lane (pce/h)

q_{al} = Arrival flow rate for the left lane (pce/h)

d = Direction of approach (NB, SB, 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.

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

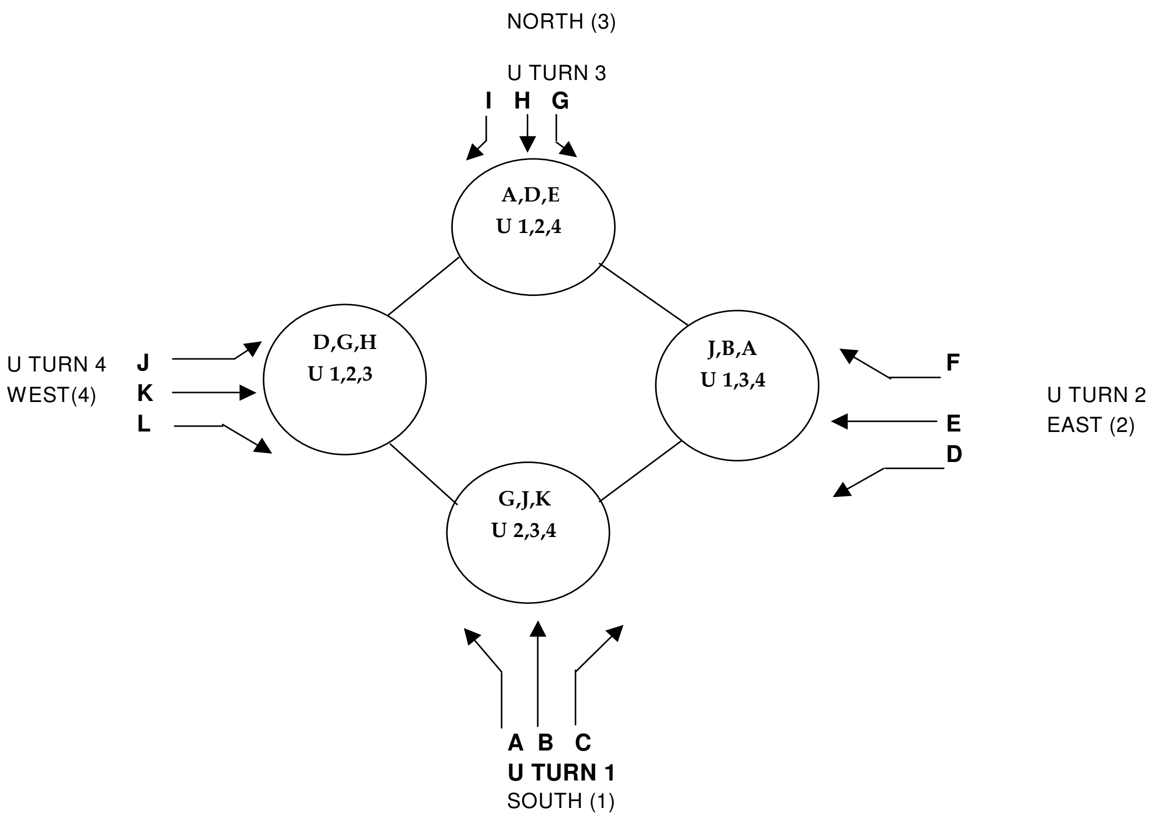

Figure 2-6 Circulating Volume at Entry

For instance, for the vehicles that will pass by the northbound approach include the southbound left (g), the eastbound left (j) and through (k), and the U-turns from the westbound (2), southbound (3) and eastbound (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.

$$q_{cr} = \Sigma_d \, VOL'_c * P_c * \Psi \qquad (2–18)$$

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

Where,

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

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

q_{cr} = Circulating flow at entry for the right lane (pce/h)

q_{cl} = 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.

$$Q_e = \left(\frac{3600}{\beta}\right) * \left(\left(1 - \frac{\Delta_c * q_c}{3600}\right) + \left(\frac{\beta * \Phi_c * q_c}{2 * 3600}\right)\right) * e^{-\frac{\lambda}{3600} * (\alpha - \Delta_c)}$$

Equation 2-20: Adjusted Base Capacity Equation

Where,

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

β = Follow up headway (seconds/vehicle)

α = Critical gap (seconds/vehicle)

Δ_c = Intrabunch headway (seconds/vehicle)

q_c = Circulating flow at entry (pce/hour)

Φ_c = 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 grater 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, t_f. Thus, t_f 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(t_f) 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.

2.3 Summary

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 is 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 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.

3. Data Collection

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 Abeba 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 Study sites

After the training, the necessary geometric and peak hour traffic data were collected at ten roundabouts. These ten 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 twenty-nine roundabouts in Addis Ababa, that are indicated on the NORTEC MAP of Addis Ababa, and their size more or less are related to their leg numbers. Clearly in terms of number, ten roundabouts can represent the twenty-nine roundabouts. 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 are 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)

Roundabouts with Three - legs or approaches

1. Gerji Imperial
2. Adwa – Aboare

Roundabouts with Four – legs or approaches

3. Bole – Medhanialem
4. Piazza – Degole
5. Arrat Kilo
6. Georgis – Woizron

Roundabouts with Five – legs or approaches

7. Sidist Kilo
8. Tewodros
9. Minilik

Roundabouts with Six – legs or approaches

10. Mexico

3.2 Geometric Data

As per the requirement of both aaSIDRA Version 2.1 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. 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 3-1.

Please see the roundabouts geometry in the Appendix – B

Table 3-1 Summery of intersection Geometry

No.	Roundabout Name	No. Legs	Numbers of circulatory Lane	Island Diameter (m)	Circulatory Road width (m)	Inscribed Circle Diameter (m)
1.	GERGI-IMPERIAL	3	2	21	12	33
2.	ADWA-ABOARE	3	2	15	11	26
3.	BOLE -MEDHANIALEM	4	3	36	15	51
4.	PIASSA-DEGOL	4	2	15	7	22
5.	GORGIS-WOIZRON	4	2	22	10	32
6.	4-KILLO	4	3	30	25	55
7.	6-KILLO	5	3	51	25	76
8.	TEWODROS	5	3	40	25	65
9.	MINILIK	5	3	55	30	85
10.	MEXICO	6	3	65	12	77

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 22m to 85m, which can be categorized from mini-roundabouts to urban multilane roundabouts according to Roundabout Information Guide.

As shown in Figure 3-1, when the central island diameter increases the circulatory lane numbers also increases. Out of 10 roundabouts, 6 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.

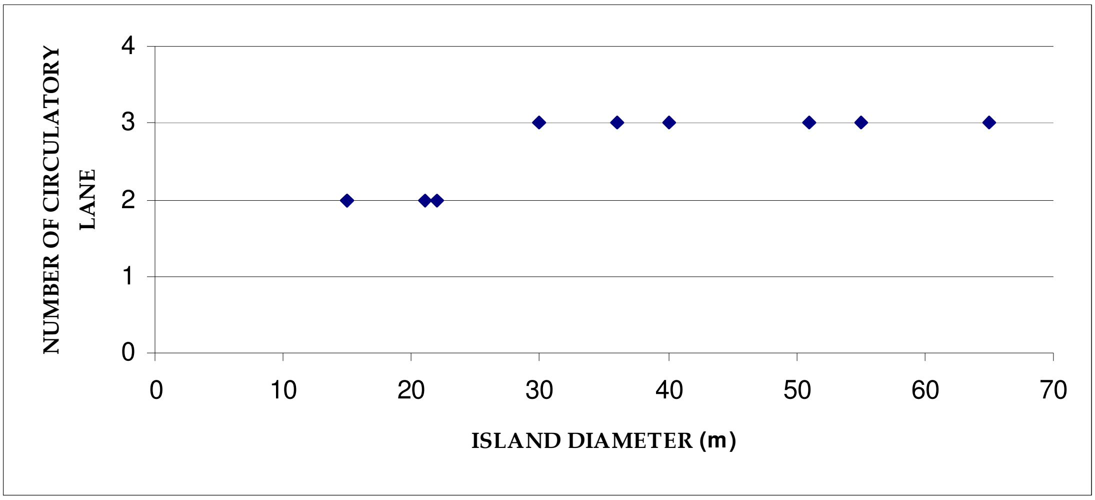

Figure 3-1 Island Diameter Vs Number of Circulatory Lane

Number of legs at junction and island diameters relationships is established by curve fitting techniques as shown on Figure 3-2 and it shows that there is a linear relationship with good R mean square results which is 0.81. The island diameter linearly increases with the approaches leg numbers. Therefore, it is a justified representative (chosen) sample, which is based on leg numbers.

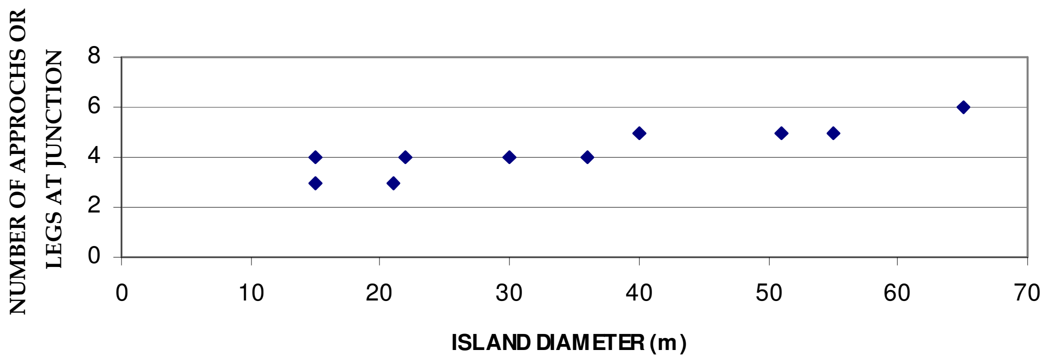

Figure 3-2 Island Diameter Vs Number of Legs

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 3-2 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 3-2 Summery of legs or Approaches Geometry

No.	Roundabouts	Leg No.	Number of Entry lane	Average Lane width (m)
1	GERGI-IMPERIAL	1	2	3.8
		2	3	3.7
		3	3	3.8
2	ADWA-ABOARE	1	1	4.5
		2	1	4.5
		3	3	3
3	BOLE -MEDHANIALEM	1	2	3.3
		2	3	3.3
		3	1	4.3
		4	1	6
4	PIASSA-DEGOL	1	1	5
		2	1	6
		3	1	6
		4	3	4
5	GORGIS-WOIZRON	1	2	4.5
		2	2	3.6
		3	1	5.8
		4	2	4.5
6	4-KILLO	1	4	3.1
		2	2	3.65
		3	2	3.8
		4	1	3.15
7	6-KILLO	1	1	3
		2	2	3.5
		3	2	3
		4	2	4
		5	2	4
8	TEWODROS	1	4	3
		2	1	6
		3	2	4
		4	1	6
		5	1	6
9	MINILIK	1	2	4.5
		2	3	3.2
		3	2	4.5
		4	2	4.5
		5	1	5
10	MEXICO	1	3	3.1
		2	3	3
		3	2	4.5
		4	3	4
		5	3	3
		6	2	4.5

3.3 Traffic Data

Traffic movements of vehicle and vehicles' volume classification are important parameters for capacity analysis using either aaSIDRA or Acklick's Base Capacity formula. 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 3-3. The data is collected for one hour or 60 minutes duration. For detailed information on the movement of vehicles, please see Appendix A.

Figure 3-3 and Figure 3-4 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), Minilik 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.

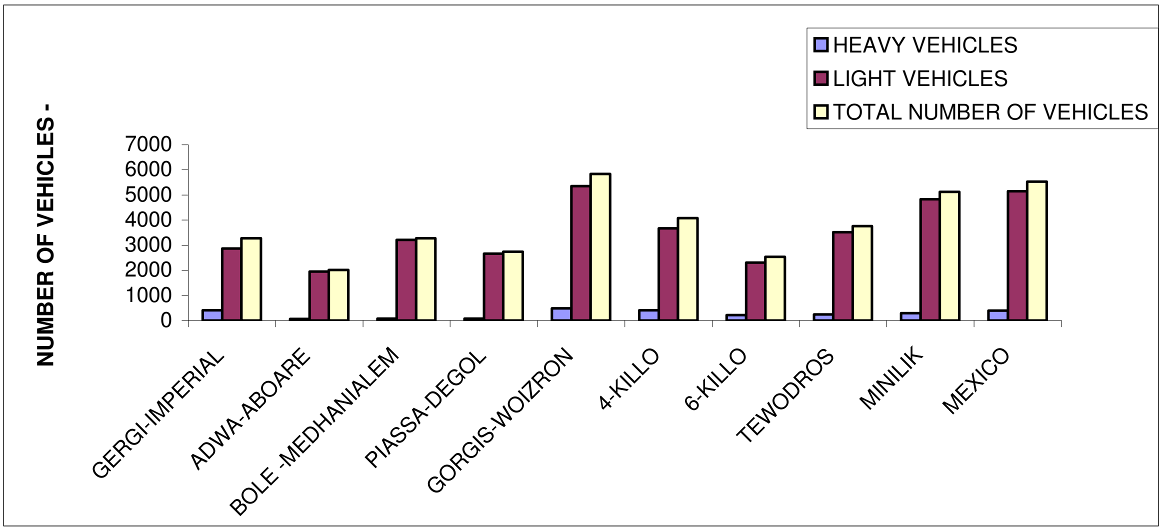

Figure 3-3. Maximum Peak Hour Vehicles Volume Distribution On Intersections

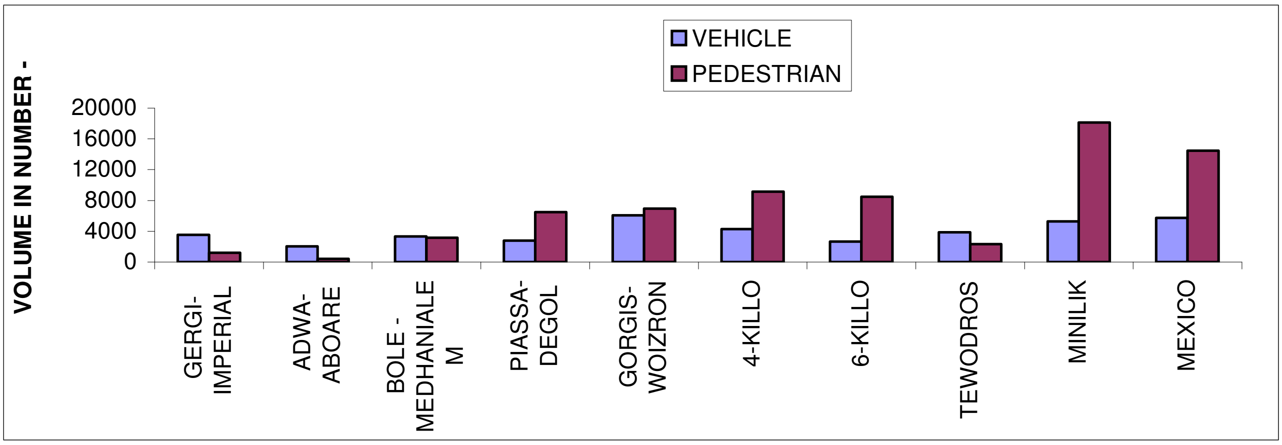

Figure3-4 Pedestrians Vs Vehicles Volume At Junctions

The percentage of heavy vehicles at the majority of the intersection does not exceed 10% as shown in table 3-3. Only Gergi-Imperial has 13% of heavy vehicles, out of the total number of vehicles 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 3-3 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	Heavy Vehicles			Light Vehicles	Total Numbers of Vehicles	Total Traffic (PCU)	Percentage of Heavy Vehicles	Number Of Pedestrians on the Intersection
		Bus and Dump Truck	Truck and Trailer	Total					
1	GERGI-IMPERIAL	326	87	413	2868	3281	3531	13	1222
2	ADWA-ABOARE	60	0	60	1954	2014	2044	3	409
3	BOLE-MEDHANIALEM	59	14	73	3209	3282	3325	2	3141
4	PIASSA-DEGOL	78	0	78	2660	2738	2777	3	6488
5	GORGIS-WOIZRON	477	3	480	5357	5837	6078	8	6940
6	4-KILLO	401	2	403	3676	4079	4281	10	9140
7	6-KILLO	220	0	220	2313	2533	2643	9	8480
8	TEWODROS	242	1	243	3519	3762	3884	6	2309
9	MINILIK	295	1	296	4831	5127	5275	6	18133
10	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 3-4. The traffic movement data with detailed information is available in the Appendix A.

From Table 3-4, 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 3-4 SUMMARIZED ENTRY TRAFFIC FLOW ON ROUNDABOUT APPROACH LEGS

ROUNDABOUT	LEG NO.	ENTRY TRAFFIC ON LEGS (PCU)	PERCENTAGE OF TRAFFIC SHARE
GERGI-IMPERIAL	1	919	26
	2	1626	46
	3	986	28
ADWA-ABOARE	1	149	7
	2	591	29
	3	1304	64
BOLE -MEDHANIALEM	1	1425	43
	2	1047	31
	3	65	2
	4	790	24
PIAZZA-DEGOL	1	573	21
	2	941	34
	3	179	6
	4	1084	39
GORGIS-WOIZRON	1	796	13
	2	709	12
	3	561	9
	4	4012	66
4-KILLO	1	1922	45
	2	734	17
	3	814	19
	4	811	19
6-KILLO	1	197	7
	2	809	31
	3	562	21
	4	608	23
	5	469	18
TEWODROS	1	1508	39
	2	338	9
	3	1597	41
	4	350	9
	5	91	2
MINILIK	1	2453	54
	2	1324	29
	3	174	4
	4	492	11
	5	118	3
MEXICO	1	1142	20
	2	681	12
	3	861	15
	4	1197	21
	5	1022	18
	6	835	15

4. Analysis and Discussions

4.1 General

Taking in to consideration all the above summarized data, we can proceed to the capacity analysis using aaSIDRA for all roundabouts and Accelik's Base formula for 2 lanes circulatory flow. However, some additional information are 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 from Gergi - Imperial roundabouts which is attached in the appendix-A.

Environmental factor-1 and lane utilization factors 100 have been used in this analysis, except for the Gergi-Imperial roundabout which has higher heavy vehicle volume, and for roundabouts that have higher pedestrian volumes (Minilik 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 he capacity analysis of roundabouts .

4.2 Analysis Result

aaSIDRA capacity analysis produced the following results. The capacity analysis results for the intersections are summarized in Table 4-1. 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 4-1, it is seen that 6 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 4-1 also shown peak flow or entry flow verses effective capacity

Table 4-1 Summarized capacity analysis results on the intersections

Roundabout	TOTAL VEHICLE FLOW	EFFECTIVE CAPACITY	DEG.SATURATION (V/C)	LOS
GERGI-IMPERIAL	3531	3582	0.986	E
ADWA-ABOARE	2044	4092	0.500	A
BOLE – MEDHANIALEM	3325	4636	0.717	B
PIASSA-DEGOL	2777	2326	1.194	F
GORGIS-WOIZRON	6078	2810	2.163	F
4-KILLO	4281	4313	0.993	E
6-KILLO	2643	5960	0.443	A
TEWODROS	3884	5696	0.682	B
MINILIK	5275	3203	1.647	F
MEXICO	5732	3909	1.466	F

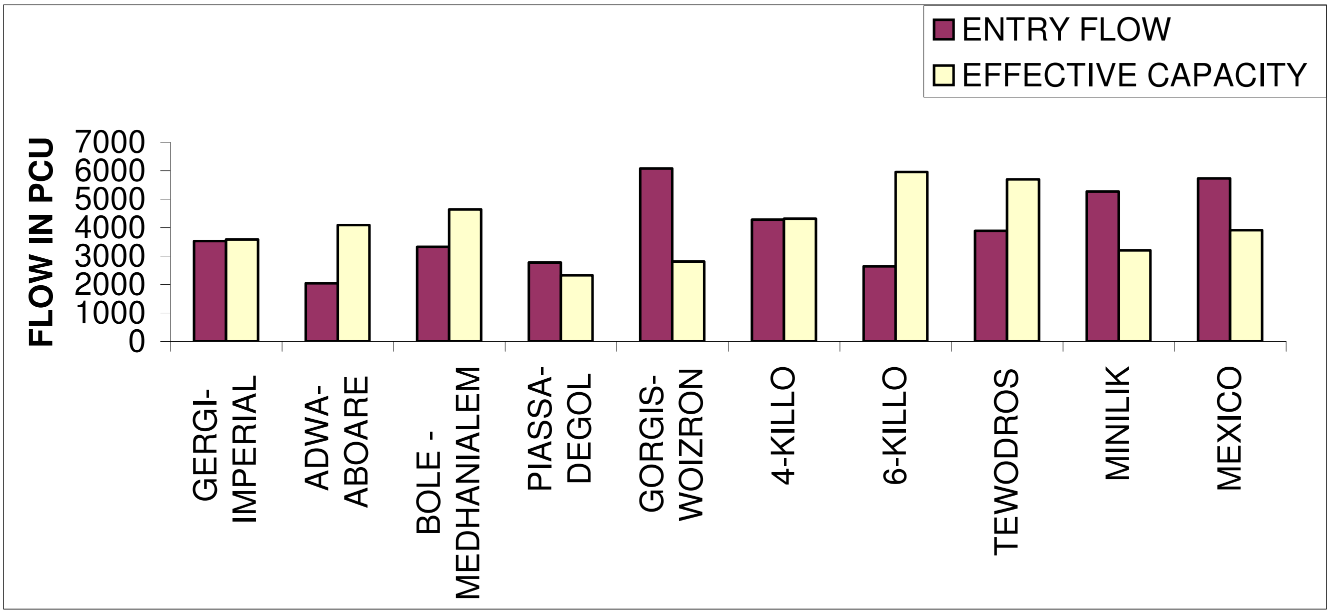

Figure 4-1 Peak Flow Vs Effective Capacity

To give a clear picture of the result Figure 4-2 also presents degree of saturation with 0.85 being the recommended limit by HCM.

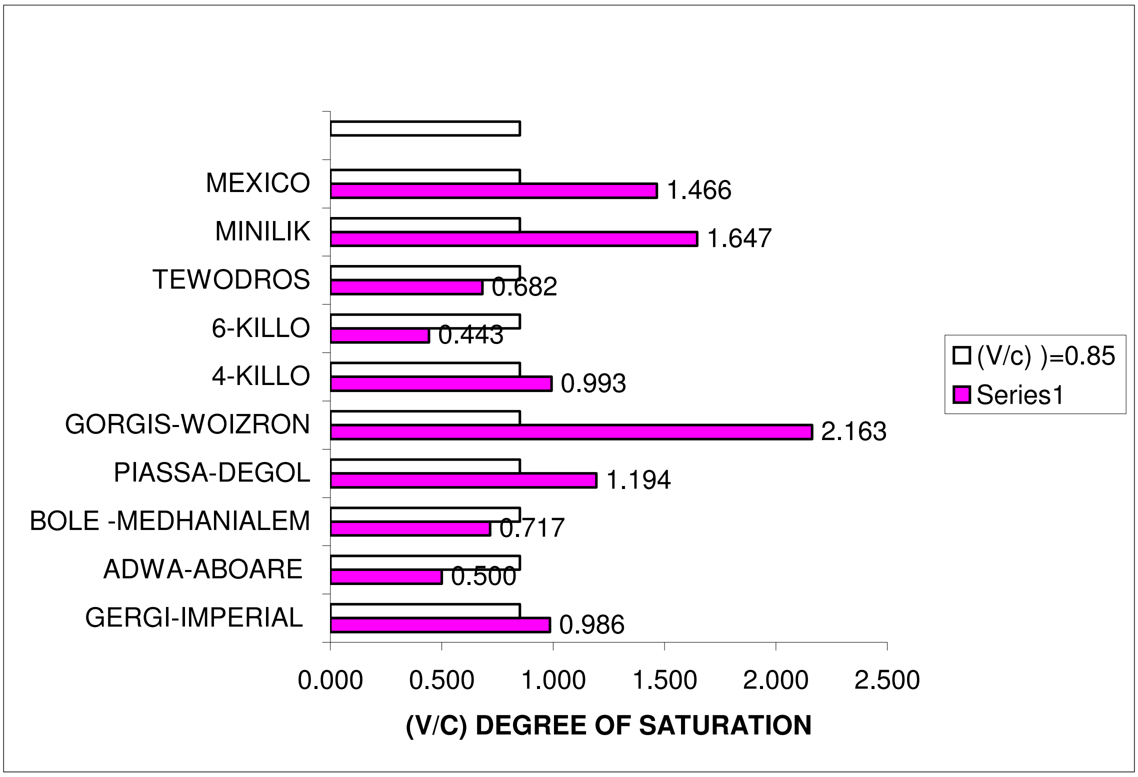

Figure 4-2 Degree Of Saturation At Intersections

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 4-3 clearly shows this relationship with a reasonable R-squared or coefficient of determination, which is 0.79.

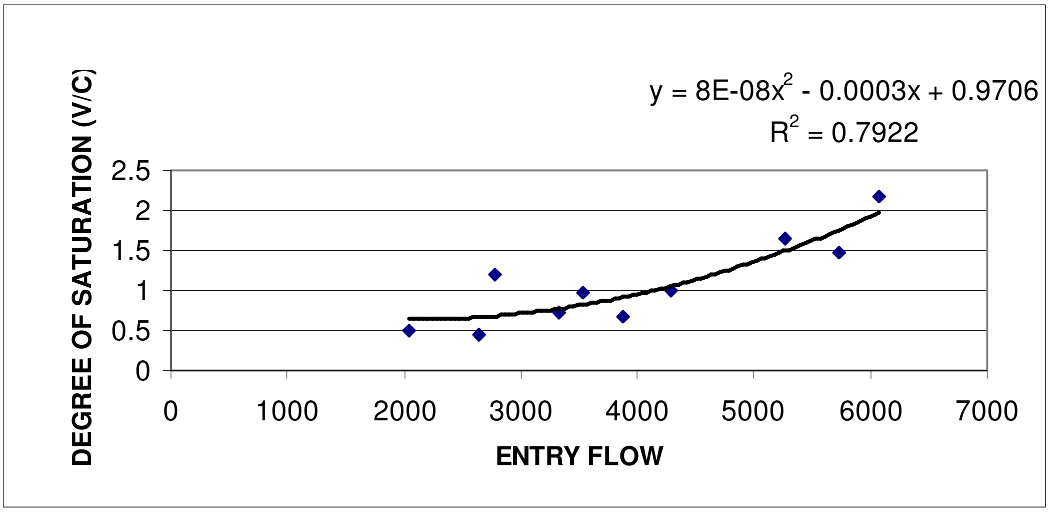

Figure 4-3 Entry Flow Vs Degree Of Saturation For The Intersection

Mexico, Minilik and Georgis-Woizron have higher entry flow at their intersection more than 4000 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 4-2.

Table 4-2 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
GERGI-IMPERIAL	1	919	1276	0.956	961	0.106
	2	1626	323	0.597	2724	-0.253
	3	986	752	0.442	2231	-0.408
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
BOLE -MEDHANIALEM	1	1425	309	0.718	1985	-0.132
	2	1047	612	0.396	2644	-0.454
	3	65	1596	0.148	439	-0.702
	4	790	677	0.605	1306	-0.245
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
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
4-KILLO	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
6-KILLO	1	197	1091	0.328	601	-0.522
	2	809	637	0.444	1822	-0.406
	3	562	712	0.417	1348	-0.433
	4	608	998	0.4	1520	-0.45
	5	469	617	0.247	1899	-0.603
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
MINILIK	1	2453	976	1.296	1893	0.446
	2	1324	1449	1.63	812	0.78
	3	174	665	1.647	106	0.797
	4	492	2091	0.333	1477	-0.517
	5	118	1708	0.252	468	-0.598
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 4-2 which is based on HCM (Capacity Manual of Highway), we can easily identify the legs which are in a critical condition.

Table 4-3: Legs with Critical Condition (V/C>0.85)

Roundabout	No. of legs (v/c) > 0.85
Gergi-Imperial	1
Piazza-Degol	2
Georgis-Woizron	3
4- Kilo	1
Minilik	3
Mexico	4

A total of 14 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 developed relationship is shown in figure 4-4 below.

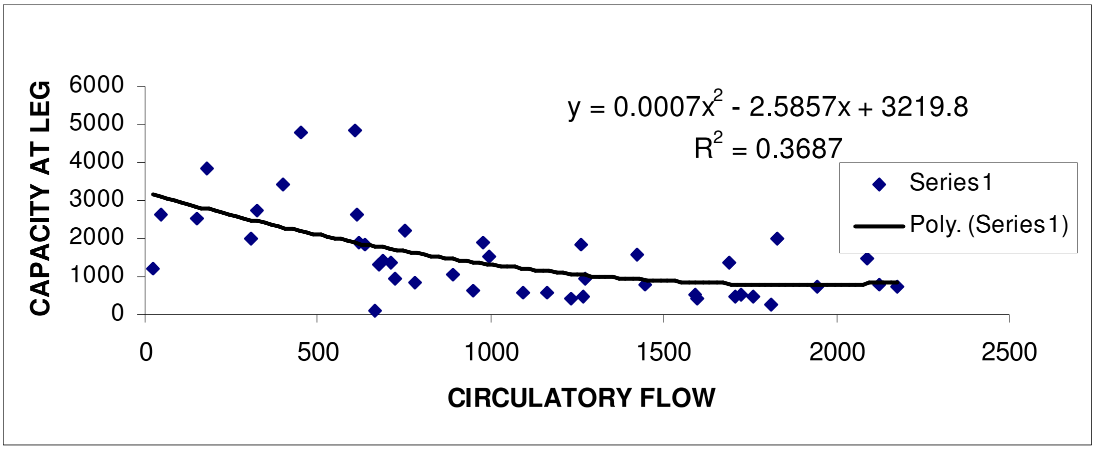

Figure 4-4 Opposing Circulatory Flows Vs Capacity At Legs

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 0.3687. 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.

Next, groups were created in order to observe the influence of the remaining parameters and to rearrange the data in Table 4-2. Table 4-4 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 4-4 clearly shows the created groups.

Table 4-4 Leg Groups Based On Number Of Circulatory And Entry Lanes

GROUP	NUMBER OF ENTRY LANES	NUMBER OF CIRCULATORY LANES
1	1	2
2	2	2
3	3	2
4	1	3
5	2	3
6	3	3

Table 4-2 is rearranged using the groups as shown on table 4-5

TABLE 4-5: THE REARRANGED TABLE FROM TABLE 4-2 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
GERGI-IMPERIAL	1	2	2	919	1276	961	0.956
GORGIS-WOIZRON	2	2	2	709	1164	582	1.219
GORGIS-WOIZRON	4	2	2	4012	148	2503	1.603
GERGI-IMPERIAL	2	3	2	1626	323	2724	0.597
GERGI-IMPERIAL	3	3	2	986	752	2231	0.442
PIASSA-DEGOL	4	3	2	1084	182	3844	0.282
BOLE - MEDHANIALEM	3	1	3	65	1596	439	0.148
BOLE - MEDHANIALEM	4	1	3	790	677	1306	0.605
4-KILLO	4	1	3	811	784	817	0.993
6-KILLO	1	1	3	197	1091	601	0.328
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
MINILIK	5	1	3	118	1708	468	0.252
BOLE - MEDHANIALEM	1	2	3	1425	309	1985	0.718
4-KILLO	2	2	3	734	893	1803	0.407
4-KILLO	3	2	3	814	1831	1173	0.694
6-KILLO	2	2	3	810	617	1824	0.444
6-KILLO	3	2	3	562	998	1348	0.417
6-KILLO	4	2	3	608	712	1520	0.4
6-KILLO	5	2	3	469	637	1899	0.247
MINILIK	1	2	3	2490	665	1921	1.296
MINILIK	3	2	3	845	1708	513	1.647
MINILIK	4	2	3	496	976	1489	0.333
MEXICO	3	2	3	861	1424	1560	0.552
MEXICO	6	2	3	836	2176	749	1.116
BOLE - MEDHANIALEM	2	3	3	1047	612	2644	0.396
MINILIK	2	3	3	1324	2091	812	1.63
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
4-KILLO	1	4	3	1922	610	4854	0.396
TEWODROS	1	4	3	1508	449	4803	0.314

Using curve-fitting techniques in table 4-5 for all 6 groups, opposing circulating flow versus capacity or effective capacity curve was created. The created curves are shown below in figure 4-5. The curves show >= 0.75 R- mean square (coefficient of determination) for all linear relationships which is acceptable. Figure 4-5 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.

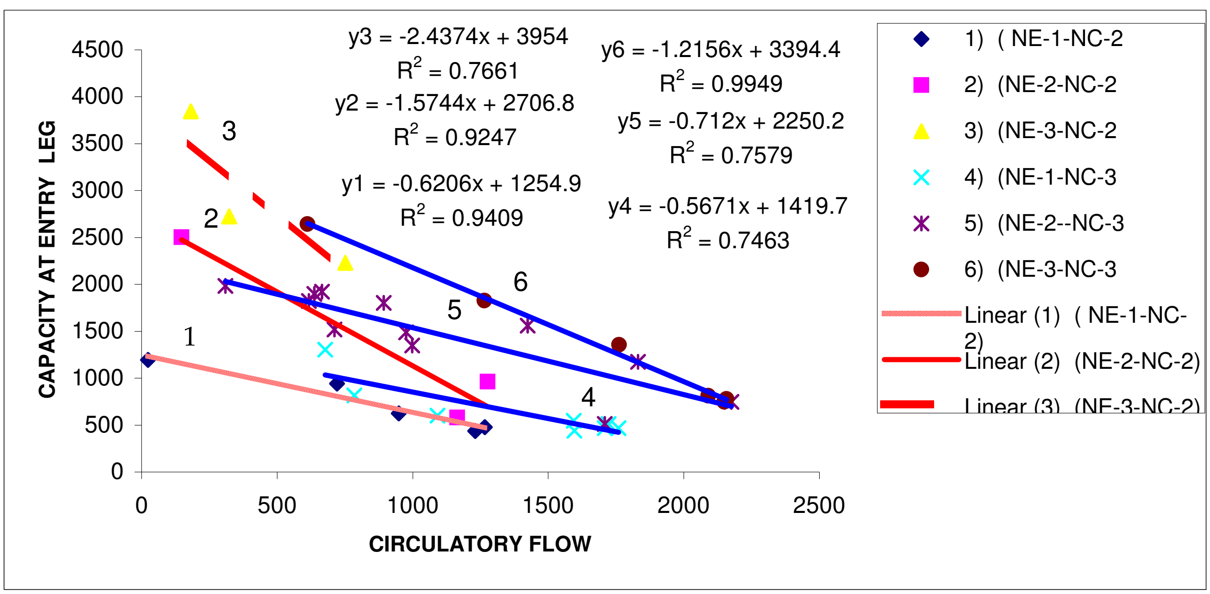

Figure 4-5 Circulatory Flow Vs Capacity At Leg For Different Value Of Number Entry And Circulatory Lanes

Observing figure 4-5 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 4-5 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 4-2 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 4-5 or charts.

Table 4-5 Summery of the condition of the roundabouts using the figure 4-5 or chart

Roundabout	Leg no.	Problem
Gergi-Imperial	1	Entry lane number not adequate
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
4-Killo	4	Entry lane number not adequate
Minilik	1	There is high traffic even if the circulatory lane number is 3 which means that it cannot handle the traffic
Minilik	2	There is high traffic even if the circulatory lane number is 3 which means that it cannot handle the traffic
Minilik	3	Entry lane number not adequate
Mexico	1	There is high traffic even if the circulatory lane number is 3 which means 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 means 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 means 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 means that it cannot handle the traffic but has narrow circulatory road width.

5. Conclusions and Recommendations

5.1 Conclusions

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 carryout the capacity analysis with some geometric elements using aaSIDRA.

High traffic entry flows at Gorgis-Woizron, Minilik 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, Minilik 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.

After additional study or peak hour data collection for the roundabouts that have high and unbalanced traffic flow, their replacement with other junction type is recommended. The roundabouts, which are located at the ring road, are not providing the intended services since this device connects high-speed primary road and access road. Therefore, replacement of these roundabouts by other junction type is recommended after careful study.

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 researchs only insight on the theme 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 intersections. 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

1- Gurgi Imperial

Afternoon 5:00-6:00	
Leg	number of pedestrians
1	191
2	753
3	278
Total	**1222**

2- ADWA

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

Afternoon 5:00-6:00	
Leg	number of pedestrians
1	125
2	285
3	75
Total	**485**

3-Medhahnialem (BOLE)

Morning from 8:00-9:00	
Leg	number of pedestrians
1	400
2	495
3	1930
4	837
Total	**3662**

Afternoon 5:00-6:00	
Leg	number of pedestrians
1	401
2	520
3	1475
4	745
Total	**3141**

6-killo

Morning from 8:00-9:00	
Leg	number of pedestrians
1	1795
2	1110
3	615
4	765
5	1210
Total	**5495**

Afternoon 5:00-6:00	
Leg	number of pedestrians
1	2905
2	1150
3	1455
4	835
5	2135
Total	**8480**

4-killo

Morning from 8:00-9:00	
Leg	number of pedestrians
1	675
2	1995
3	485
4	2950
Total	**6105**

Afternoon 5:00-6:00	
Leg	number of pedestrians
1	1155
2	2480
3	1240
4	4265
Total	**9140**

Gorgis

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

Afternoon 5:00-6:00	
Leg	number of pedestrians
1	1255
2	2079
3	2210
4	1396
Total	**6940**

5- Piassa Degol

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

Afternoon 5:00-6:00	
Leg	number of pedestrians
1	1483
2	1405
3	2270
4	1330
Total	**6488**

8- Tewodros square

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

Afternoon 5:00-6:00	
Leg	number of pedestrians
1	285
2	625
3	440
4	1483
5	520
Total	**3353**

9- Minilk

Morning from 8:00-9:00	
Leg	number of pedestrians
1	2355
2	4000
3	4113
4	1940
5	5725
Total	**18133**

Afternoon 5:00-6:00	
Leg	number of pedestrians
1	1100
2	1590
3	2128
4	1350
5	5120
Total	**11288**

10- Mexico

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

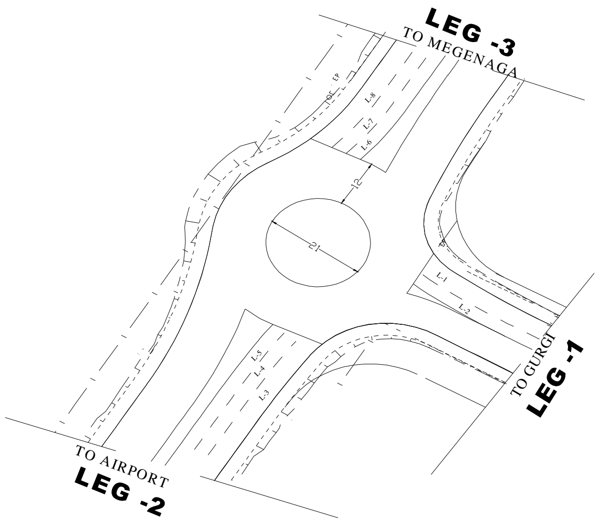
Afternoon 5:00-6:00	
Leg	number of pedestrians
1	3970
2	2695
3	3631
4	1240
5	2198
6	5925
Total	**19659**

MASURED CRITICAL GAP AND FOLLOW UP HEADWAY

GERGI-IMPERIAL Roundabout

	Critical Gap left		follow up-left		Critical Gap right		follow up-right
1	3.48	1	2.7	1	3.74	1	2.61
2	3.75	2	3	2	2.97	2	2.35
3	4	3	2.3	3	1.94	3	2.97
4	4	4	3.1	4	2.71	4	1.68
5	4.26	5	2.8	5	3.74	5	2.71
6	5.81	6	3.3	6	2.19	6	1.68
7	3.75	7	2.97	7	3.75	7	2.51
8	4	8	5.55	8	2.97	8	2.97
9	5.29	9	2.7	9	2.71	9	1.42
10	6.06	10	2.3	10	3.22	10	1.87
11	3.74	11	2.8	11	3.22	11	2.38
12	3.22	12	2.6	12	2.19	12	1.94
13	4.78	13	2.5	13	4	13	1.68
14	4	14	2.9	14	2.45	14	1.94
15	4.42	15	3.75	15	2.19	15	2.45
16	4	16	2.6	16	2.45	16	1.94
17	4	17	2.97	17	2.19	17	2.71
18	4.26	18	3.8	18	2.45	18	2.45
19	4.78	19	2.8	19	3.45	19	1.94
20	4.56		57.44	20	2.71		42.2
	86.16		**3.02**		57.24		**2.22**
Average	**4.308**				**2.862**		

APPENDIX -B
(GEOMETRIC DATA AND
aaSIDRA & Acklick's Base ANALYSIS)



GERGI - IMPERIAL BOMBARLY ROUNDABOUT

1- Number of approaches or legs - 3
2- Number of circulating lane - 2
3- Inscribed circle diameter - 44m
4- Central island diameter -21m
5- Truck apron width - 0

	Leg1	**Leg2**	**Leg3**	**Leg4**	**Leg5**	**Leg6**
Number of entry lanes	**2**	**3**	**3**			
Average entry width	**3.8m**	**3.7m**	**3.8m**			

aaSIDRA output

```
GERGI-IMPERIAL BOMBARLY ROUNDABOUT
 3-LEG OR APPROACH
 Intersection ID:  RO-1    Roundabout

 Table R.0 - ROUNDABOUT BASIC PARAMETERS
 -------------------------------------------------------------------------------
                                            Circulating/Exiting Stream
  Cent  Circ  Insc  No.of No.of Av.Ent -----------------------------------------
 Island Width Diam. Circ. Entry Lane    Flow  %HV  Adjust. %Exit  Cap.    O-D
  Diam                  Lanes Lanes Width  (veh/       Flow   Incl. Constr. Factor
   (m)   (m)   (m)                  (m)     h)        (pcu/h)       Effect
 -------------------------------------------------------------------------------
 South:  South (BOLE) LEG-2
   21    11    43     2     3    3.70    323   0.0     323     0      N    0.937
 -------------------------------------------------------------------------------
 East:  East(GERGI) LEG-1
   21    11    43     2     2    3.80   1276   0.0    1276     0      N    0.750
 -------------------------------------------------------------------------------
 North:  North (MEGENAGA)-3
   21    11    43     2     3    3.80    752   0.0     752     0      N    0.818
 -------------------------------------------------------------------------------
```

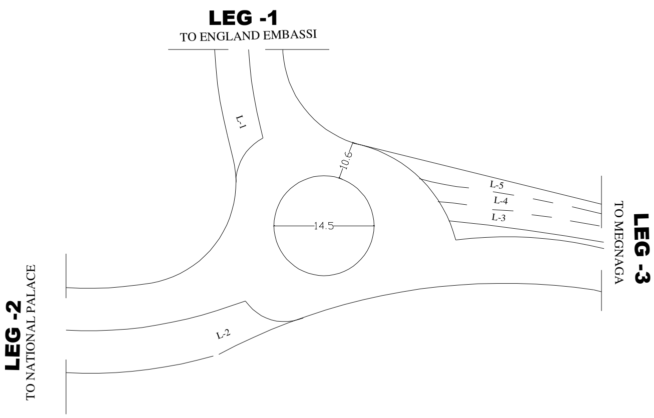
GERGI-IMPERIAL BOMBARLY ROUNDABOUT
3-LEG OR APPROACH
Intersection ID: RO-1 Roundabout

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 (BOLE) LEG-2										
Thru	1	Subdominant	323	23.5	72.7	1.75	0.290	4.23	27.6	2.53
	2	Dominant	323	23.5	72.7	1.75	0.290	3.93	25.6	2.35
Right	3	Subdominant	323	23.5	72.7	1.75	0.290	4.75	30.9	2.84
East: East(GERGI) LEG-1										
Left	1	Subdominant	1276	30.0	23.5	1.04	0.560	3.70	30.8	2.60
	2	Dominant	1276	30.0	23.5	1.04	0.560	3.56	29.6	2.49
Right	2	Dominant	1276	30.0	23.5	1.04	0.560	3.56	29.6	2.49
North: North (MEGENAGA)-3										
Left	1	Subdominant	752	23.5	31.2	1.14	0.406	3.77	24.6	2.48
	2	Subdominant	752	23.5	31.2	1.14	0.406	3.77	24.6	2.48
Thru	2	Subdominant	752	23.5	31.2	1.14	0.406	3.77	24.6	2.48
	3	Dominant	752	23.5	31.2	1.14	0.406	3.41	22.2	2.24

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 (BOLE) LEG-2								
2	T	1276	2137	0.597	2.5	A	6.3	44
3	R	350	884	0.396	2.7	A	3.1	22
		1626		0.597		A	6.3	44
East: East(GERGI) LEG-1								
10	L	752	763	0.986*	59.4	E	23.1	162
6	R	167	170	0.982	55.5	E	23.1	162
		919		0.986		E	23.1	162
North: North (MEGENAGA)-3								
11	L	323	731	0.442	6.4	A	3.3	23
8	T	664	1504	0.441	3.3	A	3.4	24
		987		0.442		A	3.4	24
ALL VEHICLES:		3532		0.986		E	23.1	162



ADWA ROUNDABOUT

1- Number of approaches or legs - 3
2- Number of circulating lane - 2
3- Inscribed circle diameter - 35.7m
4- Central island diameter -14.5m
5- Truck apron width - 0

	Leg1	**Leg2**	**Leg3**	**Leg4**	**Leg5**	**Leg6**
Number of entry lanes	**1**	**1**	**3**			
Average entry width	**4.5m**	**4.5m**	**3.0m**			

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```
ADWA-ABOARAY ROUNDABOUT
 3-LEGS OR APPROACH
 Intersection ID:  RO-2        Roundabout


 Table R.0 - ROUNDABOUT BASIC PARAMETERS
 ----------------------------------------------------------------------------
                                           Circulating/Exiting Stream
  Cent  Circ  Insc  No.of No.of Av.Ent ---------------------------------------
 Island Width Diam. Circ. Entry Lane    Flow  %HV  Adjust. %Exit  Cap.    O-D
  Diam              Lanes Lanes width  (veh/        Flow   Incl.  Constr. Factor
   (m)   (m)   (m)               (m)     h)        (pcu/h)        Effect
 ----------------------------------------------------------------------------
 East:  East(MEGNAGA) LEG-3
   15    11    37     2     3    3.00     47   0.0     47     0      N    0.998
 ----------------------------------------------------------------------------
 NorthWest:  NW (ENGLAND EMB.) LEG-1
   15    11    37     2     1    4.50   1231   0.0   1231     0      N    0.912
 ----------------------------------------------------------------------------
 SouthWest:  SW (NATIONAL PAL.) LEG-2
   15    11    37     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

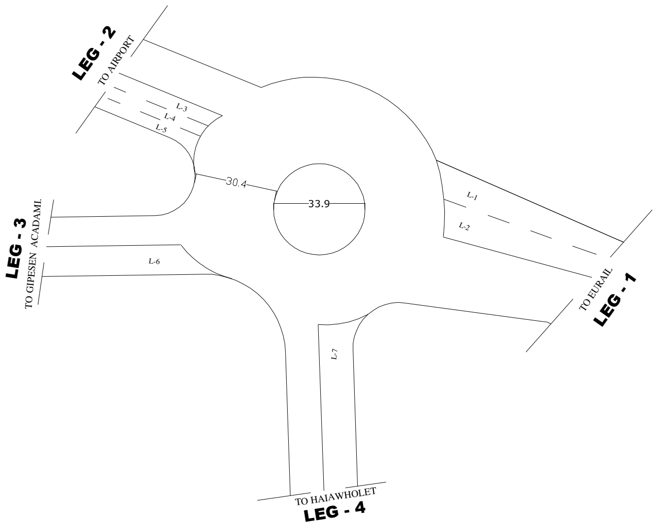
Table S.6 - INTERSECTION PERFORMANCE

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)	Longest Queue 95% Back (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



BOLE MEDAHINIALEM ROUNDABOUT

1- Number of approaches or legs - 4
2- Number of circulating lane - 3
3- Inscribed circle diameter - 66m
4- Central island diameter -36m
5- Truck apron width - 0

	Leg1	Leg2	Leg3	Leg4	Leg5	Leg6
Number of entry lanes	**2**	**3**	**1**	**1**		
Average entry width	**3.3m**	**3.3m**	**4.3m**	**6m**		

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```
BOLE MEDAHINIALM ROUNDABOUT
 4-LEGS OR Approaches
 Intersection ID:  RO-3    Roundabout

Table R.0 - ROUNDABOUT BASIC PARAMETERS
-----------------------------------------------------------------------------
                                              Circulating/Exiting Stream
 Cent  Circ  Insc  No.of No.of Av.Ent ---------------------------------------
Island Width Diam. Circ. Entry Lane    Flow  %HV  Adjust. %Exit  Cap.   O-D
 Diam              Lanes Lanes Width  (veh/        Flow   Incl. Constr. Factor
  (m)   (m)   (m)               (m)     h)        (pcu/h)       Effect
-----------------------------------------------------------------------------
South:  South(EURAIL)LEG-1
  36    15    66      3     2    3.30    309   0.0    309     0     N    0.949
-----------------------------------------------------------------------------
North:  North (AIRPORT)LEG-2
  36    15    66      3     3    3.30    612   0.0    612     0     N    0.886
-----------------------------------------------------------------------------
NorthWest:  NW (MOYENCO) LEG-3
  36    15    66      3     1    4.30   1596   0.0   1596     0     N    0.806
-----------------------------------------------------------------------------
West:  West (HAYAWHOLET)LEG-4
  36    15    66      3     2    3.00    677   0.0    677     0     N    0.902
-----------------------------------------------------------------------------
```

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(EURAIL)LEG-1										
Left	1	Subdominant	309	28.1	91.0	2.00	0.313	4.25	33.2	2.78
Thru	1	Subdominant	309	28.1	91.0	2.00	0.313	4.25	33.2	2.78
	2	Dominant	309	28.1	91.0	2.00	0.313	3.99	31.1	2.61
North: North (AIRPORT)LEG-2										
Thru	1	Subdominant	612	28.1	46.0	1.03	0.319	3.69	28.8	2.55
	2	Subdominant	612	28.1	46.0	1.03	0.319	3.69	28.8	2.55
Right	3	Dominant	612	28.1	46.0	1.03	0.319	3.11	24.3	2.15
NorthWest: NW (MOYENCO) LEG-3										
Left	1	Dominant	1596	29.4	18.4	1.25	0.732	2.82	23.0	2.56
Thru	1	Dominant	1596	29.4	18.4	1.25	0.732	2.82	23.0	2.56
Right	1	Dominant	1596	29.4	18.4	1.25	0.732	2.82	23.0	2.56
West: West (HAYAWHOLET)LEG-4										
Left	1	Subdominant	677	30.0	44.3	1.07	0.356	4.43	36.9	2.90
Right	2	Dominant	677	30.0	44.3	1.07	0.356	3.87	32.3	2.53

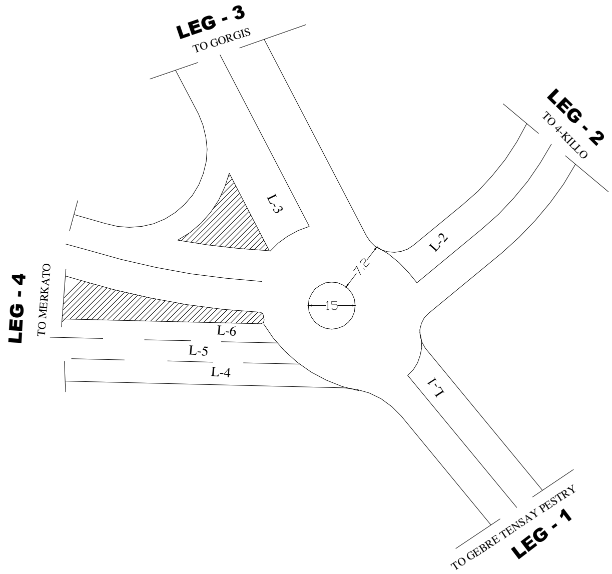
Table S.6 - INTERSECTION PERFORMANCE

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(EURAIL)LEG-1									
1425	0.718	1.81	2.72	4.6	0.78	0.77	65	33.14	27.3
North: North (AIRPORT)LEG-2									
1047	0.396	0.59	0.89	2.0	0.63	0.37	19	19.10	28.0
NorthWest: NW (MOYENCO) LEG-3									
66	0.148	0.11	0.17	6.1	0.73	0.73	6	1.51	26.6
West: West (HAYAWHOLET)LEG-4									
791	0.605	1.12	1.68	5.1	0.74	0.86	37	18.23	27.1
ALL VEHICLES:									
3329	0.718	3.64	5.45	3.9	0.72	0.66	65	71.97	27.5
INTERSECTION (persons):									
4994	0.718		5.45	3.9	0.72	0.66		71.97	27.5

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)
South: South(EURAIL)LEG-1								
1	L	550	766	0.718*	5.4	B	9.3	65
2	T	875	1219	0.718*	4.1	B	9.4	65
		1425		0.718		B	9.4	65
North: North (AIRPORT)LEG-2								
8	T	631	1674	0.377	2.3	A	2.4	17
9	R	416	1051	0.396	1.7	A	2.7	19
		1047		0.396		A	2.7	19
NorthWest: NW (MOYENCO) LEG-3								
27	LTR	66	446	0.148	6.1	A	0.8	6
		66		0.148		A	0.8	6
West: West (HAYAWHOLET)LEG-4								
10	LR	791	1308	0.605	5.1	B	5.3	37
		791		0.605		B	5.3	37
ALL VEHICLES:		3329		0.718		B	9.4	65



PIASSA DEGOL ROUNDABOUT

1- Number of approaches or legs - 4
2- Number of circulating lane - 2
3- Inscribed circle diameter - 29.1m
4- Central island diameter -14.7m
5- Truck apron width - 0

	Leg1	Leg2	Leg3	Leg4	Leg5	Leg6
Number of entry lanes	**1**	**1**	**1**	**3**		
Average entry width	**5.0m**	**6.0m**	**6.0m**	**4m**		

```
PIASSA DEGOL ROUNDABOUT
 4-LEG OR APPROACH
 Intersection ID:  RO-5    Roundabout
Table R.0 - ROUNDABOUT BASIC PARAMETERS
 ------------------------------------------------------------------------------
                                                          Circulating/Exiting Stream
 Cent  Circ  Insc  No.of No.of Av.Ent ---------------------------------------
Island Width Diam. Circ. Entry Lane    Flow  %HV  Adjust. %Exit  Cap.    O-D
 Diam              Lanes Lanes Width  (veh/       Flow    Incl. Constr. Factor
  (m)   (m)   (m)              (m)     h)         (pcu/h)       Effect
 ------------------------------------------------------------------------------
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

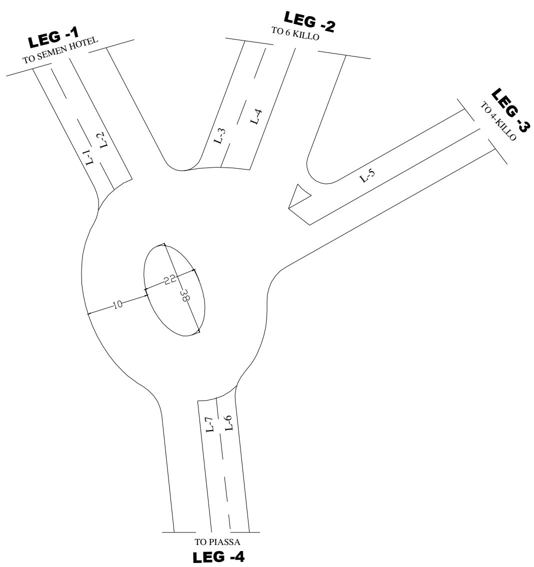
Table S.6 - INTERSECTION PERFORMANCE

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)	Longest Queue 95% Back (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 ROUNDABOUT

1- Number of approaches or legs - 4
2- Number of circulating lane - 2
3- Inscribed circle diameter - 42m
4- Central island diameter -22m
5- Truck apron width - 0

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

GORGIS (WIZRO) ROUNDABOUT
4-LEGS OR APPROACH
Intersection ID: RO-6 Roundabout

```
Table R.0 - ROUNDABOUT BASIC PARAMETERS
------------------------------------------------------------------------------
                                           Circulating/Exiting Stream
 Cent  Circ  Insc  No.of No.of Av.Ent ----------------------------------------
Island Width Diam. Circ. Entry Lane    Flow  %HV  Adjust. %Exit  Cap.    O-D
 Diam              Lanes Lanes Width  (veh/        Flow   Incl. Constr. Factor
  (m)   (m)   (m)              (m)      h)        (pcu/h)       Effect
------------------------------------------------------------------------------
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

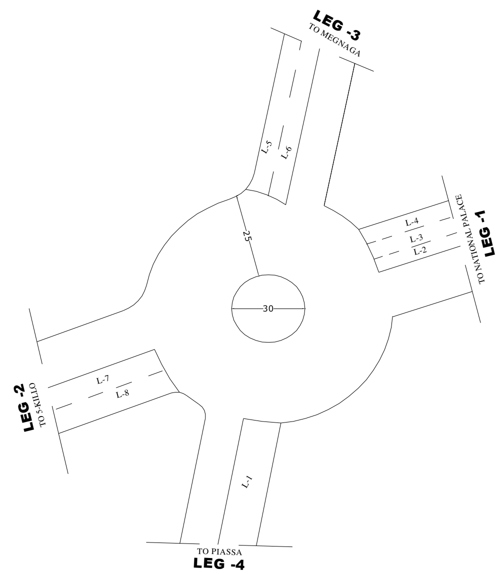
Total Flow (veh/h)	Deg. Satn x	Total Delay (veh-h/h)	Total Delay (pers-h/h)	Aver. Delay (sec)	Prop. Queued	Eff. Stop Rate	Longest Queue (m)	Perf. Index	Aver. Speed (km/h)
South: South (PIASSA)LEG-4									
4013	1.603	1213.61	1820.41	1088.7	1.00	21.92	7332	2546.41	1.3
East: East (4-KILLO)LEG-3									
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,
```



4-KILLO ROUNDABOUT

1- Number of approaches or legs - 4
2- Number of circulating lane - 3
3- Inscribed circle diameter - 80m
4- Central island diameter -20m
5- Truck apron width – 4.9

	Leg1	**Leg2**	**Leg3**	**Leg4**	**Leg5**	**Leg6**
Number of entry lanes	**4**	**2**	**2**	**1**		
Average entry width	**3.10m**	**3.65m**	**3.8m**	**3.15m**		

```
4-killo roundabouts
 4-legs or approaches
 Intersection ID:  RO-4       Roundabout

 Table R.0 - ROUNDABOUT BASIC PARAMETERS
 ------------------------------------------------------------------------------
                                             Circulating/Exiting Stream
  Cent  Circ  Insc  No.of No.of Av.Ent ---------------------------------------
 Island Width Diam. Circ. Entry Lane    Flow  %HV  Adjust. %Exit  Cap.    O-D
  Diam               Lanes Lanes Width  (veh/       Flow   Incl. Constr. Factor
  (m)    (m)   (m)                (m)    h)        (pcu/h)        Effect
 ------------------------------------------------------------------------------
 South: nouth(NATIONAL P.)LEG-1
   30    20    70     3     4    3.10    610   0.0    610     0      N    0.857
 ------------------------------------------------------------------------------
 East: East(MEGENAGA)LEG-3
   30    20    70     3     2    3.80   1831   0.0   1831     0      N    0.645
 ------------------------------------------------------------------------------
 North:  North (5-KILLO) LEG-2
   30    20    70     3     2    3.65    893   0.0    893     0      N    0.828
 ------------------------------------------------------------------------------
 West:  West (PIASSA) 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(NATIONAL P.)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(MEGENAGA)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 (5-KILLO) 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 (PIASSA) 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

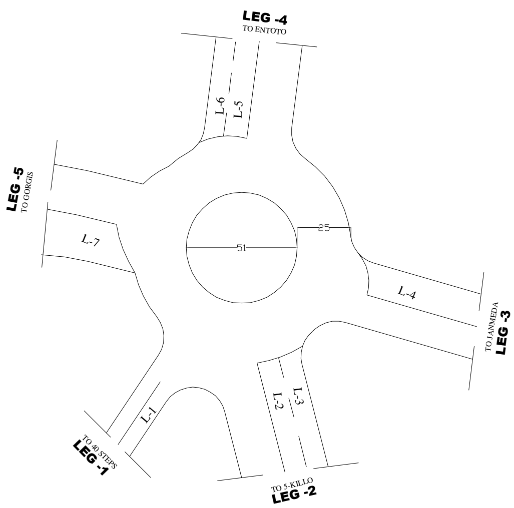
Table S.6 - INTERSECTION PERFORMANCE

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(NATIONAL P.)LEG-1									
1922	0.396	1.30	1.95	2.4	0.78	0.43	32	36.76	27.5
East: East(MEGENAGA)LEG-3									
814	0.694	1.77	2.66	7.8	0.90	1.11	43	21.42	25.8
North: North (5-KILLO) LEG-2									
734	0.407	0.56	0.83	2.7	0.71	0.50	21	14.24	27.7
West: West (PIASSA) 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)	(m)
South: nouth(NATIONAL P.)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(MEGENAGA)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 (5-KILLO) 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 (PIASSA) 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,
     M, 16 Jan 2007
```



6-KILLO ROUNDABOUT

1- Number of approaches or legs - 5
2- Number of circulating lane - 3
3- Inscribed circle diameter - 100.6m
4- Central island diameter -40m
5- Truck apron width – 5.3

	Leg1	**Leg2**	**Leg3**	**Leg4**	**Leg5**	**Leg6**
Number of entry lanes	**1**	**2**	**1**	**2**	**2**	
Average entry width	**3.0m**	**3.5m**	**6m**	**4m**	**4m**	

```
6-KILLO (ARBEGOCH) ROUNDABOUT
 5-LEGS OR APPROACHS
 Intersection ID:  RO-7       Roundabout
Table R.0 - ROUNDABOUT BASIC PARAMETERS
 -------------------------------------------------------------------------------
                                        Circulating/Exiting Stream
  Cent  Circ  Insc  No.of No.of Av.Ent ----------------------------------------
 Island Width Diam. Circ. Entry Lane    Flow  %HV  Adjust. %Exit  Cap.    O-D
  Diam              Lanes Lanes Width  (veh/        Flow   Incl. Constr. Factor
   (m)   (m)   (m)               (m)     h)        (pcu/h)        Effect
 -------------------------------------------------------------------------------
 South: South (5-KILLO)LEG-2
   51    20    91     3     2    3.50    617   0.0    617     0      N    0.957
 -------------------------------------------------------------------------------
 East:  East (JANMEDA) LEG-3
   51    20    91     3     2    3.00    998   0.0    998     0      N    0.858
 -------------------------------------------------------------------------------
 North:  North (ENTOTO) LEG-4
   51    20    91     3     2    4.00    712   0.0    712     0      N    0.902
 -------------------------------------------------------------------------------
 West:  West (GORGIS) LEG-5
   51    20    91     3     2    4.00    637   0.0    637     0      N    0.921
 -------------------------------------------------------------------------------
 SouthWest:  S.West (40 STEPS) LEG-1
   51    20    91     3     1    3.00   1091   0.0   1091     0      N    0.912
 -------------------------------------------------------------------------------
```

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 (5-KILLO)LEG-2										
Left	1	Subdominant	617	30.0	48.6	1.62	0.459	3.66	30.5	2.66
Thru	1	Subdominant	617	30.0	48.6	1.62	0.459	3.66	30.5	2.66
	2	Dominant	617	30.0	48.6	1.62	0.459	3.26	27.1	2.37
Right	2	Dominant	617	30.0	48.6	1.62	0.459	3.26	27.1	2.37
East: East (JANMEDA) LEG-3										
Left	1	Subdominant	998	30.0	30.1	1.24	0.536	3.78	31.5	2.59
Thru	1	Subdominant	998	30.0	30.1	1.24	0.536	3.78	31.5	2.59
	2	Dominant	998	30.0	30.1	1.24	0.536	3.23	26.9	2.21
Right	2	Dominant	998	30.0	30.1	1.24	0.536	3.23	26.9	2.21
North: North (ENTOTO) LEG-4										
Left	1	Subdominant	712	30.0	42.1	1.34	0.442	3.08	25.6	2.61
Thru	1	Subdominant	712	30.0	42.1	1.34	0.442	3.50	29.2	2.97U
	2	Dominant	712	30.0	42.1	1.34	0.442	3.50	29.2	2.97U
Right	2	Dominant	712	30.0	42.1	1.34	0.442	2.75	22.9	2.33
West: West (GORGIS) LEG-5										
Left	1	Subdominant	637	30.0	47.1	1.29	0.394	3.18	26.5	2.66
Thru	1	Subdominant	637	30.0	47.1	1.29	0.394	3.18	26.5	2.66
	2	Dominant	637	30.0	47.1	1.29	0.394	2.83	23.6	2.36
Right	2	Dominant	637	30.0	47.1	1.29	0.394	2.83	23.6	2.36
SouthWest: S.West (40 STEPS) LEG-1										
Left	1	Dominant	1091	30.0	27.5	1.19	0.554	3.73	31.1	2.58
Thru	1	Dominant	1091	30.0	27.5	1.19	0.554	3.73	31.1	2.58
Right	1	Dominant	1091	30.0	27.5	1.19	0.554	3.73	31.1	2.58

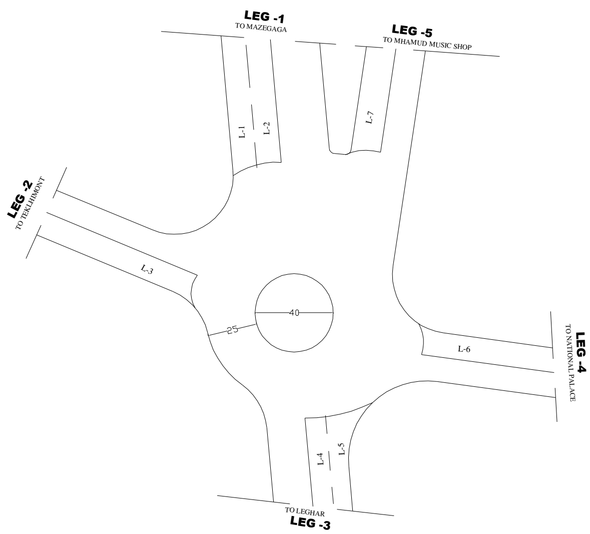
Table S.6 - INTERSECTION PERFORMANCE

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 (5-KILLO)LEG-2									
810	0.444	0.69	1.04	3.1	0.63	0.59	22	18.83	28.4
East: East (JANMEDA) LEG-3									
563	0.417	0.74	1.11	4.7	0.76	0.81	21	14.53	27.8
North: North (ENTOTO) LEG-4									
609	0.400	0.48	0.72	2.8	0.61	0.54	16	13.94	28.4
West: West (GORGIS) LEG-5									
469	0.247	0.21	0.32	1.6	0.50	0.30	9	9.60	28.7
SouthWest: S.West (40 STEPS) LEG-1									
198	0.328	0.28	0.42	5.1	0.71	0.73	13	4.99	27.7
ALL VEHICLES:									
2649	0.444	2.40	3.60	3.3	0.64	0.58	22	61.88	28.3
INTERSECTION (persons):									
3974	0.444		3.60	3.3	0.64	0.58		61.88	28.3

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 (5-KILLO)LEG-2								
1	L	150	338	0.444*	3.4	A	3.1	21
2	T	632	1423	0.444*	3.0	A	3.1	22
3	R	28	63	0.444*	2.8	A	3.1	22
		810		0.444		A	3.1	22
East: East (JANMEDA) LEG-3								
4	LTR	563	1351	0.417	4.7	A	3.0	21
		563		0.417		A	3.0	21
North: North (ENTOTO) LEG-4								
7	L	103	258	0.399	2.9	A	2.3	16
8	T	414	1036	0.400	2.8	A	2.3	16
9	R	92	230	0.400	2.8	A	2.3	16
		609		0.400		A	2.3	16
West: West (GORGIS) LEG-5								
10	LTR	469	1896	0.247	1.6	A	1.3	9
		469		0.247		A	1.3	9
SouthWest: S.West (40 STEPS) LEG-1								
30	LTR	198	604	0.328	5.1	A	1.9	13
		198		0.328		A	1.9	13
ALL VEHICLES:		2649		0.444		A	3.1	22

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



TEWODROS ROUNDABOUT

1- Number of approaches or legs - 5
2- Number of circulating lane - 3
3- Inscribed circle diameter - 90m
4- Central island diameter -30m
5- Truck apron width – 5m

	Leg1	Leg2	Leg3	Leg4	Leg5	Leg6
Number of entry lanes	**4**	**1**	**2**	**1**	**1**	
Average entry width	**3.0m**	**6.0m**	**4.0m**	**6.0m**	**6.0m**	

TEWODROS ROUNDABOUT
5-LEGS OR APPROACHS
Intersection ID: RO-8 Roundabout

Table R.0 - ROUNDABOUT BASIC PARAMETERS

						Circulating/Exiting Stream					
Cent Island Diam (m)	Circ Width (m)	Insc Diam. (m)	No.of Circ. Lanes	No.of Entry Lanes	Av.Ent Lane Width (m)	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

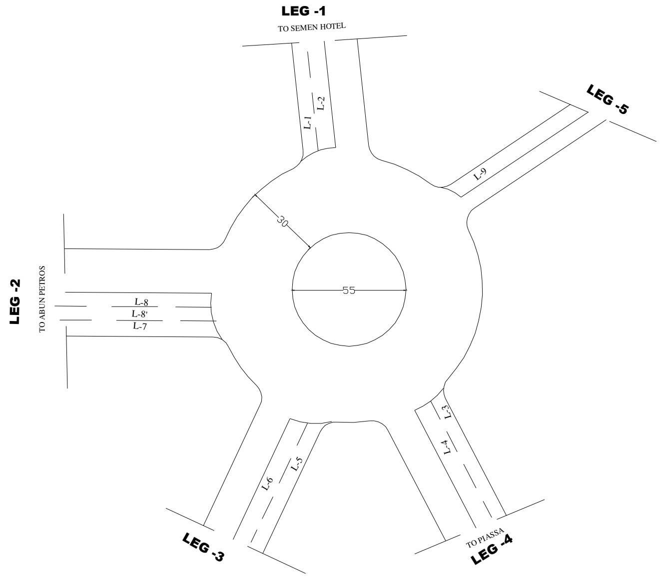
Table S.6 - INTERSECTION PERFORMANCE

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)	(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,



MINILIK ROUNDABOUT

1- Number of approaches or legs - 5
2- Number of circulating lane - 3
3- Inscribed circle diameter - 115.6m
4- Central island diameter -45m
5- Truck apron width – 5m

	Leg1	Leg2	Leg3	Leg4	Leg5	Leg6
Number of entry lanes	**2**	**3**	**2**	**2**	**1**	
Average entry width	**4.5m**	**3.2m**	**4.5m**	**4.5m**	**5.0m**	

MINILIK ROUNDABOUT
5-LEGS OR APPROACHS
Intersection ID: RO-9 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
SouthEast: S.East (PIASSA)LEG-4											
55	20	95	3	2	4.50	976	0.0	976	0	Y	0.837
NorthEast: N.East (LEG-5)											
55	20	95	3	1	5.00	1449	0.0	1449	0	Y	0.836
North: North (SEMEN HOTEL)LEG-1											
55	20	95	3	2	4.50	665	0.0	665	0	Y	0.868
West: West (ABUN PETROS)LEG-2											
55	20	95	3	3	3.20	2091	0.0	2091	0	Y	0.599
SouthWest: S.West (LEG-3)											
55	20	95	3	2	4.50	1708	0.0	1708	0	Y	0.713

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)
SouthEast: S.East (PIASSA)LEG-4										
Left	1	Subdominant	976	30.0	30.7	1.88	0.696	2.54	21.2	2.31
Thru	1	Subdominant	976	30.0	30.7	1.88	0.696	2.54	21.2	2.31
	2	Dominant	976	30.0	30.7	1.88	0.696	2.18	18.2	1.98
Right	2	Dominant	976	30.0	30.7	1.88	0.696	2.18	18.2	1.98
NorthEast: N.East (LEG-5)										
Left	1	Dominant	1449	30.0	20.7	1.68	0.822	2.39	19.9	2.17
Thru	1	Dominant	1449	30.0	20.7	1.68	0.822	2.39	19.9	2.17
Right	1	Dominant	1449	30.0	20.7	1.68	0.822	2.39	19.9	2.17
North: North (SEMEN HOTEL)LEG-1										
Left	1	Subdominant	665	30.0	45.1	2.00	0.563	2.61	21.7	2.37
Thru	1	Subdominant	665	30.0	45.1	2.00	0.563	2.61	21.7	2.37
	2	Dominant	665	30.0	45.1	2.00	0.563	2.29	19.1	2.08
Right	2	Dominant	665	30.0	45.1	2.00	0.563	2.29	19.1	2.08
West: West (ABUN PETROS)LEG-2										
Left	1	Dominant	2091	30.0	14.3	1.29	0.868	2.00*	16.7	1.20
Thru	2	Subdominant	2091	30.0	14.3	1.29	0.868	2.08	17.3	1.58
	3	Subdominant	2091	30.0	14.3	1.29	0.868	2.08	17.3	1.58
Right	3	Subdominant	2091	30.0	14.3	1.29	0.868	2.08	17.3	1.58
SouthWest: S.West (LEG-3)										
Left	1	Dominant	1708	30.0	17.6	1.44	0.827	2.00*	16.7	1.71
Thru	2	Subdominant	1708	30.0	17.6	1.44	0.827	2.40	20.0	2.19
Right	2	Subdominant	1708	30.0	17.6	1.44	0.827	2.40	20.0	2.19

Table S.6 - INTERSECTION PERFORMANCE

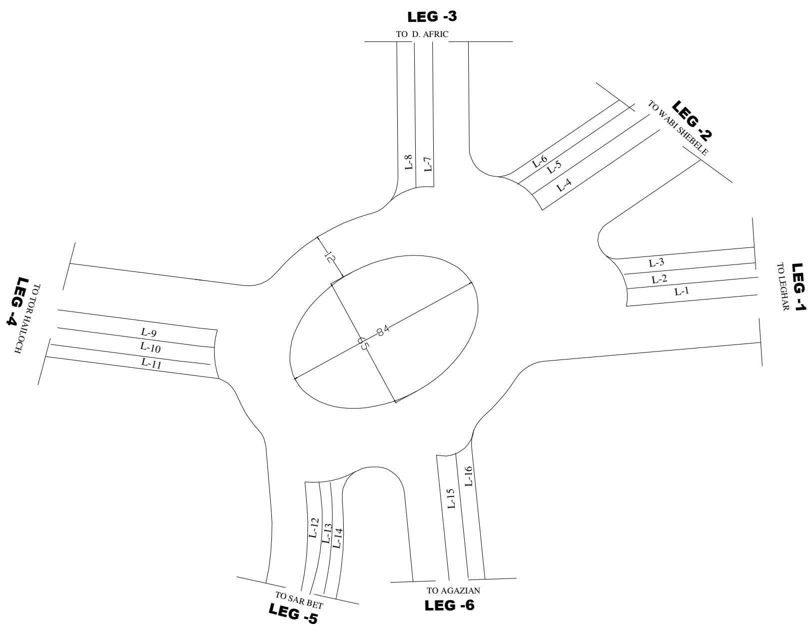
Total Flow (veh/h)	Deg. Satn x	Total Delay (veh-h/h)	Total Delay (pers-h/h)	Aver. Delay (sec)	Prop. Queued	Eff. Stop Rate	Longest Queue (m)	Perf. Index	Aver. Speed (km/h)
SouthEast: S.East (PIASSA)LEG-4									
496	0.333	0.62	0.94	4.5	0.79	0.76	19	12.62	27.9
NorthEast: N.East (LEG-5)									
119	0.252	0.50	0.75	15.2	0.86	0.93	13	3.10	37.9
North: North (SEMEN HOTEL)LEG-1									
2490	1.296	375.49	563.24	542.9	1.00	21.17	2822	1009.93	3.0
West: West (ABUN PETROS)LEG-2									
1325	1.630	244.01	366.02	663.0	1.00	10.91	2497	503.65	2.5
SouthWest: S.West (LEG-3)									
845	1.647	272.08	408.12	1159.2	1.00	22.94	2957	562.93	1.5
ALL VEHICLES:									
5275	1.647	892.72	1339.07	609.2	0.98	16.50	2957	2092.24	2.7
INTERSECTION (persons):									
7913	1.647		1339.07	609.2	0.98	16.50		2092.24	2.7

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)
SouthEast: S.East (PIASSA)LEG-4								
5	L	151	458	0.330	4.9	A	2.4	17
22	T	342	1038	0.329	4.4	A	2.7	19
23	R	3	9	0.333	4.3	A	2.7	19
		496		0.333		A	2.7	19
NorthEast: N.East (LEG-5)								
6	L	1	4	0.250	9.5	A	1.9	13
24	TR	118	469	0.252	15.2	A	1.9	13
		119		0.252		A	1.9	13
North: North (SEMEN HOTEL)LEG-1								
7	L	925	714	1.296	543.5	F	347.1	2430
8	T	1161	896	1.296	542.6	F	403.1	2822
9	R	404	312	1.295	542.4	F	403.1	2822
		2490		1.296		F	403.1	2822
West: West (ABUN PETROS)LEG-2								
10	L	696	427	1.630	1172.6	F	356.7	2497
11	T	566	599	0.945	99.1	D	20.2	142
12	R	63	67	0.940	99.1	D	20.2	142
		1325		1.630		F	356.7	2497
SouthWest: S.West (LEG-3)								
15	L	825	501	1.647*	1187.1	F	422.4	2957
31	T	19	353	0.054	8.8	A	0.4	3
32	R	1	19	0.053	8.8	A	0.4	3
		845		1.647		F	422.4	2957
ALL VEHICLES:		5275		1.647		F	422.4	2957

Level of Service calculations are based on
v/c ratio,
2007



MEXICO ROUNDABOUT

1- Number of approaches or legs - 6
2- Number of circulating lane - 3
3- Inscribed circle diameter - 89m
4- Central island diameter -57m
5- Truck apron width – 4m

	Leg1	Leg2	Leg3	Leg4	Leg5	Leg6
Number of entry lanes	**3**	**3**	**2**	**3**	**3**	**2**
Average entry width	**3.1m**	**3.0m**	**4.5m**	**4.0m**	**3.0m**	**4.5m**

Mexico roundabout
6-legs or approachs
Intersection ID: RO-10 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

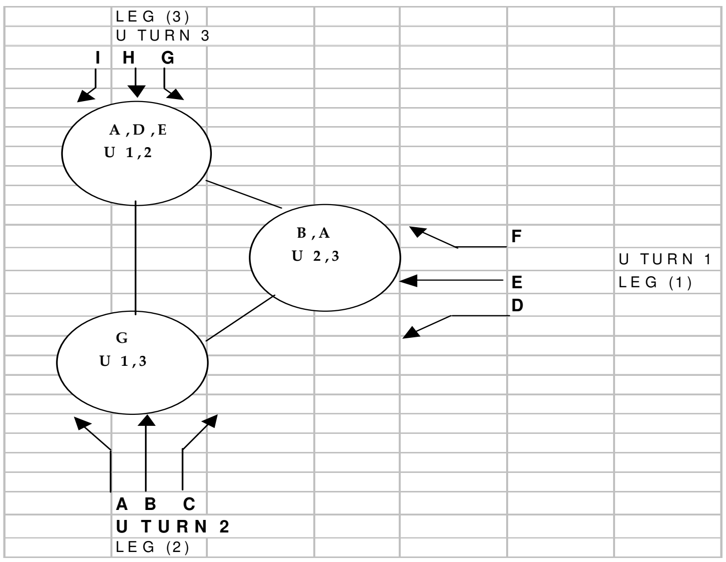
Total Flow (veh/h)	Deg. Satn x	Total Delay (veh-h/h)	Total Delay (pers-h/h)	Aver. Delay (sec)	Prop. Queued	Eff. Stop Rate	Longest Queue (m)	Perf. Index	Aver. Speed (km/h)
South: South (SARBET) LEG-5									
1022	0.560	0.85	1.28	3.0	0.84	0.60	39	24.22	27.9
SouthEast: S.EAST (AGAZIAN)LEG-6									
836	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 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 (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,

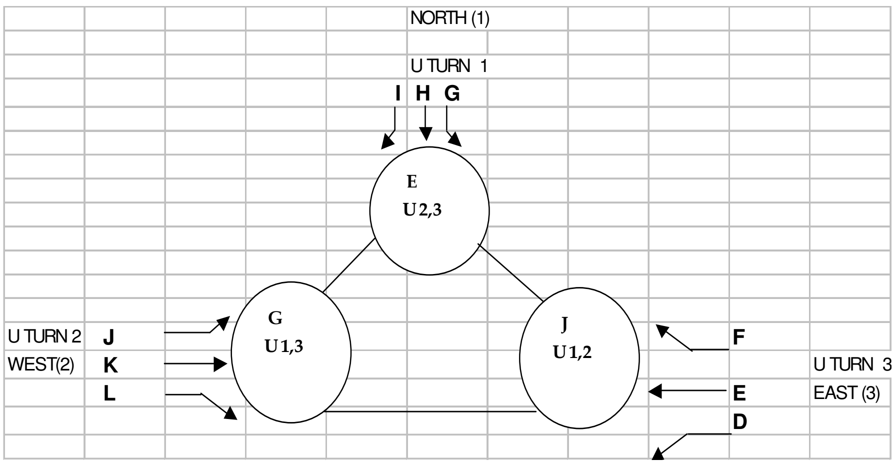
Gergi –Imperial roundabout



Using Acklick's Base Capacity formula

LEG	LANE	DIRECTON	VOLUME	LEG-V	VOL'c	q_{cr}	q_{cl}	Right Lane Ent. Flow	LEFT Lane Ent. Flow	CAPACITY right	CAPACITY left	v/c ratio right	v/c ratio left
	D	LEFT	752										
1	E	THROUGH	0	919	1276	1020.8	1276						
	F	RIGHT	167							811	339	0.59	1.31
	U1	U-TURN	0					477	443				
	A	LEFT	0										
2	B	THROUGH	1276	1625.5	322.5	258	322.5			1329	852	0.41	0.79
	C	RIGHT	349.5										
	U2	U-TURN	0					540	676				
	G	LEFT	322.5										
3	H	THROUGH	664	986.5	752	601.6	752			1066	564	0.25	0.35
	I	RIGHT	0										
	UE	U-TURN	0					269	197				

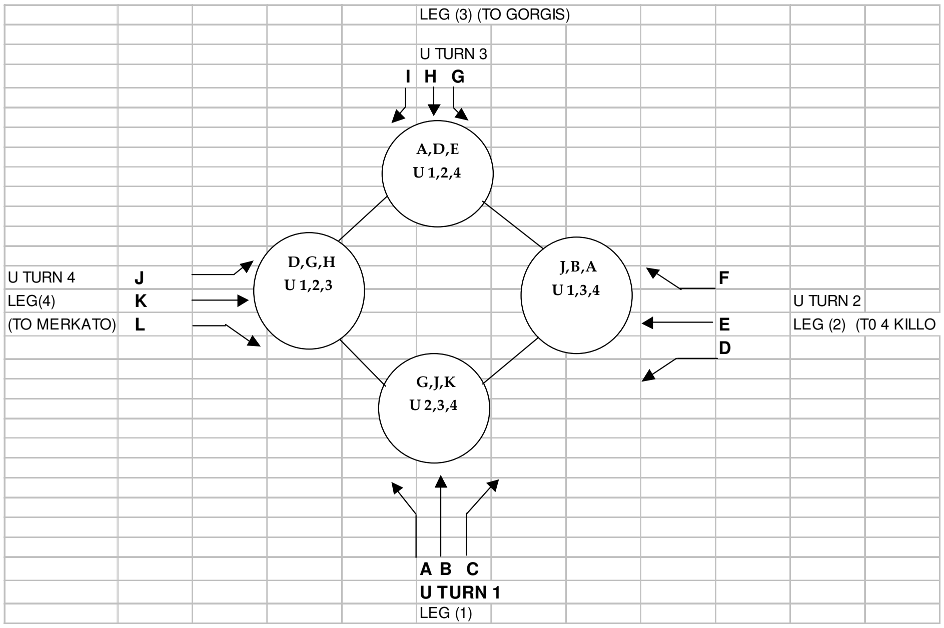
Adwa-Aboare Roundabout



Using Acklick's Base Capacity formula

LEG	LANE	DIRECTON	VOLUME	LEG-V	VOL'c	q_{cr}	q_{cl}	Right Lane Ent. Flow	LEFT Lane Ent. Flow	CAPACITY right	CAPACITY left	v/c ratio right	v/c ratio left
	G	LEFT	21										
1	H	THROUGH	0	149	1221	976.8	1221						
	I	RIGHT	128							464	206	0.32	N/A
	U1	U-TURN	0					149	0				
	J	LEFT	37.5										
2	K	THROUGH	545	582.5	21	16.8	21			1310	1001	0.44	N/A
	L	RIGHT	0										
	U2	U-TURN	0					582.5	0				
	D	LEFT	0										
3	E	THROUGH	1221	1302.5	37.5	30	37.5			1291	979	0.28	0.38
	F	RIGHT	81.5										
	U3	U-TURN	0					362.5	372				
			2034	2034									

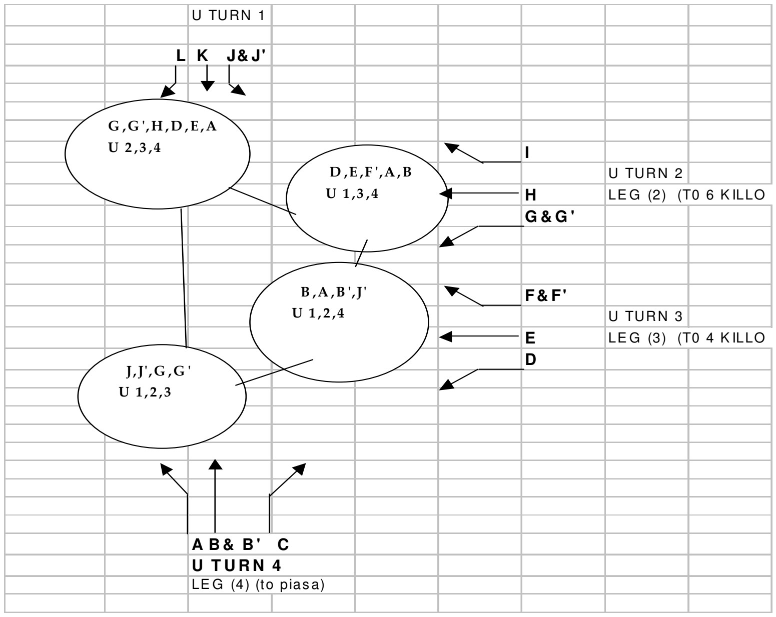
Piazza Degol Roundabout



Using Acklick's Base Capacity formula

LEG	LANE	DIRECTON	VOLUME	LEG-V	VOL'c	q_{cr}	q_{cl}	Right Lane Ent. Flow	LEFT Lane Ent. Flow	CAPACITY right	CAPACITY left	v/c ratio right	v/c ratio left
1	A	LEFT	146										
	B	THROUGH	253	573	1159	927.2	1159						
	C	RIGHT	174							804	356	0.71	0.00
	U1	U-TURN	0					572	0				
2	D	LEFT	0										
	E	THROUGH	822	941	681	544.8	681			1083	604	0.87	0.00
	F	RIGHT	119										
	U2	U-TURN	0					941	0				
3	G	LEFT	75										
	H	THROUGH	0	75	968	774.4	968			910	442	0.08	0.00
	I	RIGHT	0										
	U3	U-TURN	0					74.5	0				
4	J	LEFT	282										
	K	THROUGH	802	1084	75	60	75			1507	1116	0.39	0.16
	L	RIGHT	0										
	U4	U-TURN	0					584	177				
			2673										

Gorgis Roundabout



Using Acklick's Base Capacity formula

LEG	LANE	DIRECTON	VOLUME	LEG-V	VOL'c	q_{cr}	q_{cl}	Right Lane Ent. Flow	LEFT Lane Ent. Flow	CAPACITY right	CAPACITY left	v/c ratio right	v/c ratio left
1	J	LEFT-1	103										
	J'	LEFT-2	34										
	K	THROUGH	659	796	950	760	950						
	L	RIGHT	0							999	477	0.41	0.80
	U1	U-TURN	0					412	384				
2	G	LEFT	639										
	G'	LEFT2	0										
	H	THROUGH	0	687	1982	1585.6	1982			571	173	0.69	1.68
	I	RIGHT	48										
	U2	U-TURN	0					396	291				
3	D	LEFT	311										
	E	THROUGH	0	561	2868	2294.4	2868			344	71	1.63	0.00
	F	RIGHT1	0										
	F'	RIGHT2	250										
	U3	U-TURN	0					560	0				
4	A	LEFT	0										
	B	THROUGH1	1421	4255	776	620.8	776			1095	565	2.91	1.44
	B'	THROUGH2	1413										
	C	RIGHT	1421										
	U4	U-TURN	0					3187	812				
			6299										