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Comparative Study of Operational Performance between Roundabout and Signalized Intersection Using Sidra Software: A Case Study of Addis Ababa City

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Abstract: Traffic signals and roundabouts controls are commonly used in several at-grade junctions in urban areas for maximizing traffic efficiency and safety by separating traffic movements in time. The intersection performance is measured by comparing the parameters like- capacity, degree of saturation, delay, queue length, fuel consumption, operating costs and emission, etc. This research paper provides a comparative study of operational performance between a roundabout and signalized intersection at Gergi-Imperial. The traffic data on all approach of the intersection were collected by video camera during the most congested days of the week. The traffic volume obtained in different classes of a vehicle was converted to uniform vehicle fleet by the passenger car equivalency factor. The geometric data for the selected intersections were measured manually. Data analysis and processing were performed using SIDRA (Signalized and Unsignalized intersection Design and Research Aid) intersection software to compare the traffic flow condition at the intersection. The performance measures such as Average delay, Degree of saturation and Level of service at each intersection were interpreted for comparison. The capacities of the signalized intersection were found to be higher than the capacities of roundabout. Signalized intersection was found to be better than the roundabout in terms of the degree of operational performance.
Keywords: Average delay, Intersection Capacity, SIDRA Software, Level of Service (LOS), roundabout, Signalized Intersection, Degree of Saturation

I. INTRODUCTION

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

A junction always has a common space shared by several traffic streams. The conflicts between the traffic streams are the major sources of traffic accidents. To prevent traffic accidents, the conflicting traffic streams should be separated in time. The roundabout is a junction with a central island where the conflicting traffic streams are separated in time by the priority rules, i.e., the entry vehicles should give way to circulating vehicles. Signalized junction is a junction with traffic lights where the conflicts are separated in time by the traffic lights. In Addis Ababa, most of the intersections are congested, and their capacities are not well identified. Road traffic congestion and excessive delay during peak hours in the morning and afternoon at the intersection in Addis Ababa have increased over the years.

The study area selected for this research was Addis Ababa city which is the capital City of Ethiopia, which is located in the horn of Africa with geographical coordinates of 9°1'48'' North and 38°44'24'' East and with an average elevation of 2355m above sea level. The City has a total area of about 530.14 square kilometers and a population of 2,738,248 according to 2007 census.

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II. OBJECTIVE

A. General Objective

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

B. Specific Objectives

Specific objectives of this study are:

1) To determine the performance of roundabout and 4-Leg signalized intersection.
2) To analyze the average control delay of the roundabout and 4-Leg signalized intersection by SIDRA software.
3) To study the effect of pedestrians and heavy vehicles in the performance of intersections.
4) To evaluate and compare the current capacity of the roundabout and 4-Leg signalized intersection.

III.STATEMENT OF PROBLEM

Traffic congestion is one of the main societal and economic problems in urban areas related to transportation industries, both in developed and developing countries. Prevalently, Ethiopia is one of the countries that are in rapid economic development. This influences the travel pattern of the community from their origin to any destination. Road traffic congestion and excessive delay during peak hours in the morning and afternoon at junction in Addis Ababa have increased over the year. This traffic congestion, long queues and excessive delay during peak hours in the morning and afternoon at junction have major problems in the city. However; little research was available to compare the study of operational performance between roundabout and signalized intersection. This problem will continue and it may more difficult in the future due to the rapid growth of population and vehicle numbers in Addis Ababa. Therefore, it is essential to evaluate and compare study of operational performance between roundabout and signalized intersection.

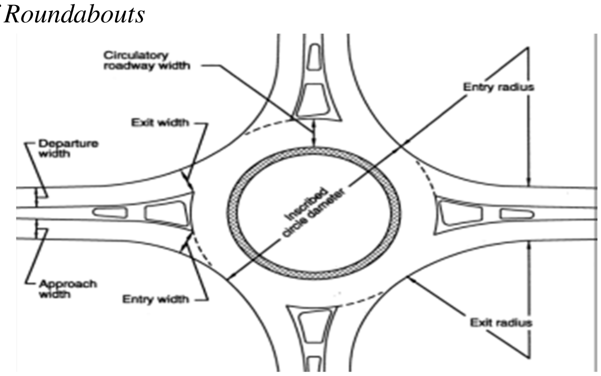
IV.LITERATURE REVIEW

A. Intersection Traffic Control

The intersection is an area shared by two or more roads. This area is designated for the vehicles to turn to different directions to reach their desired destinations. Its main function is to guide vehicles to their respective directions. Traffic intersections are complex locations on any highway. This is because vehicles moving in different direction want to occupy same space at the same time. Also, the pedestrians also seek same space for crossing. Both from accident and capacity perspective, the study of intersection are very important especially in the case of urban scenario. Types of intersection traffic control include: Basic rules of the road, give way control, two-way stop control, and all-way stop control, channelization islands, roundabouts, signalized intersection, Grade separation .

B. Roundabout

1) *General:* A roundabout is a channelized intersection at which all traffic moves anticlockwise around a central traffic island . All traffic-through, as well as turning, enters this one way flow. Although usually circular, the central island of a roundabout can be oval or irregularly shaped. Roundabouts can be appropriate design alternative to both stop controlled and signal-controlled intersections, as they have fewer conflict points than traditional intersections (eight versus 32, respectively) .
2) *Geometric Features of Modern Roundabouts:* Geometric elements of roundabouts play an important part in the efficiency of roundabouts operational performance. The good geometric design will improve not only capacity but also safety, which is a major concern for road design. Basic elements for design consideration of roundabouts are:
3) *Description of Basic Elements of Roundabouts*



Major Geometric Features of Modern Roundabout

a) Inscribed circle diameter inscribed circle diameter is the basic parameter used to define the size of a roundabout. It is measured between the outer edges of the circulatory roadway.
b) Circulatory roadway width the circulatory roadway width defines the road width for vehicle circulation around the central island. It is measured as the width between the outer edge of this road and the central island. It does not include the width of any mountable apron, which is defined to be part of the central island.
c) Approach width the approach width is the width of the roadway used by approaching traffic upstream of any changes in width associated with the roundabout. The approach width is typically no more than half of the total width of the roadway.
d) The departure width is the width of the roadway used by departing traffic downstream of any changes in width associated with the roundabout. The departure width is typically less than or equal to half of the total width of the roadway.
e) Entry width the entry width defines the width of the entry where it meets the inscribed circle. It is measured perpendicularly from the right edge of the entry to the intersection point of the left edge line and the inscribed circle.
f) Exit width the exit width defines the width of the exit where it meets the inscribed circle. It is measured perpendicularly from the right edge of the exit to the intersection point of the left edge line and the inscribed circle.
g) Entry radius the entry radius is the minimum radius of curvature of the outside curb at the entry.
h) Exit radius the exit radius is the minimum radius of curvature of the outside curb at the exit

4) *Roundabout Categories:* For this guide, roundabouts have been categorized according to size and environment to facilitate discussion of specific performance or design issues. There are six basic categories base d on environment, number of lanes, and size:
a) Mini-roundabouts
b) Urban compact roundabouts
c) Urban single-lane roundabouts
d) Urban double-lane roundabouts
e) Rural single-lane roundabouts and Rural double-lane roundabouts

Table : Basic design characteristics for each of the six roundabout categories

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

5) Advantages and Disadvantages

Table : Advantages and Disadvantages of Roundabouts vs. Other Alternatives

Category	Advantages	Disadvantages
Safety	Reduced number of conflict points compared to other non-circular intersections. Left-turn conflicts are removed. Elimination of high angles of conflict and high operational speeds; fewer and less severe accidents. Reduction in conflicting speeds	Crashes may temporarily increase due to improper driver education. During emergencies, signalized intersections can preempt control. Multilane roundabouts present more difficulties for pedestrians with blindness or low vision due to challenges in detecting gaps and determining that
	passing through the intersection. Reduced decision-making at the point of entry. Long splitter islands and other geometric features provide good advanced warning of the intersection. Raised level of consciousness for drivers. Facilitate U-turns that can substitute for more difficult midblock left turns.	vehicles have yielded at crosswalks. May reduce the number of available gaps for midblock unsignalized intersections and driveways
Operations	Traffic yields, nonstop, continuous traffic flow. Higher capacities experienced. Can reduce the number of lanes required between intersections, including bridges between interchange ramp terminals. During off-peak hours, signal timing can create the undue delay at signalized intersections.	Coordinated signal systems can increase the capacity of the network. As queues develop, drivers accept smaller gaps, which may increase crashes. Equal priority for all approaches can reduce the progression for high volume approaches. Cannot provide explicit priority to specific users (e.g., trains, emergency vehicles, transit, pedestrians) unless supplemental traffic control devices are provided.
Cost	No maintenance of signals (heads, loop detectors, controllers). Lower accident rate and severity; reduced accident costs.	Central island landscaping maintenance. Illumination cost. May have significant real estate impacts
Pedestrians & Bicyclists	Splitter islands provide pedestrian refuge and shorter one-directional traffic crossing. Pedestrians only need to consider one the direction of traffic at a time. Low-speed conditions improve bicycle and pedestrian safety. Depending on their skills and level of	Pedestrians, especially children, elderly, and handicapped may experience increased delay and reduced safety in securing acceptable gaps to cross. Pedestrians with vision impairments may have the most trouble establishing safe Opportunities to cross. Longer travel path.
	comfort, bicyclists have the option to take a lane to negotiate through a roundabout.	Bicycle ramps could be confused for pedestrian ramps.
Environmental	Reduced starts and stops; reduced air pollution.	Possible impacts to natural and cultural resources due to potentially greater spatial requirements at the intersection.
OSOW Truck Route (OSOW TR)	Reduction of potential obstacles at intersections (traffic signals, signing, median islands).	The geometric design may be challenging to allow the navigation of OSOW vehicles. Additional right-of-way and paved areas may be needed to accommodate OSOW vehicles.

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

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

1) Empirical models
2) Analytical models

7) *Empirical Models:* Empirical models on field data to develop relationships between geometric design features and performance measures such as capacity and delay. Empirical models are better but require some congested roundabouts for calibration and may have poor transferability to other countries
8) *Analytical Models:* Analytical models are based on the concept of gap acceptance theory. The choice of an analysis approach depends on the calibration data available. The capacity at a roundabout can be estimated using gap acceptance techniques with the basic parameters of a critical gap and follow-up time . The gap is the headway between two consecutive vehicles on the circulating flow; so, the "critical gap" is the minimum headway accepted by a driver in the entering stream. If the gap accepted is larger than minimum, them more than one driver can enter the roundabout; the headway between two consecutive vehicles in the entering flow, which utilizes the same gap, is defined as "follow-up time" .so, the analytical model calculates the roundabout capacity as a function of the critical gap, follow-up time and the circulating flow.

V. RESEARCH METHODOLOGY

To compare the operational performance of Roundabout and Signalized intersections in Addis Ababa, Gergi-Imperial intersection was selected [2].The Gergi-Imperial intersection was functioning as roundabout till 2017. It was converted to Signalized intersection in 2017. This intersection has four legs namely, Megenagna approach, Bola approach, Hayahulet approach, Gerji approach. This junction is the link between ring road and a collector road. Mostly heavy vehicles travel along the ring road. Plan view of the Gergi-Imperial roundabout is shown in Figure 1.

Figure 1: Satellite image of Gergi-Imperial Roundabout

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A. *Traffic Volume Data*

Traffic volume counts data for Gergi-Imperial intersection when it was functional as a roundabout was obtained from the Addis Ababa City Transport Program Management Office. The same intersection was converted to Signalized intersection in 2017 and the Traffic volume counts data was collected by video recording with manual transcription. The traffic volume count was made for 12 hours starting the morning 7:00 AM to the evening 7:00 PM at 15 minutes interval in both the cases. The vehicles were counted in different categories such as- cars, taxi, 4-wheel Drive, minibus taxi, Mid-bus and standard Bus, Medium and Heavy truck vehicles, etc. The vehicle volume count was converted to passenger equivalent unit to conduct an analysis. The passenger equivalent factors used to convert the number of heavy vehicles to passenger car equivalent [3] are given in Table below

Table : Conversion factors for passenger car equivalent (PCE)

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

B. *Geometric Data*

As per the requirement of the SIDRA Intersection Version 5.1, the collected geometric data included- island diameter, circulatory width, number of circulatory lanes, entry lane number and average lane width at entry for roundabout junction, and number of lanes, lane width, configurations of lanes, width of median for signalized junction.

Table 2: Roundabouts Geometry Data

Junction Name	Approach Leg	Entry Lane	Number of Circulatory lane	Island Diameter(m)	Average lane width(m)	Circulatory Road width(m)
Gergi-Imperial Roundabout	Bole	3	2	21	3.7	12
	Megenagna	3	2	21	3.7	12
	Gergi	2	2	21	3.8	12
	Hayahulet	2	2	21	3.8	12

Table 3: Signalized Intersection Geometry Data

Junction Name	Approach name	No. of Entry Lane	No. of Exit Lane	Average Lane Width(m)	Median width(m)
Gergi-Imperial Signalized	Bole	3	3	3.7	0.68
	Megenagna	3	3	3.7	0.68
	Gergi	2	2	3.8	NA
	Hayahulet	3	3	3.5	1.2

C. *Software analysis*

The Australian Road Research Board (ARRB), Transport Research Ltd., developed the SIDRA package as an aid for design and evaluation of intersections such as signalized intersections, roundabouts, two-way stop control, and yield-sign control intersections. The SIDRA Intersection software Version 5.1 was used for analyzing the data. Only four measures of effectiveness given by SIDRA output used to evaluate the performance were: 1. Average Delay, 2. Degree of saturation, 3. adequate capacity, 4. Level of service.

D. Basic Saturation Flow Rate

Saturation flow rate is the flow rate per lane at which vehicles can pass through a signalized intersection. The recommended values of saturation flow rate at intersection range between 1500 to 2000 pc/h/lane (passenger cars/hour/lane) with the corresponding headway of 2.4 and 1.9 seconds . Since, there was no related research done for standard saturation flow rate in Ethiopia, the following equation (1) was used for the estimation of saturation flow rate.

$$SFR = 990 + 288TL + 8.5SL - 26.8G \qquad \text{(Eq. 1)}$$

Where: SFR = Saturation flow rate (pc/h/lane),

TL= Number of through lanes,

SL =Speed limit (kmph),

G = Gradient in percent

VI. RESULT AND DISCUSSION

A. Traffic Volume And Flow Pattern Analysis At Gergi-Imperial Roundabout

Traffic volume distribution at Gergi-Imperial Roundabout on all approaches was plotted as shown in Figure . Megenagna and Bole approaches had a high number of traffic volumes in the morning and evening period but the evening period volume was relatively less than the morning period. Gerji and Hayahulat approach, it has almost uniform traffic volume distribution and low volume of traffic throughout the day.

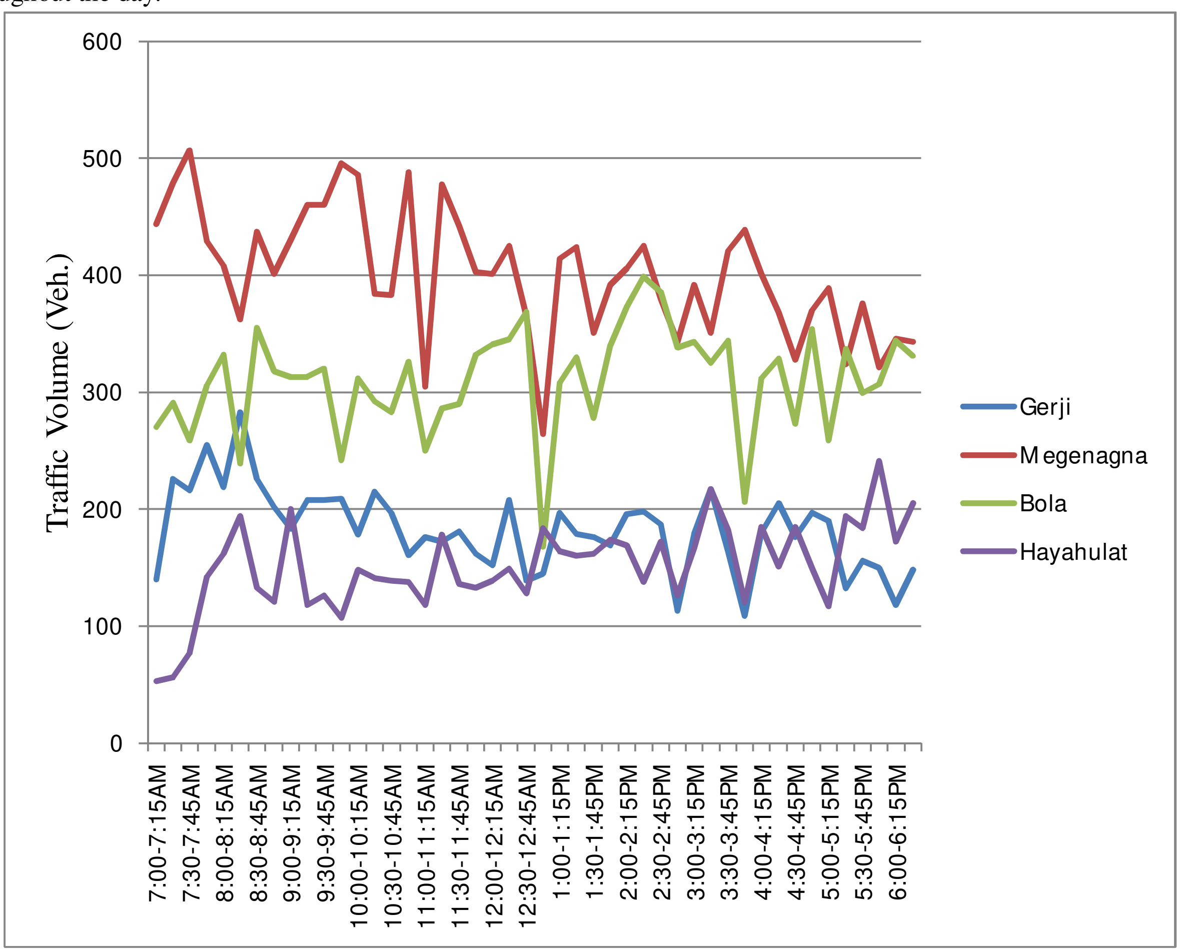

Figure 2: Total traffic volume distribution at Gergi-Imperial Roundabout Intersection

B. Traffic Volume And Flow Pattern Analysis At Gergi-Imperial Signalized Intersection

Figure 3 shows the Traffic volume distribution on all approaches for the same Gergi-Imperial intersection after converting it to the Signalized Intersection. The Megenagna approaches registered highest number of traffic volume in the morning and evening period but the night period volume was relatively less than the morning period. The Bole approach had higher traffic volume during the morning and evening peak period as compared to the Hayahulat and the Gerji approaches but lower than the Megenagna approaches. However, the Hayahulat and the Gerji approaches showed almost uniform traffic volume distribution and much lower volume of traffic throughout the day.

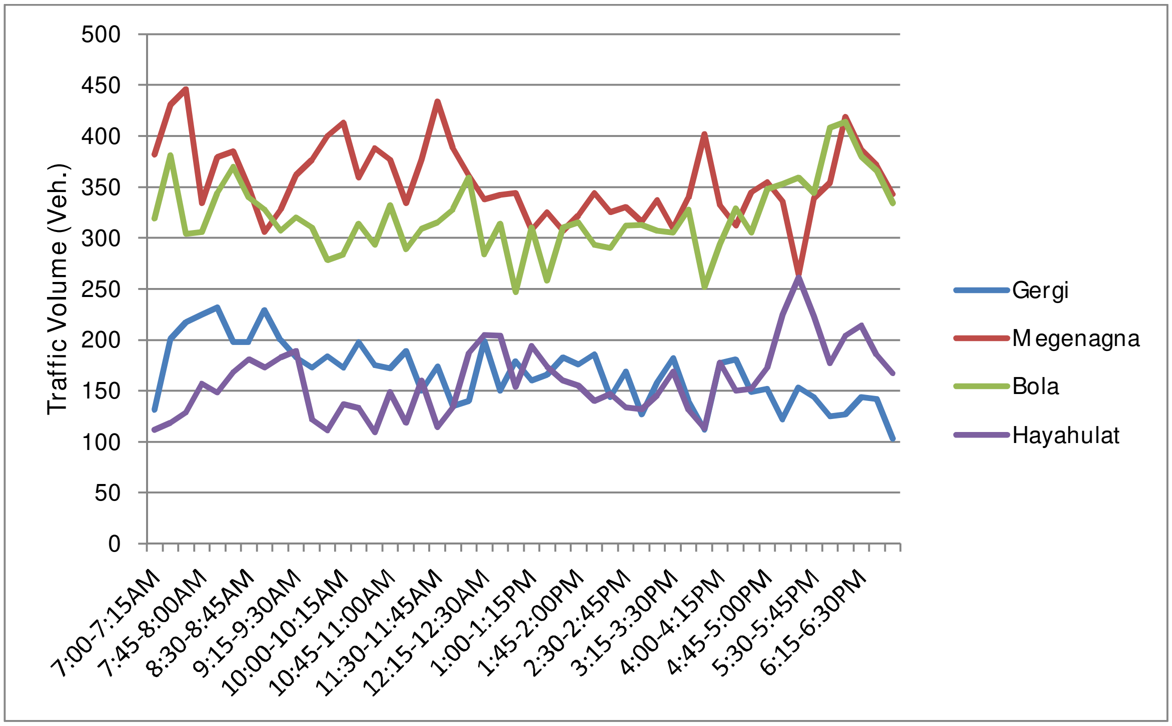

Figure 3: Total traffic volume distribution at Gergi-Imperial Signalized Intersection

C. Intersection Performance Analysis For Roundabout With Signalized Intersection

The values of the Traffic Capacity (veh/h), Degree of Saturation (V/C), Average Delay (sec) and the Level of Service obtained from the SIDRA Intersection software Version 5.1 for the four approaches of Gergi-Imperial roundabout and after converting the same into the signalized intersection are given in Table and described in the paragraphs that follow.

Table : Result of Traffic Analysis for Gergi-Imperial Roundabout and signalized intersection

Junction Name	Approach leg	Capacity (veh/h)	Degree of Saturation(V/C)	Average Delay(sec)	Level of Service
Gergi–Imperial Roundabout	Bole	812	2.954	804.7	F
	Megenagna	1443	2.320	553.7	F
	Gergi	958	1.224	119.4	F
	Hayahulet	671	1.535	252.1	F
Gergi–Imperial Signalized	Bole	1130	1.888	471.4	F
	Megenagna	1383	1.655	383.5	F
	Gergi	699	1.623	390.6	F
	Hayahulet	788	1.750	296.7	F

D. Average Delay

The Average Delay values observed at each of Approach Gergi-Imperial roundabout and the signalized intersection are compared as shown in Figure 4. The Average Delay at the Bole Approach and at the Megenagna Approach was found to be decreased by about 41.42%, and 30.74% respectively for the signalized intersection as compared to the roundabout. This indicates that the conversion of the roundabout intersection into signalized intersection helps in reducing the delay for the approaches having high traffic volume. However, the Average Delay at Gergi Approach increased about 69.43% and at Hayahulet Approach increased to about 15.03%. This is attributed to the fact that for low traffic volume in case of roundabout the vehicles can pass the intersection without waiting, whereas in signalized intersection there will be some waiting time.

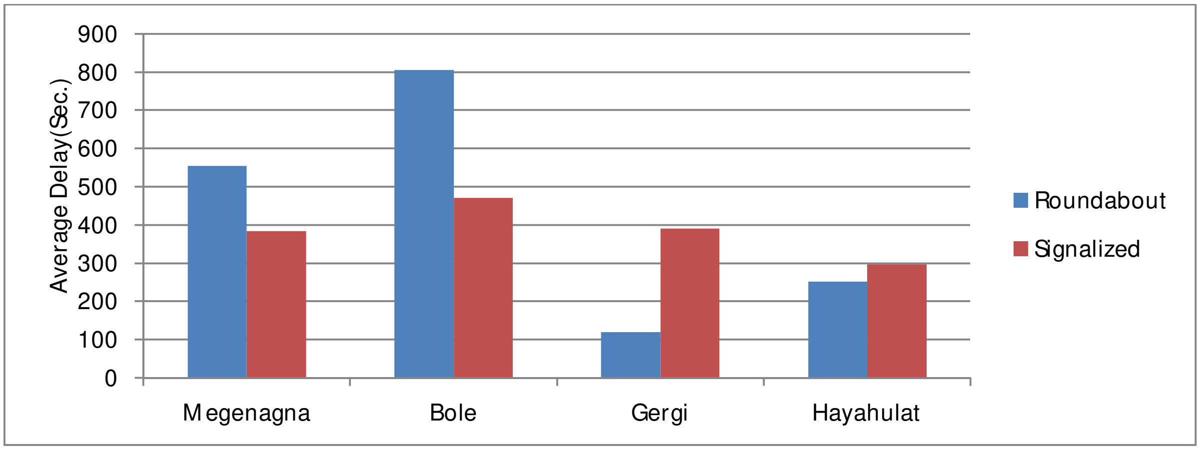

Figure : Average Delay Comparison at Gergi –Imperial Junction for roundabout and signalized intersection

E. Effective Capacity

The output from Sidra software indicated that the total effective capacity of the Gergi –Imperial roundabout is 3884 veh/h while the signalized intersection capacity was found to increase to 4000 veh/hr. It means the signalized intersection capacity is 3% more than roundabout capacity of Gergi –Imperial intersection.

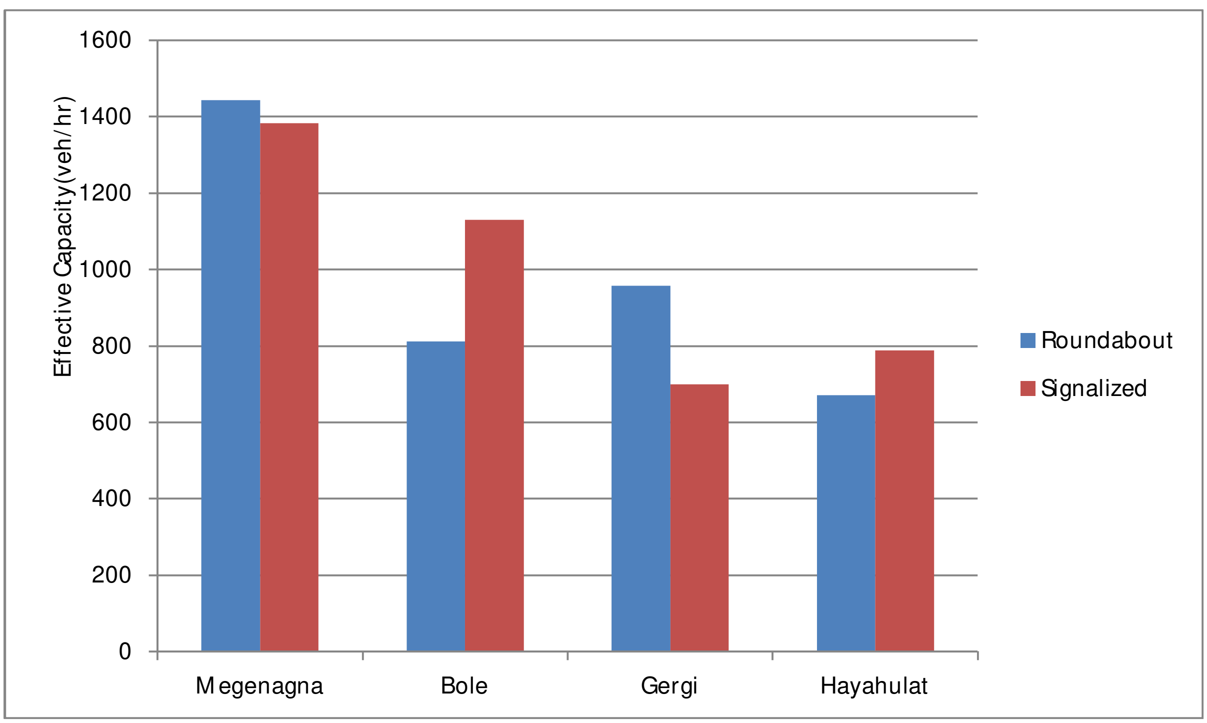

Figure 5: Effective Capacity Comparison at Gergi –Imperial Junction for roundabout and signalized intersection

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F. Degree of Saturation

The degree of saturation is a measurement of traffic flow quality that compares the number of vehicles using a given road with the number of vehicles the facility is designed to accommodate. The degree of saturation values decreased after signalization of the roundabout by about 36.09% and 28.66% at the Bole Approach at the Megenagna Approach (having 3 lanes of width 3.7m) respectively. However, the degree of saturation at Gergi Approach (having 2 lanes of width 3.8m) increased by about 24.58% and at Hayahulet Approach (having 3 lanes of width 3.5m) increased by about 12.28%. The degree of saturation values at all the intersections were found to be greater than 1 (>1) even after signalization of the roundabout, as shown in Table 4. This indicates that the arrival traffic flow is greater than the flow capacity of the lanes.

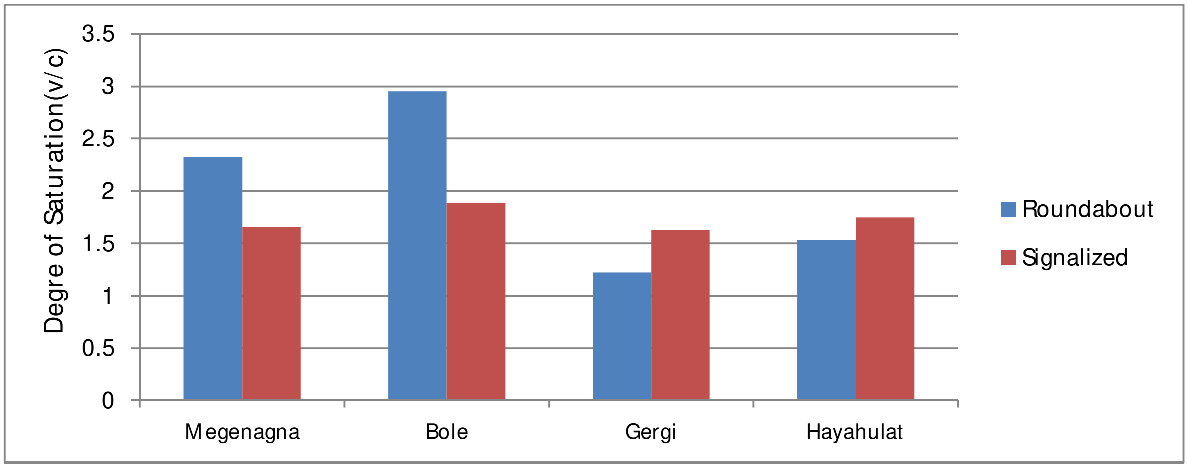

Figure : Degree of Saturation Comparison at Gergi –Imperial Junction for roundabout and signalized

G. Level Of Service

Table 4 shows that level of service (LOS) values do not differ for the roundabout and signalized intersection, but it also shows that there is an improvement regarding degree of saturation, delay and capacity values with the signalized intersection.

VII. CONCLUSION

It was found that the signalized intersection in Gergi-Imperial Intersection operated more efficiently than the roundabout. The conversion from roundabout to signalized intersection resulted in decrease in the Average delay and Degree of saturation by 22.28% and 36.09% respectively, at the same time the capacity increased by 3.00%. The Average delay was found to be higher in the morning and evening peak period. However, it is found that Gergi-Imperial Intersection works at "F" level of service. This finding reveals that new solutions to manage traffic flows have to be considered at the intersection for improving the traffic flow capacity.

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