Evaluation on the Operational Characteristics of Gerji-Imperial Roundabout: A Case Study in Addis Ababa

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Abstract: Highly congested roundabouts are usually considered as the critical points within the urban road network and the evaluation of their performance provides valuable understanding and useful indication about the performance of the city road network system. Roundabouts should be designed to operate at no more than 85 percent of their estimated capacity. Beyond this threshold, delay and queues vary significantly from their mean values. Roundabout approach is dependent on the conflicting circulating flow and the roundabout's geometric elements. In Addis Ababa, most of the intersections are congested and operate in poor LOS. During peak hours, it is common to see congestion, long queues and delay at junctions. Accordingly, the objective of the study was to evaluate the operational characteristics of the selected roundabout in Addis Ababa. This research focused on the capacity and evaluation of the level of service at Gerji Imperial Roundabout and addressed the most important element of operational characteristics. The methodology employed for this study was the quantitative descriptive research design method. 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 pedestrian volume were collected from the study area. The capacity analysis was done based on the gap – acceptance method that is adopted by SIDRA software program. Based on the results, the degree of congestion of the roundabout found out to have 1.749 which is far beyond the recommended values for a satisfactory level of service. Therefore, this indicates that Gerji-Imperial roundabout is serving in a poor level of service. It is recommended to construct road overpass or underpass at the most problematic approach to improve the operational capacity of the intersection.

Index Terms— Capacity, Conflicting flow, Congestion, Level of service (LOS).

1. INTRODUCTION

Roundabouts are increasingly recognized as an intersection control strategy that can fulfill multiple performance goals related to traffic operations and safety that meets social goals related to sustainability, complete streets, context-sensitive design, economic development, and others. Some transportation agencies have recently constructed or approved the use of a series of roundabouts on arterial rather than the traditional solution of coordinated signalized intersections. While anecdotal reports suggest that functionality independent roundabouts on a corridor are successful in meeting performance goals, little research has been conducted to objectively determine the efficacy of this alternative as compared to a series of coordinated signalized intersections. 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 [1].

The modern roundabout is a type of intersection that indirectly provides traffic control without the use of stop signs or traffic signals. These roundabouts, if properly designed, can provide safety and traffic flow benefits when compared to stop controlled and signal controlled intersections. Due to the safety and operational benefits that roundabouts provide, they have become increasingly popular in recent years. This increase in roundabout construction has prompted an increase in research regarding roundabout effectiveness and how they affect the various aspects of transportation systems [2].

In Addis Ababa, most of the junctions are congested and their capacities or level of services is not well identified. During peak hours, it is common to see congestion, long queues and delay at junctions. Hence, evaluation of the capacities of junctions is very important since it is directly related to delays, accidents, high operation costs, and environmental degradation. Therefore, the aim of this research is to assess the level of service at Gerji Imperial roundabout in Addis Ababa.

In order to seek for a solution of the problems, a questions were formulated as follows:

i. What is the volume - to - capacity ratio that represents the most critical approach?
ii. What is the average delay per vehicle before entering the roundabout?
iii. What are the contributory factors which cause delay of vehicles?
iv. What is the existing level of service (LOS) of the roundabout?

2. RESEARCH METHODOLOGY

2.1 Study area

Addis Ababa is the capital City of Ethiopia, which is located within 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 km². The City is divided into 10 administrative sub-cities and 99 Kebeles and it is the most important business and commercial center of the country. The rapid increase of the Addis Ababa population is the main cause of the increasing demand for transportation and mobility. This may create major operational problems, especially during the peak periods.

In order to evaluate the operational characteristics of roundabouts in Addis Ababa, the researcher selected as illustrated in Table 3.1 from the major road corridors which represents significant traffic activates in Addis Ababa.

Table 2.1: Selected Intersection of Study

Intersection Type	Intersection Name	No. of approaches	Location
Roundabout	Gerji-Imperial	4	On Eastern Ring road

Figure 3.1 Location of the study area(Source: Google Earth 2017)

2.2. Study Design

In order to evaluate the operational characteristics of the selected roundabout, it is required to determine the level of service of the junction through field observations, including traffic volume data, geometric data and other relevant data are collected. Then by using the selected methods of analysis the data's are reduced and analyzed. Based on the output of the analysis discussing about the contributory factors which affects the operational characteristics of the roundabout and accordingly discussing about the remedial measures.

2.3 Sample Size and Sampling Procedure

Since the selected roundabout is the existing junction in the Addis Ababa city, the required inputs are collected directly from the study area.

2.4 Study Variables

The study variables are categorized into two. These are dependent variable and independent variables.

Dependent variable

- Level of service (LOS)

Independent Variables

- Vehicle type and volume
- Lane width
- Lane number
- Capacity
- Traffic flow conflict
- Road conditions
- Delay
- Saturation flow rate

2.5 Data Collection Process

To achieve the aim of the the study and to answer the formulated research questions, different data are required, and these data are categorized into two: (1)Primary data, and (2) Secondary data.

2.5.1 Traffic Volume Count Survey and Conversion factor

Traffic volume studies are conducted to determine the number, movements and classification of vehicles at the selected roundabout approaches. For this research, traffic data collection was carried out by using manual traffic count using skilled persons. In a manual traffic count a skilled person was assigned to vehicles as well as pedestrians in every entry approach of Gerji Imperial round. The traffic volume data has been conducted by considering different types of vehicles

(light vehicle, busses and dump trucks and trailers) and movement mechanism (through turn, left turn and right turn) by using the standard record sheet for the manual traffic volume count for one identified peak hour from 5:00pm – 6:00pm, Thursday of the week. The high pedestrian volume also has a significant effect on capacity. For this reason numbers of pedestrian were carried out by using the same method along the direction of their movements.

Therefore, by using the manual traffic count method the data were collected from the selected roundabout as shown in Table 2.2.

Table 2.2 vehicles and pedestrian flow data on each leg at peak hour (5:00 PM-6:00 PM)

Approach Legged	Vehicle Type	Traffic Volume	Pedestrian volume
Bole	Light Vehicle	1160	1178
	Buss and DT	131	
	Trailer	16	
Gerji	Light Vehicle	819	854
	Buss and DT	26	
	Trailer	1	
Megenagna	Light Vehicle	1200	1104
	Buss and DT	22	
	Trailer	11	
Hayahulet	Light Vehicle	887	540
	Buss and DT	43	
	Trailer	0	

The different types of vehicles in a traffic stream have different characteristics like width, length, height and mass; these different size vehicles have different capacity impacts. Volumes are typically expressed in passenger car vehicles per hour (v/h), to convert other vehicle types to Passenger Car Equivalents (pce), the conversion factors are used to get passengers car equivalents as indicated in Table 2.3.

Table 2.3 Conversion factors for passenger car equivalents (pcu) [3]

Vehicle Type	Passenger Car Equivalent (pce)
Car	1.0
Single-unit truck or bus	1.5
Truck with trailer	2.0
Bicycle or motorcycle	0.5

By using the conversion factor, the traffic volume at peak hour in the passenger car unit is summarized in Table 2.4.

Table 2.4 Total Traffic flow at peak hour on each leg in (PCU)

Leg	Vehicle Type	Traffic Volume	pcu conversion factor	PCU
Bole	Light Vehicle	1160	1.00	1160
	Buss and DT	131	1.50	197
	Trailer	16	2.00	32
	Sum			**1389**
Gerji	Light Vehicle	819	1.00	819
	Buss and DT	26	1.50	39
	Trailer	1	2.00	2
	Sum			**860**
Megenagna	Light Vehicle	1200	1.00	1200
	Buss and DT	22	1.50	33
	Trailer	11	2.00	22
	Sum			**1255**
Hayahulet	Light Vehicle	887	1.00	887
	Buss and DT	43	1.50	65
	Trailer	0	2.00	0
	Sum			**952**

In order to see the proportion of the entry flow from every approach legged, the following tabulation is carried out in Table 2.5.

Table 2.5 Entry Peak Hour Traffic Flow and Percentage of traffic Share on each approach Legged

Sr. No.	Junction Name	Approach Leg	Entry Traffic on Leg (PCU)	% of Traffic Share
1	Gerji-Imperial	Bole	1389	31.2
		Gerji	860	19.3
		Megenagna	1255	28.2
		Hayahulet	952	21.4

2.5.1 Geometric Data requirement for SIDRA Software

As per the requirement of the SIDRA Intersection Version 5.1, different geometric data are required, such as, island diameter, circulatory width, number of circulatory lanes, entry lanes, entry lane number and average lane width at the entry of roundabout junction. These data are measured using tape meter and also by observing on the roundabout existing configuration. The collected geometric data are summarized in Table 2.6.

Table 2.6 Summary of Existing Roundabout Geometry data

Junction name	Approach Leg	Entry Lane	Number of circulatory lane	Island Diameter (m)	Average lane width	Circulatory road width (m)
Gerji-Imperial	Bole	3	2	21	3.6	11
	Gerji	2	2	21	3.0	11
	Megenagna	3	2	21	3.6	11
	Hayahulet	3	2	21	3.3	11

The secondary data which are required for this research found from different references, books, standards, different researches and from the Addis Ababa city admiration authority.

2.6 Data Processing and Analysis

Evaluation of operational characteristics of intersections can be classified into two types: empirical and analytical models. Empirical models use observations at many different intersections under all types of conditions to develop regression equations that match intersection characteristics with intersection capacity. Analytical models estimate capacity based on gap-acceptance relationships that do not require observations under congested conditions. Since the Empirical Method depends on geometric elements of the roundabout, it is sometimes difficult to find the necessary geometric features (elements) on the Addis Ababa roundabout. In this regard, the Analytical Method is more realistic than Empirical Method since it considers the traffic environment. Therefore, for this research, Analytical Method is used.

2.6.1 Analysis Software

There are different computer software's to analyze traffic operations at roundabouts and signalized intersections. The software can be dived into two types: macroscopic and microscopic models. The macroscopic models use traffic volume flows to model intersections as isolated locations. On the other hand, the microscopic models simulate the movement of individual vehicles, thereby allowing a network-wide analysis. For research, one of the macroscopic models (SIDRA) software program is applied to analyze traffic operations at roundabout. In fact, AACRA also recommends SIDRA Intersection software for capacity analysis, which was developed by using analytic methods with some geometric elements. For this research, the Signalized & Un-signalized Intersection Design and Research Aid (SIDRA) software is preferred for capacity analysis for the following reasons:

- It is commercially available tool to offer geometric and gap acceptance capability within a single product.
- It has employed a combination of geometric and gap acceptance modeling approach in order to take into account the effect of roundabout geometry on driver directly through gap-acceptance modeling; and
- It can be calibrated for local conditions and it is highly flexible.

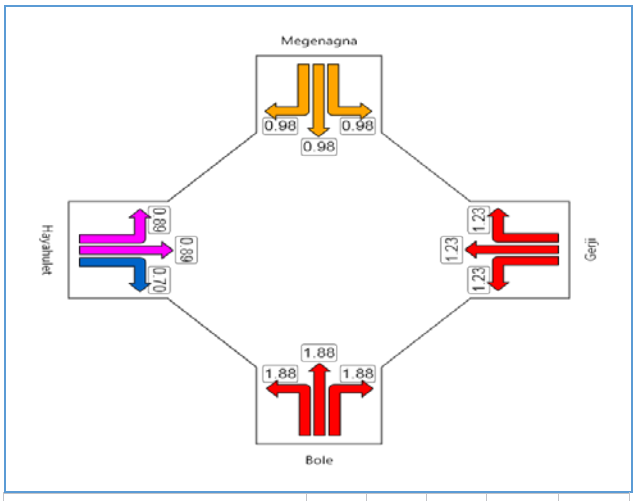
3. ANALYSIS, RESULTS AND DISCUSSION

During The analysis of the study was done on the selected roundabout using the collected data and following the procedures mentioned from the research methodology with the aid of SIDRA Intersection Version 5.1 Software, the results are presented in the following sections with brief explanations.

3.1 Volume to capacity ratio

Volume to capacity ratio or degree of saturation provides a direct assessment of the sufficiency of a given roundabout. While, there are no absolute standards for the degree of saturation, the Australian design procedure suggests that the degree of saturation for an entry lane should be less than 0.85 for satisfactory operation. When the degree of saturation exceeds this range, the operation of the roundabout will likely deteriorate rapidly. As the output of the analysis in Figure 3.1 shows that the degree of

saturation for Gerji-Imperial roundabout is 1.88 which is higher than the tolerable value and this indicated that Gerji-Imperial roundabout is surveying beyond its capacity.



	South	East	North	West	Intersection
Degree of Saturation	1.88	1.23	0.98	0.89	1.88

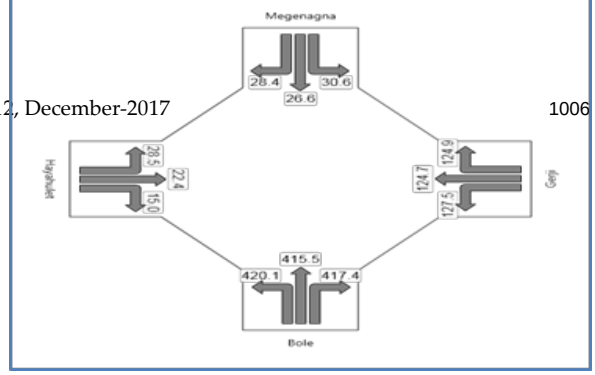
Color code based on Degree of Saturation

[< 0.6] [0.6 – 0.7] [0.7 – 0.8] [0.8 – 0.9] [0.9 – 1.0] [> 1.0] Continuous

Figure 3.1 Degree of Saturation

3.2 Average delay per vehicle

Delay is a standard parameter used to determine the performance of an intersection. The Highway capacity manual identifies delay as the primary measure of effectiveness for both signalized and un-signalized intersection, with the level of service determined from the delay estimate. The output of the analysis in Figure 3.2 shows that the average delay per vehicle is 168.5seconds, which is far beyond the recommended values for each level of service. Hence, this indicated that Gerji-Imperial roundabout is serving in a poor level of service.



	South	East	North	West	Intersection
Delay (Average)	416.6	125.8	28.0	22.1	166.8

Figure 3.2 Average Delay

3.3 The contributory factors which causes delay of vehicles.

3.3.1 Unbalanced number of entry and circulatory lane:

According to AACRA geometric design manual, the number of circulating lanes from any particular approach must be equal to or greater than the maximum number of entry lanes on that approach. As the layout of the analysis Table 4.1 shows that the maximum number of entry lane is 3 and the number of circulating lanes is 2 which is less than the number of entry lane. This unbalanced number of entry lane and circulatory lane affects the operational characteristics of the roundabout.

Table 3.1 Geometry – Approach data

Geometry - Approach Data					
Location	Name	Type	No. of App. Lanes	No. of Exit Lanes	Circulatory Lanes
South	Bole	Two-way	3	3	2
East	Gerji	Two-way	2	2	2
North	Megenagna	Two-way	3	3	2
West	Hayahulet	Two-way	3	3	2

3.3.2. Unbalanced approach legs:

As it is mentioned in the analysis, North – South approach is main high speed traffic lane, and the East – West approach is just access road, both approaches have different traffic volumes, different percentages of heavy vehicles and different approach speed. And such cases, a roundabout is not recommended as a traffic control device according to FHWA. While, as it is shown in the roundabout geometric layout in Figure 3.3, Bole to Megenagna approach is a ring road with

high travel speed and Hayahulet to Gerji is just an access road.

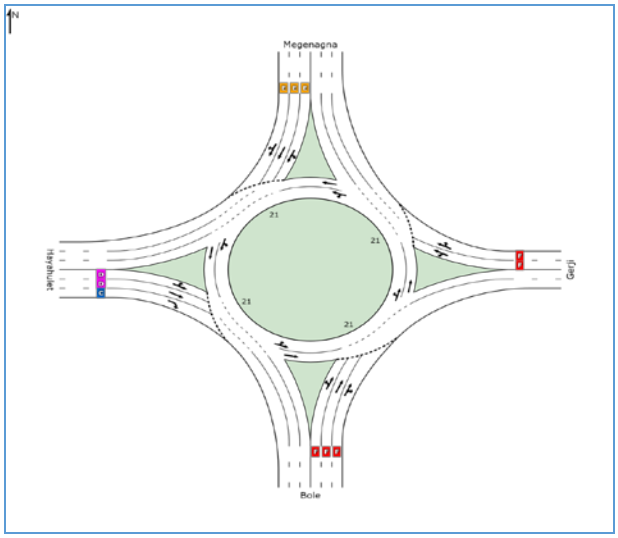


Figure 3.3 Geometric layout

3.3.2.1. Inadequacy of inscribed circle diameter:
According to FHWA, the recommended inscribed circle diameter range for urban double lane roundabout is 45m – 55m and the existing inscribed circle diameter of Gerji-Imperial roundabout is 43m which is less than the minimum recommended value. This was one of the contributory factors which have great impact on the capacity of the roundabout. Inadequate inscribed circle diameter cannot accommodate a sufficient number of vehicles in the circulatory lane.

3.3.2.2. Pedestrian crossing volume
Pedestrian crossing at a marked crossing that gives them priority over entering motor vehicles can have a significant effect on the entry capacity. Accordingly, the following analysis output Table 4.2 shows that high volume of pedestrian which has priority over entering vehicles is one of the contributory factors which affect the capacity of the roundabout.

Table 3.2 Roundabout Pedestrian effects

ROUNDABOUT ENTRY			
Turn	Pedestrian Flow Rate	Circulating Flow Rate	Adjustment Factor
South: Bole			
Left	1280	1118	0.493
Thru	1280	1118	0.493
Right	1280	1118	0.493
East: Gerji			
Left	928	879	0.657
Thru	928	879	0.657
Right	928	879	0.657
North: Megenagna			
Left	1200	613	0.561
Thru	1200	613	0.561
Right	1200	613	0.561
West: Hayahulet			
Left	587	1361	0.842
Thru	587	1361	0.842
Right	587	1361	0.842

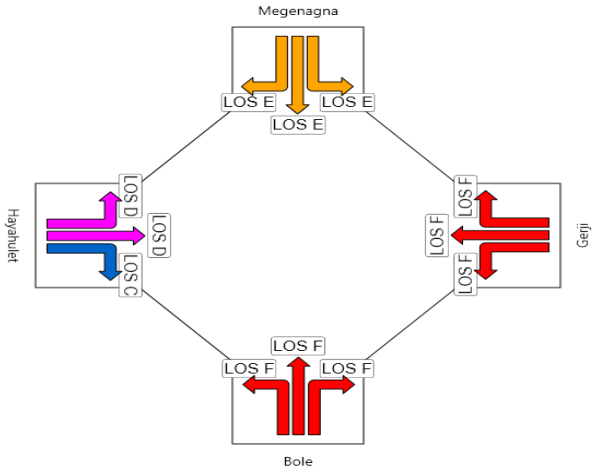
3.3.2.3. High percent (No table of figures entries found) **of heavy vehicle**
The entry of heavy vehicles into the traffic stream affects the number of vehicles that can be served. According to the Highway Capacity Manual 2000, trucks, buses, and recreational vehicles (RVs) are the three groups of heavy vehicles adversely affect traffic in two ways:

- They are larger than passenger cars and occupy more roadway space; and
- They have poorer operating capabilities than passenger cars, particularly with respect to acceleration, deceleration, and the ability to maintain speed on upgrades.

3.4 Level of service (LOS)
Quality of service requires quantitative measures to characterize operational conditions. Level of service (LOS) is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.

Six levels of service (LOS) are defined for each type of facility that has analysis procedures available. Letters designate each level, from A to F, with LOS A representing the best operating conditions and LOS F the worst.

Accordingly, the output of the analysis using SIDRA intersection version 5. 1 Software indicates that the level of service of Gerji-Imperial Roundabout is F, this indicates that the quality of service is the worst, as shown in Figure 3.4.



	South	East	North	West	Intersection
LOS	**F**	**F**	**E**	**D**	**F**

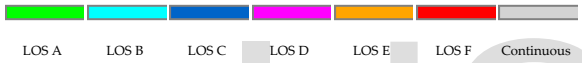


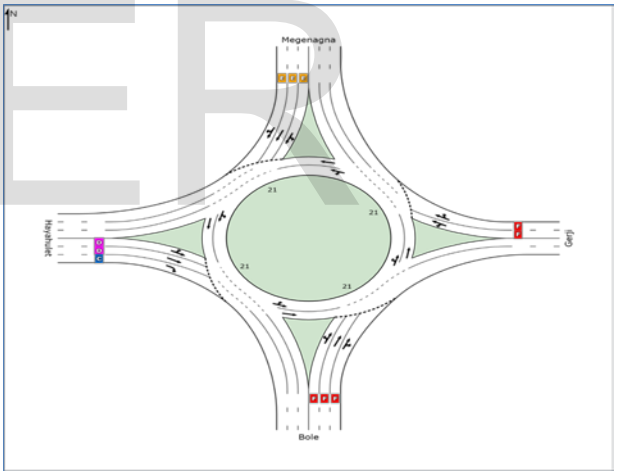
Figure 3.4 Level of Service

The movement summary of analysis result of SIDRA Intersection Software is shown in Table 3.3 to see the summary of demand flow, heavy vehicles, degree of saturation, and average delays at every turn.

Table 3.3 Movement summary of Gerji-Imperial Roundabout

Movement Performance – Vehicles											
Mov ID	Turn	Demand Flow	HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue		Prop. Queued	Effective Stop Rate	Average Speed
							Vehicles	Distance			
		veh/h	%	v/c	sec		veh	m		per veh	km/h
South: Bole											
1	L	226	2.5	1.877	420.1	LOS F	76.0	608.5	1.00	8.69	4.2
2	T	905	9.9	1.877		LOS F	89.4	735.7	1.00	9.26	4.0
3	R	377	4.1	1.877	417.4	LOS F	77.9	618.7	1.00	8.77	4.0
Approach		1509	7.3	1.877	416.6	LOS F	89.4	735.7	1.00	9.05	4.0
East: Gerji											
1	L	327	1.7	1.228	127.5	LOS F	35.7	275.2	1.00	4.58	10.5
2	T	272	1.6	1.228	124.7	LOS F	35.8	275.9	1.00	4.59	10.2
3	R	327	1.7	1.228	124.9	LOS F	35.8	275.9	1.00	4.59	10.1
Approach		926	1.7	1.228	125.8	LOS F	35.8	275.9	1.00	4.59	10.3
North: Megenagna											
1	L	341	1.1	0.977	30.6	LOS E	10.6	81.3	0.80	2.00	20.8
2	T	750	2.4	0.977	26.6	LOS E	11.3	87.4	0.79	1.92	21.2
3	R	273	0.9	0.977	28.4	LOS E	10.6	81.3	0.80	1.94	20.8
Approach		1364	1.8	0.977	28.0	LOS E	11.3	87.4	0.80	1.95	21.0
West: Hayahulet											
1	L	259	1.7	0.886	28.5	LOS D	7.8	60.4	0.94	1.63	21.2
2	T	517	3.4	0.886	22.4	LOS D	8.9	69.9	0.96	1.66	22.2
3	R	259	1.7	0.704	15.0	LOS C	4.3	32.9	0.89	1.19	24.3
Approach		1035	2.6	0.886	22.1	LOS D	8.9	69.9	0.94	1.54	22.4
All Vehicles		4834	3.7	1.877	166.8	LOS F	89.4	735.7	0.93	4.58	8.4

The level of service summary is also shown in Figure 3.5 to see all directional movement and its level of service.



	South	East	North	West	Intersection
LOS	F	F	E	D	F

Figure 3.5 Summary of Level of Service

4. CONCLUSION

The following conclusions are drawn from the findings of the study:

Based from the results of the study, the volume-to-

capacity ratio for Gerji-Imperial roundabout is 1.749. This means that the roundabout was over-congested. For satisfactory operation the degree of saturation should be less than 0.85. Therefore, the operational characteristic of the roundabout is unsatisfactory. Likewise, the average delay of vehicles incurred at the roundabout is about 508.4 seconds which are beyond the range of tolerable values. It is therefore concluded that the roundabout is serving beyond its capacity. In addition, the contributory factors causing the delay of vehicles, was the unbalanced approach number of lanes and the number of circulating lanes, including high traffic volume and pedestrians, inadequacy of inscribed circle diameter, and the roundabout connection with different road types. Moreover, the researcher concluded that the overall level of service of the roundabout based from the results, is rated F which means the roundabout was serving at a poor level of service.

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