

# Performance Analysis of a Roundabout and a 3-leg Intersection Under Heterogeneous Traffic

Abdul Awwal, Aarish Khan



**Abstract:** This paper addresses the analysis of the operational performance of a roundabout and a 3-legged intersection located in quite a busy area of the Aligarh city. The city has an urban population of around 0.9 million people. The roundabout and 3-legged intersection are located in the close proximity of busy commercial areas and schools. Roundabout that has been taken under consideration is un-signalized and 3-legged intersection is priority controlled. The Current study has been undertaken analyze the operational execution of the two intersections and to pave the way for forthcoming investigations related to improvement of the intersections in the Aligarh District region. Traffic data was accumulated on weekdays during peak periods (5:30 pm to 6:30 pm). Video recording was taken in consideration to accomplish this task. The traffic was categorized in 3 classes; light vehicles, heavy vehicles and bicycles. To execute the evaluation of functioning performance of both intersections, SIDRA INTERSECTION software has been used. Results have shown that both the roundabout and 3-legged intersection are operating nearly at their maximum capacities and Level of Service (LOS) is not adequate for such amount of traffic influx into both the intersections. Volume to capacity (v/c) ratio has revealed that both the roundabout and 3-legged intersection are in an unstable state and roundabout condition is worse than the 3-legged intersection as the heavy vehicle volume influx is quite higher for the roundabout.

**Keywords :** Capacity, Level of Service, SIDRA Intersection, Heterogenous Traffic

## I. INTRODUCTION

In the modern transportation infrastructure, congestion of the traffic at road intersections is an ever-growing setback [1]. The expanding number of vehicles is making the situation worse as the people are more inclined to own private vehicles [2], [3]. The socio-economic status of people has led the drastic growth in the ownership of the vehicles globally especially in developing countries leading to the intensification of the problem of congestion in these countries [4]. In a study, Dargay et al. developed a model that envisaged vehicle ownership in 45 countries constituting 75% of the global population. They inferred that in 2002, 800 million vehicles were registered in these countries and by 2030; they are expected to surge by 2 billion in number. China alone will own 390 million vehicles by the commencement of 2030 and 56% of the global vehicles will be owned by the non-OECD countries, which were just 24% at the end of 2002 [6].

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\* Correspondence Author

Abdul Awwal\*, Department of Civil and Construction Engineering, NTUST, Taipei, Taiwan. Email: [awwal123@gmail.com](mailto:awwal123@gmail.com)

Aarish Khan, School of Civil Engineering, Carleton University, Ottawa, Canada. Email: [aarishkhan@zhcet.ac.in](mailto:aarishkhan@zhcet.ac.in)

This explains the severity of the presence of the massive number of vehicles on roads globally and obviously, so much large number of vehicles would cause in the reduction of the performance of the intersections in urban as well as non-urban areas. This encouraged the researchers to conduct studies on the performance of intersections to find effective ways to alleviate the congestion at intersections. In 2014, a study was undertaken on roundabouts, priority-controlled and signalized intersection in the city of Auckland revealed that roundabouts performed effectively for a moderate amount of traffic while for lower traffic volume, the functionality of priority-controlled intersection was reported to be outnumbering other sorts of intersections [8]. An investigation conducted in Medan city, Indonesia revealed that delay and degree of saturation are effective measures to compute the performance of roundabouts [5]. A study was undertaken by Rao et al. (2017), in the city of Vishakhapatnam, India on three intersections under heterogeneous traffic conditions evaluated the traffic streams on the selected routes based on capacity, critical gap, and Level of Service (LOS) [7]. Another research conducted in the city of Anand, Gujarat, India investigated the performance of 2 roundabouts and 1 un-signalized intersection using the IRC-65 method and HCM-2000 method [9]. Naik et al. (2017) computed the capacity and LOS of un-signalized intersections (one 4-legged and three 3-legged) using the method of conflict and suggested numerous ways to enhance the functionality of the intersections [10]. In Surat city, Marfani et al. (2018) researched the road intersections' operational performance and suggested numerous techniques to improve the functionality of the intersections in the city [11].

Several studies have undertaken comparative investigative studies on roundabouts and un-signalized three-legged and four-legged intersections in various countries. But, a few studies have embarked on comparative analyses of the performance of intersections for heterogeneous traffic. In India, numerous studies have addressed the issue of congestion at intersections and performed the comparative analyses for roundabouts and un-signalized three-legged intersections but these studies have been carried out in megacities like Delhi, Mumbai, etc. or cities where populations are more than 2 million. There is lack of studies, which have taken on small size cities (population less than 1 million) like Aligarh, which has a population of approximately 0.9 million [12], where this study has been performed for a roundabout and a 3-legged un-signalized intersection located 796 m apart

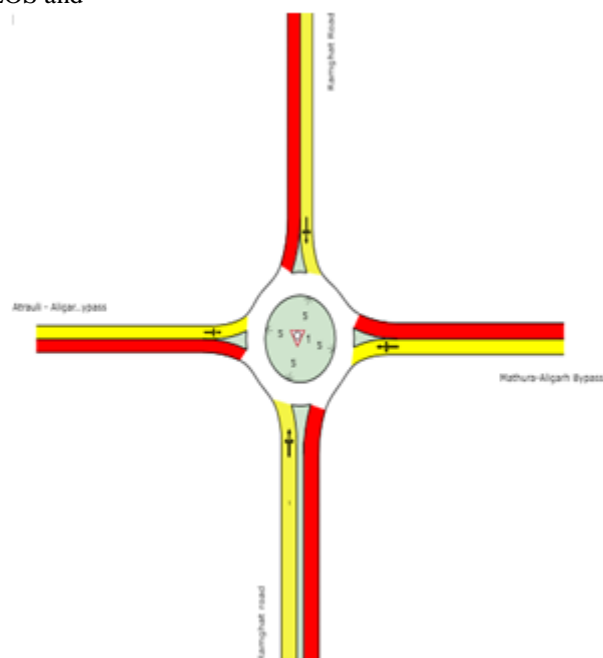


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**Figure 1: Roundabout and 3-leg Intersection location**

on a major arterial as shown in Figure 1. This arterial connects several important places of Aligarh city with each other. The roundabout under study is one of the important intersections of the city as it attracts traffic from two bypasses and a national highway coming from Moradabad city as shown in Figure 2 (a). The 3-legged intersection as shown in Figure 2 (b) is a giveaway controlled type intersection and has more importance than many intersections in the city as several schools, hospitals, shopping malls are located nearby it, which attracts a large number of vehicles through this intersection. This has made the authors undertake a comparative study of these two intersections. This study makes a comparison between these two intersections in terms of operational performance taking capacity, LOS, delay, travel speed, etc. as a measure of performance. SIDRA INTERSECTION traffic simulations and analyzing software has been made use of to analyze and simulate the intersections and their operational functionality and performance. Several Suggestions have also been listed in the last section for the enhancement of the capacity and LOS and



**Figure 2 (a): Roundabout Layout in SIDRA**  
reduction in a delay while traversing these two intersections.

## II. DATA COLLECTION AND METHODS

For the study, a roundabout situated at a point where a large amount of traffic passes through it, (two bypasses delivering

heavy vehicle traffic and a national highway and a major arterial connecting several places of the Aligarh city) and a 3-legged un-signalized intersection (Giveaway Control type) were selected. The traffic volume data was collected for peak period in the evening on weekdays (Monday to Saturday) and an average value was taken for each leg of each intersection (roundabout and 3-legged intersection). For roundabout, both bypasses and national highway are two way – two lane (median is not provided) and major arterial is a one-way – one lane (divided road with traffic separator) as shown in Figure 2 (a). In the case of 3-legged intersection, two legs are one way – one lane and one leg is two way – two lane (no median exists) [refer to Figure 2(b)]. The criteria for the selection of roundabout and 3-legged intersection were based on the following assumptions:

- (a) Both roundabout and 3-legged intersection should be un-signalized.
- (b) The gradient is absent, i.e. flat roads.
- (c) Pedestrian interference is at a minimum level.

The geometrical measurements of the roundabout and the 3-legged intersection have been provided in Table I and Table II. The measurement was performed with the usage of simple measuring tape. Video recording was taken at peak hour 5:30 pm to 6:30 pm (as this is the time when the people return to their homes especially the people who come to the city to perform their jobs) to compute the traffic volume. The traffic was categorized into light vehicles (cars, 3-wheelers, van), heavy vehicles (Buses, large trucks) and bicycles. It was assumed that no pedestrian interference is present to simulate the smooth operation of both intersections. The movements of the traffic have been depicted in Figures 2(a) and 2(b) for the roundabout and 3-legged intersection respectively.

**Table I: Geometrical parameters of roundabout**

| Leg                              | Entry Radius (m) | Median (m) | Approach Lane Length (m) | Approach Lane Width (m) |
|----------------------------------|------------------|------------|--------------------------|-------------------------|
| Ramghat Road                     | 20               | 2.0        | 240                      | 4.6                     |
| Mathura Bypass                   | 20               | -          | 100                      | 3.82                    |
| National Highway                 | 20               | -          | 150                      | 3.75                    |
| Atrauli Bypass                   | 20               | -          | 85                       | 3.20                    |
| Central Island Diameter          |                  |            | 5.0 m                    |                         |
| Circulating Width                |                  |            | 7.0 m                    |                         |
| Inscribed Diameter of roundabout |                  |            | 17 m                     |                         |

**Table II: Geometrical Parameters of 3-leg Intersection**

| Leg                     | Lane Length (m) | Lane Width (m) | Median (m) |
|-------------------------|-----------------|----------------|------------|
| Dodhpur                 | 85              | 3.40           | -          |
| OLF <sup>a</sup> School | 150             | 5.4            | 2.0        |
| Quarsi                  | 180             | 5.45           | 2.0        |

OLF<sup>a</sup> = Our Lady of Fatima

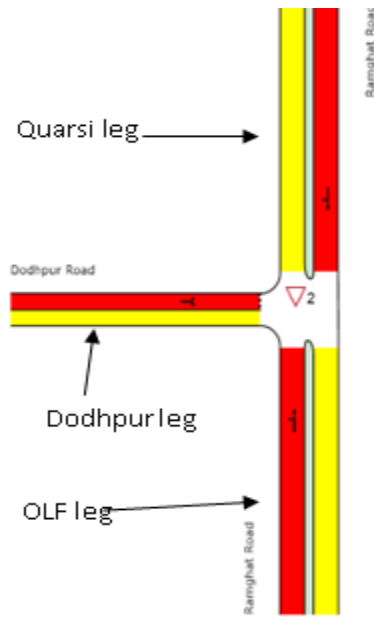


Figure 2 (b): 3-Leg Intersection Layout in SIDRA

Numerous studies have taken capacity, LOS, delay (geometric and control), travel speed into consideration to quantify the operational performance and efficiency of the intersections [13-20]. To simulate and analyze with efficacy and to be compliant with previous studies, we also have taken these traffic flow parameters as the performance measure of the roundabout and 3-legged undertaken for this particular study.

### III. RESULTS & DISCUSSION

#### A. Traffic Volume

Table III and IV presents the volume of the traffic entering into the roundabout and 3-legged intersection respectively. From Table 3, it could be said that Light vehicles (LV) are the dominant category of the vehicle inflow into the roundabout. The share of the heavy Vehicles such buses and trucks is about 10.65%. Non-motorized vehicles like bicycles staked significantly more than heavy vehicles that is about 23.6% of the total traffic inflow into the roundabout. Ramghat Road (RR) is the most occupied leg of the roundabout carrying about 45% of the total traffic influx. This could be attributed to return of the workers from factories located in the city area, people from offices at this time (5:30 pm onwards). The same reason explains the highest number of bicycles influx through this leg (about 86% of total bicycle volume). The bus traffic through RR leg is higher than any other leg because a large number of buses leaves the city to take rural people to their homes at this time of evening. National Highway (NH) leg is least busy because during this time of evening, least number of people travel to the city. LV are the least in volume for NH leg for the same reason of returning of the people to their homes in surroundings of the city.

Although the volume of buses and bicycles is higher for NH leg than Mathura Bypass and Atrauli Bypass legs. It could be featured in the presence of several factories and shopping malls located about 4 km away from the roundabout on this leg. Mathura Bypass leg is the third busiest in terms of vehicle influx into the roundabout. 20% of the aggregate volume of traffic is arriving through this leg. It could be

seen that LV and truck traffic through the leg is quite high, which could be, ascribed to the arrival of vehicles from Mathura city as well as Grand Trunk (GT) road.

Table III: Traffic Volume Influx into the Roundabout(Veh/hr)

| Vehicle Category       | Leg  |                   |                |                | Total Influx |
|------------------------|------|-------------------|----------------|----------------|--------------|
|                        | NH   | Ramghat Road (RR) | Mathura Bypass | Atrauli Bypass |              |
| Light Vehicles         | 704  | 1485              | 1120           | 1001           | 4310         |
| Buses                  | 50   | 135               | 37             | 23             | 245          |
| Trucks                 | 47   | -                 | 130            | 276            | 453          |
| Bicycles               | 80   | 1335              | 67             | 66             | 1548         |
| Leg Total              | 881  | 2955              | 1354           | 1366           | 6556         |
| Motorized Vehicles     | 5008 |                   |                |                |              |
| Non-motorized Vehicles | 1548 |                   |                |                |              |

Table IV: Traffic Volume Influx into 3-legged Intersection (Veh/hr)

| Vehicle Category       | Leg  |                   |                |                | Total Influx |
|------------------------|------|-------------------|----------------|----------------|--------------|
|                        | NH   | Ramghat Road (RR) | Mathura Bypass | Atrauli Bypass |              |
| Light Vehicles         | 704  | 1485              | 1120           | 1001           | 4310         |
| Buses                  | 50   | 135               | 37             | 23             | 245          |
| Trucks                 | 47   | -                 | 130            | 276            | 453          |
| Bicycles               | 80   | 1335              | 67             | 66             | 1548         |
| Leg Total              | 881  | 2955              | 1354           | 1366           | 6556         |
| Motorized Vehicles     | 5008 |                   |                |                |              |
| Non-motorized Vehicles | 1548 |                   |                |                |              |

Atrauli Bypass leg attracts traffic from several settings located on this bypass as well as HV vehicles bypass city from GT road to NH going to Moradabad city that explains the largest number of trucks influx through this leg. Muley et al. (2014) reported similar results about the effect of traffic volume at roundabout operational performance during peak hours [22]. Table IV depicts the traffic influx into the 3-legged intersection. Similar to RR leg in case of the roundabout, OLF leg, in this case, has the highest inflow of vehicles of about 49% that is 4% more than the RR leg of roundabout. Correspondingly, both the LV and bicycle volume (94.45% of total influx through this leg) entering to intersection through OLF leg is highest as in the case of RR leg. The identical cause as in the case of RR leg might also be ascribed to this influx. A quite good volume of workers, professional people return to their homes using Dodhpur leg. The difference between LV and bicycle traffic is not significant for this leg as this leg attracts the people is quite a good amount who work in shops, malls, and other commercial places. A few professional offices or government offices deliver the traffic through this leg that leads to a lesser number of people owning a car or using 3-wheeler commuting through this intersection. LV makes up a greater portion of the total influx through Quarsi leg (about 90% of total influx) which is due to the significant number of cars and 3-wheelers coming from Atrauli Bypass and Mathura Bypass inside the city.

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|                  |      |      |
|------------------|------|------|
| National Highway | 1820 | 1908 |
| Atrauli Bypass   | 1612 | 1370 |
| Total            | 9188 | 7904 |

## B. Capacity and Level of Service (LOS)

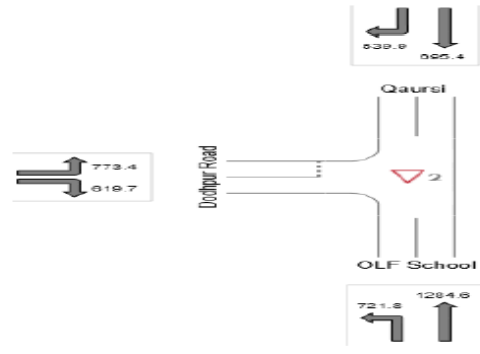
Figures 3(a), 3(b), Table V, and Table VI present the capacity scenario of the roundabout and 3-legged intersection respectively. For roundabout, only Ramghat Road (RR) leg is getting the vehicle influx more than its capacity and hence this situation is resulting in worst Level of Service (LOS) i.e. LOS F [Figure 4(a)]. According to Highway Capacity Manual, LOS F is the condition of traffic on the road when the vehicle is stuck and not able to move [21], the same condition happens on weekdays during peak time in the evening for this leg of roundabout. It could be well explained by the study that is explored by the Kang and Nakmura (2016) which concluded that with the increasing percentage of heavy vehicles, the capacity of the roundabout is dropped. Although, trucks are not authorized to pass through RR leg still a large number of buses find the way to destination through this leg, which justifies why this leg is so congested and LOS is in worst condition [24]. Mathura Bypass and National Highway legs have traffic inflow demand almost equal to the capacity i.e. the difference in capacity and demand of traffic is not significant but LOS is A and B [Figure 4(a)] for these two legs respectively. This could be due to the geometry of the legs and less number of bicyclists, which could have hampered the movement of the motorized vehicle. Atrauli Bypass leg has less demand than its capacity to accommodate the traffic influx. This might be resulted because of a reduced number of bicyclists and less number of heavy vehicles in contrast to light vehicles such as cars, 3-wheelers, etc. 3-legged intersection situation is somehow different from the roundabout, as only one leg exposed to higher traffic than its accommodation capacity, the existing movements (left-turn and right turn are having LOS D and LOS E respectively) because of the heavy bicycle and LV traffic inflow during peak time from Dodhpur area and other commercial regions located nearby. Though the traffic inflow of Quarsi leg is not excessive but the right turn experienced a LOS C due to the heavy traffic on Dodhpur leg and as there is no hindrance in traffic movement in a straight direction, the LOS is A. Both movements of OLF school leg is not exposed to any sort of obstacles in traffic path as a reason of that the LOS for both the movements is A; the probable cause could be that OLF school leg is on a major road which is given priority over Dodhpur leg movements. This is in virtuous concurrence with the study conducted by Said (2016) who investigated the performance of a 3-legged un-signalized intersection in the state of Kelantan, Malaysia that determined the peak hour and LOS of the intersection as well as LOS of the legs of the intersection [23].

**Table V: Capacity & Demand of Roundabout**

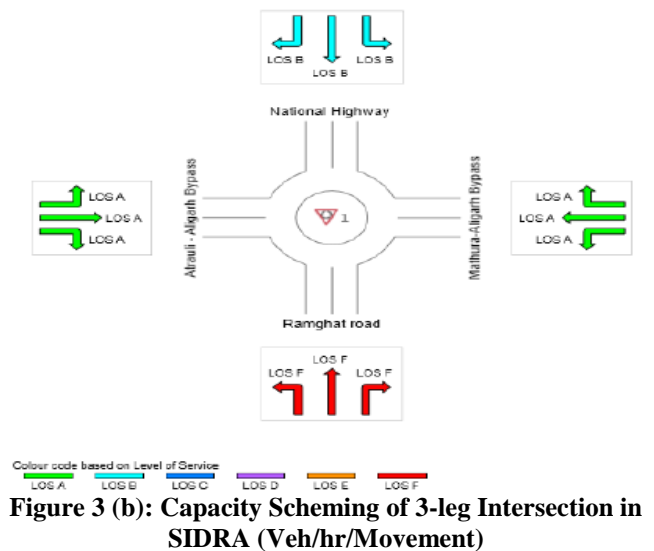
|                |          |        |
|----------------|----------|--------|
| Leg            | Capacity | Demand |
| RR             | 2660     | 3090   |
| Mathura Bypass | 1618     | 1536   |

**Table VI: Capacity & Demand of 3-leg Intersection**

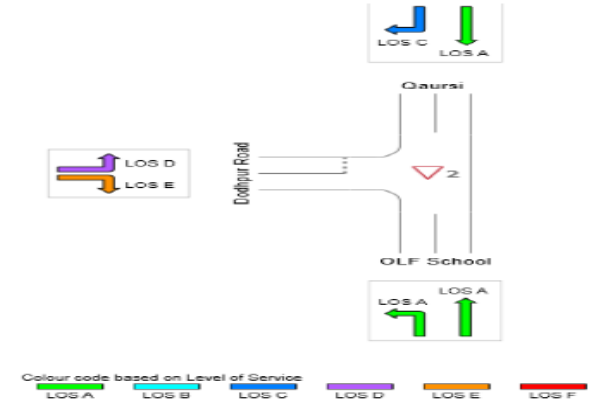
|            |          |        |
|------------|----------|--------|
| Leg        | Capacity | Demand |
| OLF School | 2006     | 1918   |
| Quarsi     | 1234     | 1128   |
| Dodhpur    | 1393     | 1387   |
| Total      | 4633     | 4433   |



**Figure 3 (a): Capacity Scheming of Roundabout in SIDRA (Veh/hr/Movement)**



**Figure 3 (b): Capacity Scheming of 3-leg Intersection in SIDRA (Veh/hr/Movement)**



**Figure 4 (a): Level of Service of Roundabout (per Leg per Movement)**



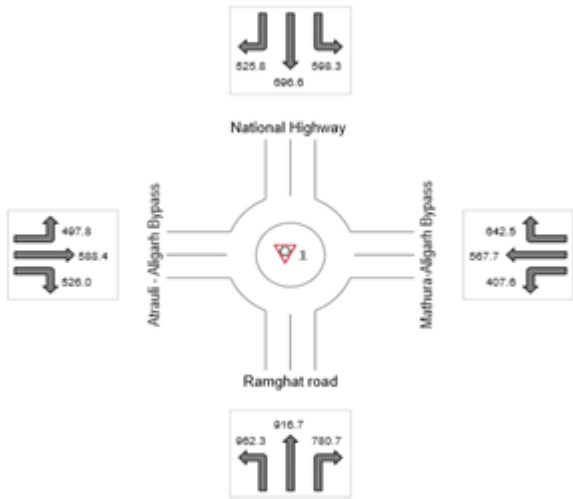


Figure 4 (b): Level of Service of 3-leg Intersection (per Leg per Movement)

C. Degree of Saturation (V/C ratio)

Degree of saturation has been found from one of the indispensable criteria that are used to designate and indicate the operation efficiency of an intersection. It is taken as the ratio of volume influx (v) into the intersection and capacity (c) of the intersection for a specific period of time and could be articulated as;

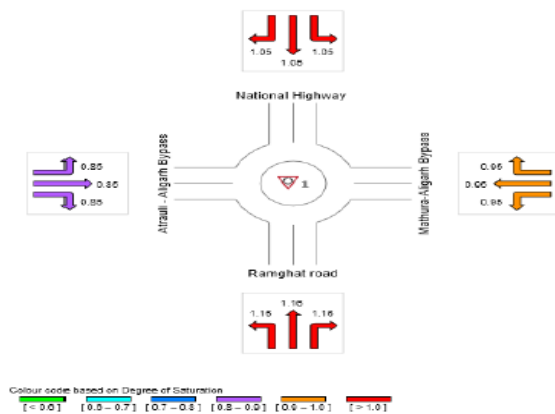


Figure 5 (a): V/C ratio of Roundabout (per leg per movement)

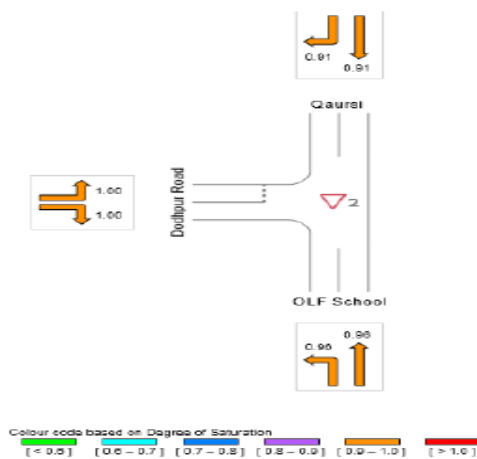


Figure 5 (b): V/C ratio of 3-leg Intersection (per leg per movement)

Table VII: Degree of Saturation (V/C Ratio)

| Degree of Saturation |                           |                             |                           |                  |                       |            |             |                  |
|----------------------|---------------------------|-----------------------------|---------------------------|------------------|-----------------------|------------|-------------|------------------|
| Roundabout           |                           |                             |                           |                  | 3-legged Intersection |            |             |                  |
| Approaches           |                           |                             |                           | Interse<br>ction | Approaches            |            |             | Interse<br>ction |
| Ram<br>ghat<br>Road  | Mat<br>hura<br>Byp<br>ass | Nati<br>onal<br>High<br>way | Atr<br>auli<br>Byp<br>ass |                  | OLF<br>Sch<br>ool     | Qu<br>arsi | Dod<br>hpur |                  |
| 1.16                 | 0.95                      | 1.05                        | 0.85                      | 1.16             | 0.96                  | 0.91       | 1           | 1                |

the range of v/c is normally from 0 to 1. If the volume is greater than capacity, v/c ratio exceeds 1.0 and if the volume is nearly equal to capacity then v/c ratio becomes high and intersection could reach an unstable performance condition [25]. Figure 5 (a) and 5 (b) and Table VII represent the degree of saturation of both roundabout and 3-legged intersection. In the case of the roundabout, Ramghat Road (v/c=1.16) and National Highway (1.05) legs are over-saturated and in a state of jam. As expected, both left turning and right turning movements as well as a straight movement also experience oversaturating condition for both these approaches. Mathura Bypass approach has a degree of saturation of 0.95 which means this approach's operational performance is affected significantly as Australian design procedure has recommended a value of (v/c = 0.85) as a limit to perform with efficiency for an approach or an intersection [26]. v/c ratio for Atrauli Bypass approach is 0.85 that proposes that this approach is working with good efficiency during peak periods but if the volume grows than this approach could also enter into an unstable state. 3-legged intersection is operating in a saturated condition unlike roundabout that could be articulated in an over-saturated condition but 3-legged intersection is functioning in a meta-unstable state as the v/c ratio is equal to 1.0 overall (refer to Table VII). Both the OLF School and Quarsi approaches have v/c ratio equal to 0.96 and 0.91 respectively (> 0.85) that could be attributed to the unstable state of these two approaches. On the contrary, Dodhpur approach experiences exactly v/c ratio equal to 1.0 and is in a complete saturation.

IV. CONCLUSION

The current study has evaluated and compared the operational performance of a roundabout (un-signalized) and a 3-legged un-signalized intersection (priority controlled). It was found that both roundabout and 3-legged intersection are in an unstable state and operating at their maximum capacity. Level of Service (LOS) of both the type of intersections was found not satisfactory. V/C ratio has brought the fact to light that operational condition of the roundabout is much worse than the 3-legged intersection as the heavy volume influx into the roundabout is excessive than the 3-legged intersection.



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## AUTHORS PROFILE



**Abdul Awwal** is currently a PhD student of Geotechnical Engineering in Department of Civil and Construction Engineering at National Taiwan University of Science and Technology (NTUST), Taipei, Taiwan. He has Pursued his Masters in Transportation Engineering From University of Technology, Johor Bahru, Malaysia and Bachelor of Technology in Civil Engineering from Aligarh Muslim University. He is affiliated Member of American Society of Civil Engineers, Public Young

Member of Institute of Transportation Engineers. He has written his dissertation on "Traffic Noise for Different Types of Pavement" and has submitted a Research article entitled "Road Traffic Noise for Asphalt and Concrete Pavements".



**Aarish Khan** is currently a Master student in Civil Engineering at School of Civil Engineering, Carleton University, Canada. He has earned his Bachelor's degree in Civil Engineering from Zakir Husain College of Engineering & Technology, Aligarh Muslim University with First Division. He is Student Member of American Society of Civil Engineers. He has worked on "Analysis & Design of Intersections in Aligarh City" in his Bachelor's degree project.