Chinese Journal of Geotechnical Engineering

Volume 44 | Issue 2 | Year 2022

# An Empirical Approach for Evaluation and Improvement of Roundabouts in Hyderabad

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**Keywords:** Intersection; Roundabout; Capacity; Control Delay; LOS; VISSIM.

**DOI:**

10.11779/CJGE202202.2

**ABSTRACT**: Roundabouts are fairly common in busy areas to reduce the conflict points. This study is carried out to evaluate the performance of existing roundabouts to cater the present traffic and suggest improvements for the future traffic. Due to rapid urbanization they may not work efficiently. In no-lane based heterogeneous traffic conditions performance is based on control delay and degree of saturation (V/C ratio). The main objective of this paper is to evaluate the performance of roundabout by assessing the Level of Service (LOS) using empirical models based on capacity and control delay and to make necessary improvements if required. For this study a total of 6 hour traffic data was used (out of 20 hours) from two roundabouts with 4-legged intersection in Hyderabad with different geometry and traffic characteristics. Data on geometric design elements including entry width, circulating width, weaving length and roundabout diameter measured through field survey during off peak period. Approach volume and entry delay were measured during peak and off-peak periods using video cameras. Evaluation is done using V/C ratio, control delay and LOS, based on the results of evaluation, micro simulation models were developed for poorly performing roundabout using VIISIM and enhancement is provided.

## 1. INTRODUCTION

Transportation is an infrastructure provision for the social, economic, cultural and administrative development of the nation. But in order to see that proper interaction materialize in practice, a provision of suitable transportation system is provided. Road network is an important aspect of transportation system as it connects each and every part of the country. The traffic performance of a roadway network is greatly influenced by the traffic flow through that intersections. With increase in traffic in medium and large cities is of big problem to develop a network which would be able to satisfy the traffic requirement. Intersection is main part of this road network and is to be designed properly so as to handle the traffic scenario effectively. In addition, it is complicated by fact that each intersection has its unique properties of physical layout, vehicle flow rates, turning movements, pedestrian movements and etc. Un-signalized intersections play a crucial role in road network to divert the traffic into respective lanes. They provide free movement of traffic without any constraint. But it has a drawback of large number of conflict points. As number of lanes increase, the number of conflict points at the intersection also increases drastically. Roundabout is a type of intersections, which functions without any priority rules to the traffic on any of the intersecting road, neither STOP signs nor Police-controlled, and the traffic is of heterogeneous nature. Introduction of roundabouts at intersection had many advantages other than eliminating the conflict points which lead to perpendicular crashes. It reduces driver confusion developed with perpendicular conflict at junctions and also decreases the queuing caused due to signalization.

Delays to vehicles at urban uncontrolled intersections depend on several factors. The most important among these being the major street approach volume, left turning movement, vehicular composition etc. The extent of intersection of these factors and their collective effect on delay caused to vehicles need to be studied in detailed for better traffic management at these intersections. Field studies due to resources constraint may not include all these, the limited samples that might be obtained will be sufficient to evaluate the effect of various parameters.

Moreover, queuing theory and other mathematical relationships that had been used in most of earlier studies to estimate delay to vehicles at intersections, are not appropriate for the conditions (absence of queue) prevailing at urban uncontrolled intersections under mixed traffic condition.

## 2. BACKGROUND STUDY

Roundabouts has been the area of interest for many of the researchers since long back. Many significant studies have been conducted on traffic behaviour at roundabouts over years taking into account the change in shape and size of roundabouts. Roundabout is one of the type of intersection in which road traffic flows almost continues in one direction around a central island. Traffic delay is used for evaluating the performance of at-grade intersections controlled by stop signs, traffic signals, and roundabouts.

Developed countries like Germany, United States, United Kingdom, France and Australia have done research on capacities and in developing countries (Chandra and Rastogi, 2012, Al, Masaeid and Faddah, 1997). There are basically two methods of capacity estimation they are based on gap acceptance process and based on empirical formulae which are based on the geometry of intersections including entry width, entry angle, the number of lanes in entry and circulatory area etc. The U.K. method is based on the formula proposed by Transport and Road Research Laboratory (TRRL). Geometric parameters like entry width, flare length, sharpness of the flare, entry bend radius, entry angle, inscribed circle diameter, etc. are mainly considered in UK method (Kimber 1980). The Swiss method is similar to the U.K. method but considers the effect of existing traffic in the direction opposite to the entering traffic (Bovy et al., 1991).

### 2.1 Various empirical models developed across the world

Timely researches had been carried out to change its shape and size. The progress of being a modern roundabout from the ancient rotaries has seen considerable changes through ages.

The Indian formula (IRC-65 1976) for estimation of capacity of a roundabout is based on Wardrop’s equation, which is empirical in nature and takes into account the geometric elements like entry or exit width, length and width of weaving section, and the proportion of weaving traffic with respect to the total traffic in weaving section. According to HCM (2000), the capacity of a roundabout entry (Qe) was a function of the one flow variable, circulating flow (Qc) in a negative exponential regression setting, while the HCM (2010) proposes an analytical approach based on critical gap and follow-up time to determine the entry capacity of a roundabout. Chandra and Rastogi (2012) carried out a comparative assessment of UK Method, German Method, Swiss Method, US Method and IRC method of capacity estimation and reported that IRC method estimates a higher value of capacity compared to other methods.

Rastogi et.al (2014), the entry capacity of the roundabout with larger diameter Central Island is found to be more than that of roundabout with smaller diameter. The relationship between entry capacity and circulating flow is found to be negative exponential i.e. the entry capacity decreased exponentially with an increase in the circulating flow. Prakash et.al (2014) the analysis revealed strengths and weaknesses of each intersection types under a range of demand and traffic conditions. At low traffic demand, priority controlled intersections outperformed the other two forms of intersection control. At moderate traffic demand, roundabout performed the best while at high traffic demand, signalised intersections performed the best.

Patnaik et.al., (2016) this paper evaluated capacity of an entry flow which found to vary immensely with the changing geometrics of the roundabout. A model was developed using empirical analysis based on five such geometric parameters, which proved to be significant for estimating the capacity. The parameters used in this equation had a multiplicative relation with the conflicting flow. Ren et.al., (2016) this paper evaluates the performance of the capacity estimation for single-lane roundabouts using analytical models [including the highway capacity manual (HCM) 2000 model, the German Highway Capacity Manual (GHCM) model, the signalized and un-signalized intersection design and research aid (SIDRA) model and a new roundabout capacity (NRC) model] and an empirical model (the HCM 2010 model). Zhou et.al (2016) Using several roundabouts in Changchun as case studies, this article uses V/C ratio and delay to evaluate roundabout performance. Based on the result of evaluation, the micro-simulation model of the poorly-performing roundabout is built and enhancement is proposed.

**2.1.1 UK TRRL model**
The 1st model for estimating the capacity of roundabout by Kimber (1980) for roundabouts is based on empirical analysis. UK is having many roundabouts which are operated at capacity flow at that time. The effect of various geometric parameters on the entry capacity was determined and six geometrics were selected to form a model. Linear relationship was found between the entry capacity and the circulating flow.

**2.1.2 French model**
Three parallel modeling efforts was going on in France to develop the equation for capacity. The model developed by Louah (1992) is an exponential regression- based model that takes into account the influence of exiting flow and a number of geometric parameters. This model considers both entry and the exit flow and also considers two different conflicting flows. The model also considers driver behavior along with geometrics by taking the follow-up time.

**2.1.3 Jordan model**
Al-Masaeid and Faddah (1997) developed a capacity model by collecting the data collected from about 10 roundabouts and then analysis was carried out using different lanes of roundabout. To develop the model based on traffic flow and geometrics total of 27 lanes were considered to obtained the data. The relationship between the estimated entry capacity, circulating flow and roundabout geometric variables had a multiplicative form.

**2.1.4 US Federal Highway Administration model**
Robinson and Rodegerdts (2000) wrote a synopsis of Federal Highway Administration (FHWA) guide on capacity and performance of roundabouts which included single-lane roundabouts, double-lane roundabouts, and the capacity curves for urban compact roundabouts, as it has been used to estimate capacity in USA till HCM 2000 was formed This model developed three equations for three conditions i.e. for the single-lane roundabout, for dual-lane roundabouts and for the urban compact roundabouts.

Akcelik, R. (2011) used HCM-2010, in the SIDRA INTERSECTION software to assess the round way capacity. Mahesh et al., 2015 used HCM 2010 equation to estimate the entry capacity of an approach leg at a roundabout using field circulating flows, which resulted in queue formation in the approach.

From the detailed study on literature, it could be summarized that the geometry of a roundabout plays a vital role in determining its performance. Many researches have been carried out based on this aspect, which resulted in rigid models for different nations. When compared with other models, the models based on empiricism showed better results in some cases, while underestimated in other cases, especially, when used in different countries. Overall, it was found that the model based on geometry of roundabouts along with flow characteristics gives a better explanation of its performance under heterogeneous traffic flow conditions like India.

## 3. OBJECTIVES
The objectives of the present study are 1) To estimate the capacity of a roundabout 2). To develop a model for entry capacity of typical four-legged roundabout in heterogeneous traffic conditions.

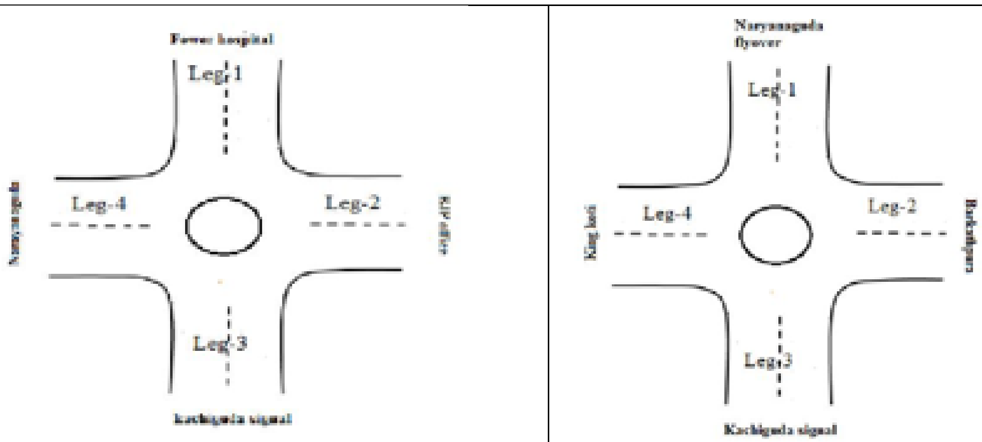
It is necessary to estimate driver behavioral parameters such as critical gap and follow-up time. Present research also concerned with estimating critical gap and follow -up time values for different vehicle categories such as motorized two-wheeler, motorized three-wheeler, small car, big car, light commercial vehicle (LCV), bus and truck. This study also aimed to develop most appropriate functional form relating entry capacity and circulating flow expressed in PCU/h. Development of a model for entry capacity at heterogeneous traffic condition by modifying HCM 2010 equation with the help of critical gap and follow-up time has also attempted in this study. The field observations, used in the present study, were collected from two different roundabouts namely, Barkathpura roundabout and Narayanguda roundabout. The data is collected using video image detection process i.e., the camera was placed over the centre to record vehicle numbers, type and speed and turning movements over the section. The study stretches are 4-legged intersection with a varying widths. Traffic data have been collected on Thursday for a period of three hours from 1.40 pm to 4.40 pm. The majority of the vehicles present in the traffic stream were cars, motorized two-wheelers, and three-wheelers. Traffic volumes varied from 3900 to 4560 vehicles/hour during the observation period and the composition in a number of vehicles and percentages are given below.

## 4. STUDY AREA METHODOLOGY

Three potential roundabouts intersections with different geometry and traffic characteristics in Hyderabad are identified based on the factors considering location of site in city, geometric characteristics and traffic composition. The flow chart showing methodology for evaluation

(1) Barkathpura roundabout (2) Narayanguda roundabout

**Fig. 1. Site showing Barkathpura and Narayanguda roundabout**




Autocad drawing of Barkathpura roundabout | Autocad drawing of Narayanguda roundabout

**Fig. 2. Autocad drawing showing Barkathpura and Narayanguda roundabout**

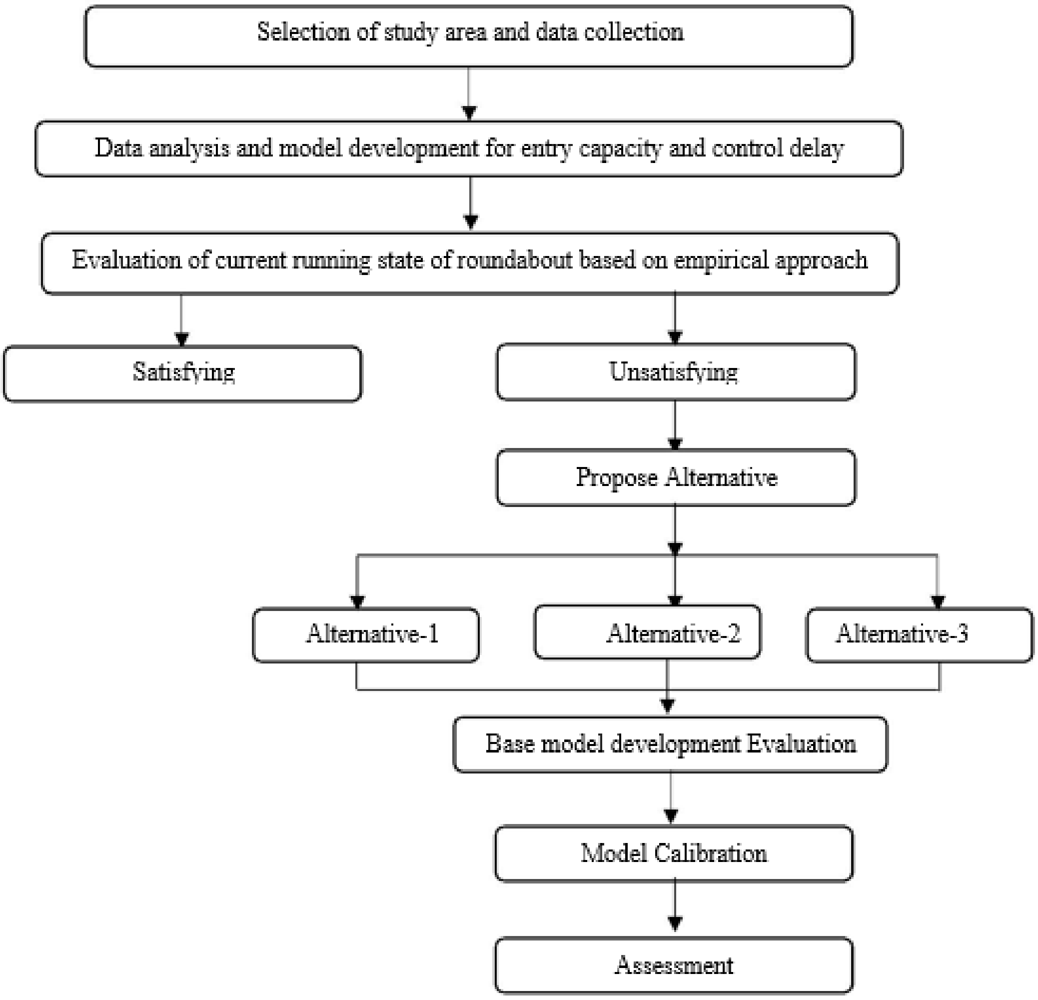



**Figure 3. Flow chart showing methodology for evaluation and alternatives**

**Table 1. Level of service based on overall vehicular delay (Source Indo HCM 2017)**

| LOS | Average Delay 'd' per |
|---|---|
| A | ≤5 |
| B | 6≤d≤15 |
| C | 16≤d≤20 |
| D | 21≤d≤35 |
| E | 36≤d≤65 |
| F | >65 |

**Table 2. Passenger Car Units for Roundabouts (IRC:65) used in the study**

| LOS | |
|---|---|
| Cars and other Light Motor vehicles (including 3 wheelers) | 1 |
| Buses and medium and heavy commercial vehicles | 2.8 |
| Motorcycles and Scooters (2 Wheelers) | 0.75 |
| Pedal cycles | 0.5 |
| Animal drawn vehicles | 4-6 |

The following regression model was produced for estimation control delay

$$Dt = 6.95 - 0.42\, We + 0.42\, Wc - 0.067\, Di + 0.0009\, Vs + 0.0007\, Vc + 0.02WL \quad (1)$$

With an adjusted R2 of 56.8 and a standard error estimate (SEE) of 0.53. The intercept, the variables and regression model were all significant at 95% confidence

The following empirical model was produced for estimating entry capacity

$$Qe = 4837.9\ X\ e^{(-7.22\times10^{-5}\times VC)}\ X\ We^{(0.762)} X\ e^{(-0.279\times ww)} X\ e^{(0.00129\times Di)} X\ eWL^{(0.072)} \quad (2)$$

## 5. DATA COLLECTION AND ANALYSIS

Traffic data showing entry traffic volume and circulating volume for each roundabout

**Table 3. Details of Entry Traffic volume at Barkatpura**

| Leg Direction | Heavy Vehicle | LMV | TW | Bicycle | Total vehicles | Traffic Volume (PCU/h) |
|---|---|---|---|---|---|---|
| N-E | 46 | 749 | 2027 | 13 | 2838 | 2409 |
| E | 23 | 764 | 2190 | 7 | 2987 | 2478 |
| S-W | 60 | 670 | 1510 | 5 | 2248 | 1977 |
| N-W | 5 | 674 | 1016 | 11 | 1709 | 1460 |

**Table 4. Details of Circulating Traffic volume at Barkatpura**

| Leg Direction | Vehicle count | | | | |
|---|---|---|---|---|---|
| | Left turning | Straight | Right | Traffic Volume (PCU/h) | Circulating Volume (PCU/h) |
| N-E | 409 | 1329 | 669 | 2409 | 1650 |
| E | 0 | 1246 | 745 | 2478 | 2354 |
| S-W | 161 | 1193 | 621 | 1977 | 2663 |
| N-W | 432 | 673 | 353 | 1460 | 2562 |

**Table 5.** Details of Entry Traffic Volume at Narayanguda

| Leg Direction | Heavy Vehicle | LMV | TW | Bicycle | Total vehicles | Traffic Volume (PCU/h) |
|---|---|---|---|---|---|---|
| N-E | 43 | 887 | 1945 | 3 | 2881 | 2472 |
| S-E | 0 | 44 | 130 | 5 | 181 | 146 |
| S-W | 48 | 897 | 1938 | 5 | 2891 | 2491 |
| N-W | 14 | 902 | 1757 | 5 | 2681 | 2266 |

**Table 6. Details of Circulating Traffic volume at Narayanguda**

| Leg Direction | Vehicle count | | | | |
|---|---|---|---|---|---|
| | Left turning | Straight | Right | Traffic Volume (PCU/h) | Circulating Volume (PCU/h) |
| N-E | 33 | 1411 | 1026 | 2472 | 1000 |
| S-E | 64 | 60 | 19 | 146 | 3381 |
| S-W | 669 | 1788 | 32 | 2491 | 1108 |
| N-W | 1299 | 24 | 941 | 2266 | 1842 |

**Table 7. Details showing various geometric characteristics of roundabouts**

| Leg Direction | Island Diameter (m) | Direction | Entry Width (m) | Circulating width (m) | Weaving Length (m) |
|---|---|---|---|---|---|
| Barkathpura roundabout | 42 | N-E | 4.5 | 12.8 | 46.46 |
| | | E | 6 | 12 | 58.42 |
| | | S-W | 4.5 | 12.6 | 34.14 |
| | | N-W | 6 | 11.3 | 56 |
| Narayanguda roundabout | 17 | N-E | 9.5 | 11.3 | 32.96 |
| | | S-E | 11.2 | 11 | 35.29 |
| | | S-W | 8.5 | 11.2 | 25.47 |
| | | N-W | 12 | 11.6 | 23.14 |

Chinese Journal of Geotechnical Engineering
Volume 44 Issue 2 Year 2022

## 6. EVALUATION OF ROUNDABOUTS

The Level of service based on control delay and volume by capacity are shown in below table.

**Table 8. Details showing V/C ratio, Delay and LOS of Barkatpura roundabout**

| Direction | V/C | Delay 'd' | LOS |
|---|---|---|---|
| N-E | 0.72 | 15 | B |
| E | 0.83 | 21 | D |
| S-W | 0.77 | 17 | C |
| N-W | 0.65 | 14 | B |

From the above table the overall Level of service for Barkatpura roundabout intersection is 'C'.

**Table 9. Details showing V/C ratio, Delay and LOS of Naryanguda roundabout**

| Direction | V/C | Delay 'd' | LOS |
|---|---|---|---|
| N-E | 0.64 | 14 | B |
| S-E | 0.63 | 13 | B |
| S-W | 0.77 | 18 | C |
| N-W | 0.84 | 22 | D |

From the above table the overall Level of service for Naryanguda roundabout intersection is 'C'.

## 7. MICRO SIMULATION OF ROUNDABOUT

VISSIM is a microscopic, time step by step and behaviour based simulation model developed for urban traffic modelling. The program can analyse traffic and transit operations under constraints such as traffic composition, conflict area, priority rules, lane configuration, transit stops, traffic signals, etc., thus making it as a useful tool for the proposing the various alternatives based on transportation engineering planning and measures of effectiveness. For the purpose of paper, three roundabouts are modelled to illustrate how changes in the roundabout can improve the performance of the roundabout.

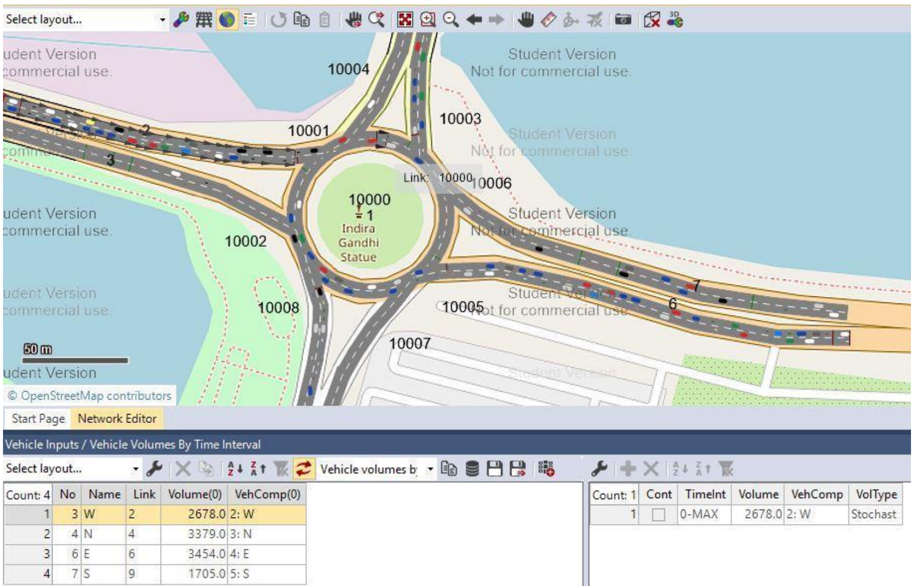



**Figure 4. Base model development of roundabout**

**Table 10 Comparison of improvement and real life scenario**

| Direction | N | E | W | S |
|---|---|---|---|---|
| V/c ratio in real life | 0.72 | 0.74 | 0.70 | 0.81 |
| V/c ratio in improvement variation range | 0.70 | 0.69 | 0.69 | 0.75 |
| V/c ratio in real life | 2.8% | 6.75% | 1.42% | 7.4% |

**Table 11 Comparison of improvement and real life scenario**

| Direction | N | E | W | S |
|---|---|---|---|---|
| Delay in real life (sec) | 18 | 19 | 17 | 0.81 |
| Delay in improvement scenario (sec) | 17 | 14 | 17 | 0.75 |
| LOS | C | B | B | 7.4% |

## 8. RESULTS AND CONCLUSIONS

From the control delay model, it can be seen that delay increases as the entry volume increases. This refers to the increase in probability of forming a queue at the roundabout entry while drivers are waiting for suitable gaps in the circulating roadway traffic. The delay time increases as circulating volume increases. This is because as circulating volume increases, shorter gaps are produced, and as a result, the probability of gap acceptance for the entering driver's decreases. The delay time has is due to the confusion caused by a larger circulating width for the drivers at the roundabout entries. When entry drivers look for gaps in parallel streams of traffic on the circulating roadway, they need more time to find suitable gaps and enter the roundabout.

Improvement scenario for barkatpura roundabout: Overall level of Service for Barkathpura is D, approach N-E, S-W, N-W are having LOS of B and C. But East approach is having Los of D, This can be improved by adding an extra lane width approach on East. Once extra lane width is added on East the average delay in that approach will reduce to 16 sec and Level of service will increase.

Improvement scenario for Narayanguda roundabout: The diameter of Narayanguda is very less i.e., 17m. The central island diameter (D) varied exponentially with the entry capacity. Hence, even a small variation in Central island diameter changes the entry capacity of the roundabout. So, the change in entry capacity for 15m increase in central island diameter was calculated for variation in diameter from 15m to 60m. The observation stated the 15m increase in diameter increased the entry capacity by 4% to 5%. So increase the diameter by 15m.

This article show the process to evaluate the performance of roundabout under heterogeneous traffic conditions. The LOS of a roundabout can be increased by decreasing degree of saturation and control delay. For Prasad I-max roundabout LOS is increased by providing extra lane width on East & West approaches. For Narayanguda roundabout overall diameter should increase to decrease delay and to increase LOS. Since the case study is in Hyderabad with different roundabout diameters, the methodology adopted may be applicable to other roundabouts at different cities in India with heterogeneous traffic condition. The use of microscopic simulation to model roundabout is an efficient way to experiment with different improvement strategies.

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