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Designing a Roundabout to Overcome Traffic Congestion at a Four-Armed Intersection

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Abstract. The growth rate of vehicles is increasing in most metropolitan areas, and as a result, traffic congestion is also increasing, particularly at intersections. Traffic congestion is one of the major problems faced by most of the developing countries despite the measures taken to mitigate and reduce it. In order to overcome traffic congestion, especially in four-way intersections with increasing growth rate of vehicles, roundabout design is a popular traffic management solution in urban areas. In most countries, roundabouts have been widely adopted as an alternative to signalized intersections due to their ease of operation with fewer conflict points. In a metropolitan city like Chennai, there are numerous areas facing traffic congestion. This study aims to design a roundabout for a four-armed intersection located at one of the most congested areas in Chennai, India - Porur Junction. It is a four-armed intersection with traffic on all approach roads and controlled by a signalized intersection. The effective solution would be an elevated roundabout bridge by connecting the major roads towards Poonamallee and Guindy with a two lane road and the minor roads towards Kundrathur and Arcot Road with two separate lanes, one for entering and the other for exiting the junction. The efficiency of the elevated roundabout bridge is that it has speed breakers in the entry ramp which slows down the vehicle & has a central island structure which is used to effectively manage the traffic without stopping the vehicles. After passing through the Central Island, vehicles can exit the barrier at a higher speed than the entry speed in a clockwise direction.

1 Introduction

Our generation expects progress to be fast and efficient. In today's transport world, traffic is a major concern as it is seen as slowing down the progress of the economy. Progress in our cities is synonymous with the number of flyovers. According to a study by the Central Road Research Institute (CRRI), Delhi, construction of flyovers and underpasses and widening of roads or right of way are not better approaches and solutions to deal with congestion and heavy road traffic. Within a few years of construction, such approaches have increased the number of private vehicles on the roads and worsened sustainability without reducing congestion. In Chennai, the fact remains that the flyover road remains congested, especially during peak hours. Flyovers are helpful in decongesting traffic at major intersections, but then create congestion at the next intersection. As an alternative solution, it is necessary to design and analyse an elevated roundabout bridge in place of the flyover to significantly reduce traffic congestion. The present study aims to design a roundabout for a flyover located at Porur in Chennai, India. The selected intersection has four approach roads with two-way traffic in all the approach roads. The traffic on the road consists of bicycle, car, three-wheeler (auto rickshaw, loader, tempo) and cycle, heavy vehicle (multi-axle bus, truck). The existing flyover, which cannot solve the problem of traffic congestion, is shown in (Fig. 1). As an alternative solution, it is necessary to design and analyse an elevated roundabout bridge in place of the flyover to significantly reduce the traffic congestion.

Figure 1 Showing before and after construction of Flyover in Porur- Chennai.
Source: Google Image

Previous study has found that roundabouts are designed to intelligently control the traffic flow at the intersections without using the stop signs or traffic signals. Towhidul Islam et al. (2020) briefly discussed the possible benefits after converting an intersection into a roundabout and the benefit of finding the intersections where the authority should construct more roundabouts [9]. Mahajan et al. (2013) pointed out that widening and flyover construction have become the main solution to overcome the major conflicts at intersections, such as collision between through and right turn movements. As a remedy, he has provided a new geometric concept for designing rotaries at road intersections [7]. Vasantha kumar et al. (2017) has elaborated on the design of a roundabout for an uncontrolled multi-leg intersection and has highlighted the efficiency of the roundabout in handling uncontrolled intersection traffic during peak hours. He also highlighted the methodology of traffic volumes from different approach roads, which were collected using video graphics techniques and analysed for peak hour traffic volumes [6]. Elvik, (2003) showed that roundabouts reduce the number of injury accidents by 30% to 50% and fatal accidents by 50% to 70% [1].

2 Study Area & Methodology

2.1 Overview

For this study, a four-lane intersection was selected and the geographic and vehicle data of the intersection were collected. In the data collection, the data will be analysed to determine the capacity of each entry lane, entry flow rate, circulating and existing flow rate to calculate the central island, splitter island and sight distance. As a final product of this study, we propose to convert the existing flyover to a roundabout, which will show the benefits for sustainability. Based on the following analysis, we had selected this particular location as a study area to convert the existing intersection to a roundabout and determine the suitability of a roundabout intersection.

1. Traffic flow is the same in all four directions.
2. The maximum traffic volume is 3000 vehicles per hour and the minimum is 500 vehicles per hour.
3. The proportion of right-turning traffic is very high, typically over 30%.
4. The study area is a four-way intersection and there is no provision for right-turning traffic.

2.2 Study Area

For the present study, Porur-Chennai, India is selected. The road section is shown in (Fig. 2). The traffic on the road consists of bicycle, car, three-wheeler (auto-rickshaw, loader, tempo) and bicycle, heavy vehicle (multi-axle bus, truck). The aim of the study is to design a new roundabout, mainly focused on intersections with only four legs intersecting at almost equal angles. The video data collection was carried out to obtain the current traffic volume, which is the main input for the design of a roundabout. The data collection was carried out over a period of eight hours, from 7.30 to 11.30 in the morning and from 14.30 to 18.30 in the evening on a typical working day, using a handycam from the terrace of an apartment building close to the junction.

Figure 2 Showing the Study Area

2.3 Vehicular Data Collection

In this study, the traffic volume was calculated using the video graphic method by counting the different types of vehicles approaching the intersection from all four approaches and then multiplying the values by the common factor called Passenger Car Unit (PCU). Traffic volumes were extracted for all the five classes of vehicles considered, namely two-wheelers, three-wheelers, passenger cars, light commercial vehicles (LCVs) and heavy commercial vehicles (HCVs). The class-wise traffic volumes observed from the video were converted into Passenger Car Units (PCU) using the PCU factors suggested in the IRC guidelines [3]. The PCU factors used were 0.75 for two-wheelers, 1 for three-wheelers, cars, LCVs and 2.8 for HCVs. It was found that between 9 and 10 a.m. was considered to be the maximum traffic volume compared to other hourly volumes during the morning hours. Similarly, during the evening hours, between 16.45 and 17.45, a maximum traffic volume was observed. The overall composition of the different vehicle categories also shows that there are 98% motorised and 2% non-motorised vehicles in (Fig.3). The distribution of vehicles per hour from the four entry lanes to the other lanes is shown in Table 1 and the traffic approaching the roundabout is shown in (Fig. 4).

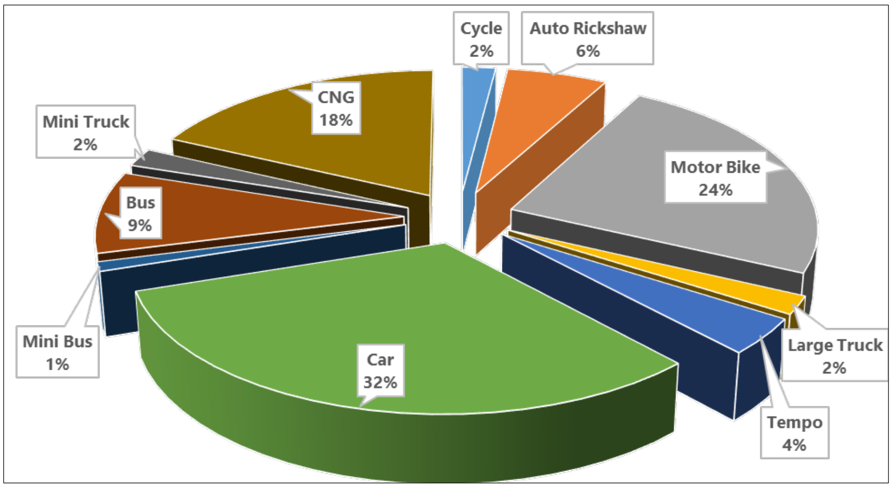

Figure 3 Showing Overall Composition of Vehicle

Table 1 Vehicle per hour Distribution from Four Entry Lane to Other Lanes

Vehicle travelling from	Vehicle travelling to	Flow (PCU/hr)	Total Flow (PCU/hr)
North	Straight	650	1393
	Left	418	
	Right	325	
West	Straight	510	1430
	Left	415	
	Right	505	
East	Straight	510	1264
	Left	200	
	Right	554	
South	Straight	355	1155
	Left	420	
	Right	380	

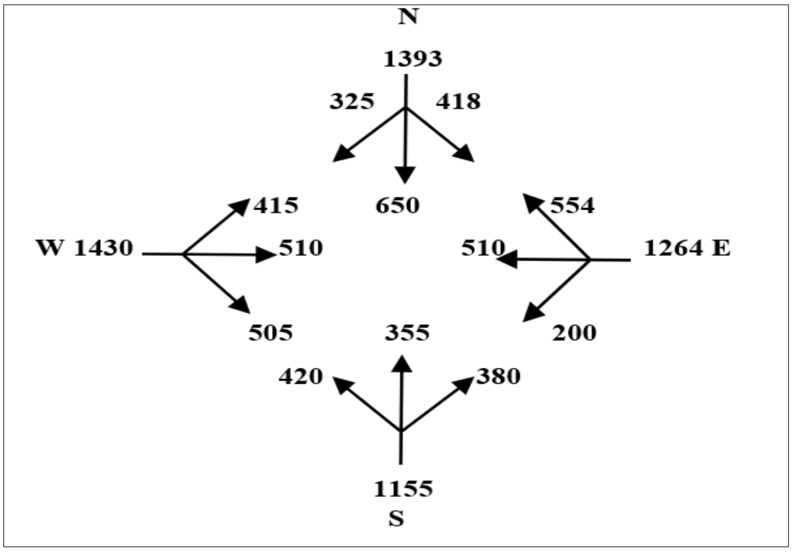

Figure 4 Showing Vehicle per Hour Distribution from Four Entry Lane

3 Design of Roundabouts Intersections

Roundabouts are designed to control the flow of traffic at junctions without the need for stop signs or traffic lights.

3.1 Shape of the roundabouts

The different types of roundabouts are circular, elliptical, turbine, tangent, etc. The shape of the roundabouts can be selected based on the number of lanes and the angle of intersection between the roads. In this study area, the circular shape is preferred because it is a four-armed intersection, where all roads of equal importance carrying approximately equal volumes intersect at approximately equal angles.

3.2 Design Speed

The IRC -65 has recommended a design speed of 30 km/h (generally 32 km/h) for roundabouts in urban and restricted areas. The elevated roundabout bridge has speed breakers in the entry ramp, which slow the vehicle and thereby reduce the speed.

3.3 Radius of curvature

Radius of curvature at entry point may be calculated by using the following formula as per IRC-65:1976,

$$e + f = \frac{V^2}{127R}$$

Where,
e – Superelevation rate
f – Friction factor
V – Design speed (in km/h)
R – Radius of curve at the entry of roundabouts (in m)
In a roundabouts, it is not possible to provide an adequate super elevation on the roads and hence the value of e = 0 in the above equation.

$e + f = \frac{V^2}{127R}$ and $e = 0$

$$f = \frac{V^2}{127R}$$

Radius of Curve, $R = \frac{V^2}{127f}$

3.4 Radius of the curve at Exit

The radius of the curve at the exit should be greater than the radius of the central island and the radius of the curve at the entrance. In general, the radius of the curve at the exit is 1.5 to 2 times the radius of the curve at the entrance. Radius of exit curve = 1.5 to 2 x radius of entry curve. In the curves of a roundabout at the exit point as per IRC-65:1976,

$$\text{Centrifugal Ratio, } \frac{P}{W} = 0.2 \text{ to } 0.4$$

3.5 Radius of the Central Island

The radius of the central island is kept larger than the radius of the curve at the entrance. In general, radius of central island = 1.33 x radius of entrance curve.

3.6 Entry and Exit Angle

The entry angle should be 600 and the exit angle should be less than the entry angle. The exit angle should be small, even tangential.

3.7 Weaving Length

The weaving length is measured along the centre of the one-way road, between the channelling islands. In practice, the length over which vehicles can weave in or out may be less than this length, taking into account that a weaving movement is equal to the change in lateral displacement.

3.8 Width of Roundabout Carriageway

The width of the carriageway at the entrance and exit of a roundabout is determined by the movement of traffic entering and leaving the roundabout. The rate of traffic growth over the design period should also be considered. In general, the IRC recommends that the minimum carriageway width should be at least 5m with the necessary widening to allow for the curvature of the road.

The carriageway width consists of two groups

1. Width of non-weaving section
2. Width of weaving section

3.8.1 Width of the non-weaving section*

The width of the non-weaving section of the roundabout is equal to the widest single entry of the roundabout and generally it should be less than the width of the weaving section.

3.8.2 Width of the weaving section

The width of the weaving section of the roundabout should be one traffic lane width (equal to 3.5 m) wider than the main entry as per IRC-65:1976,

Width of the weaving equation, $\frac{e_1+e_2}{2} + 3.5$

Where, e1 – Width of the entry (in m)

e2 – Width of the non-weaving section.

3.9 Conflict Points

It can be seen that the number of vehicles travelling on the Porur highway is very high, i.e. 650 PCUs from north to south and 554 PCUs from east to north, as can be seen in (Fig. 5).The next step is to determine the inflow and outflow volumes in each of the access roads. For the calculation of conflict points, different vehicle classes are converted into PCU (Passenger Car Units). The conflict points for the Porur junction after interpretation and analysis of the traffic data are found and presented in (Fig.5). It can be seen that the sum of inflow and outflow was found to be maximum in the Porur (north) main road, i.e. about 2717 PCUs.

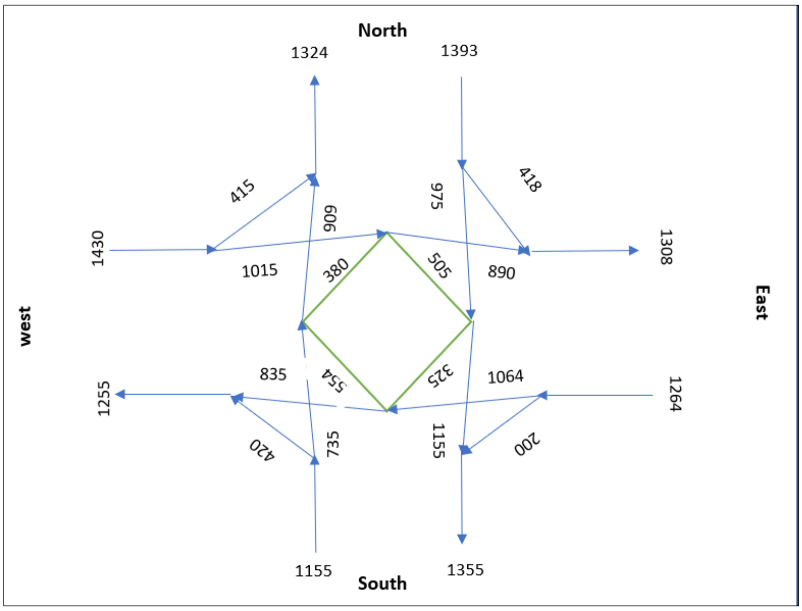

Figure 5 Showing the conflict point of the intersection.

3.10 Capacity of the Roundabout

The geometric design of the roundabout should be capable of holding the traffic flow in all directions until the design period. The practical capacity is the same as the weaving capacity, which can accommodate the lowest traffic. The capacity of the intersection (or roundabout) depends on the following factors, as shown in Table 2.

1. Width of the weaving section
2. Average width of entry into the roundabout
3. Weaving length
4. Proportion of weaving traffic

The weaving capacity can be calculated from the following section as per IRC-65:1976,

$$\text{Practical capacity, Qp} = \frac{280\,w(1+\frac{e}{w})(1-\frac{p}{3})}{(1+\frac{w}{l})} \qquad (1)$$

Where,

w – weaving section width (in m) – ranges from (6 to 18m)

e - Average of both the entry width e1 and e2

$\frac{e}{w}$ – Ratio of e and w – should be within 0.4 to 1.0

l –Length of the weaving section (in m)

P – Proportion of the weaving traffic – ratio of sum of crossing traffic (b,c) flow to the total traffic flow on the weaving section (a,b,c,d) $= \frac{b+c}{a+b+c+d}$ (varies from 0.4 to 1.0)

Table 2 Shows the parameters for the Design of Roundabout

S.No	Design Parameter	Units
1	Design speed V	30kmph
2	The width of carriage way at entry and exit	7.5m
3	Average width of entry e1 and width of non weaving section e2 (e) e1=13m e2=13m	13 m
4	Width of the weaving equation (w) $= \frac{e_1+e_2}{2} + 3.5$	16.5m
5	Length of weaving section L = 4 * W (Which is in between 18 to 90)	66 m (approved)
6	$\frac{w}{l}$ (This is in between 0.12 to 0.40.)	0.25 (approved)

3.11 Parameters of various approaches

The next step is to find out the diverging, merging and weaving traffic from each of the four approach roads. This helps to find out the section where the proportion of the weaving traffic (p), i.e., ratio of sum of Weaving ($b + c$) to the total traffic ($a + b + c + d$) is maximum. For the present intersection, the maximum proportion was found to occur between Valsarvakkam(south) and Guindy (East). The maximum weaving occurs in S– E section and P value is 0.80 which lies in between 0.4 to 1

a) Poonamallee to Valsarvakkam(N-E)

$$P_{NE} = \frac{510+380+650+325}{510+380+650+325+505+418} = 0.6689$$

b) Poonamallee to Kundrathur(N-W)

$$P_{NE} = \frac{510+505+355+554}{415+380+510+505+355+554} = 0.7076$$

c) Valsarvakkam to Guindy(S-E)

$$P_{NE} = \frac{510+554+650+505}{510+554+650+505+200+325} = 0.808$$

d) Guindy to Kundrathur(S-W)

e) $$P_{NE} = \frac{355+380+510+325}{355+380+510+325+554+420} = 0.6171$$

The maximum weaving occurs in S– E section and P value is 0.80 which lies in between 0.4 to 1

The next step is to calculate the practical capacity the rotary can handle for the given geometric conditions and proportion of weaving traffic to total traffic. The empirical formula to calculate the capacity of the rotary is given below [3].

$$Q_p = \frac{280\, w(1+\frac{e}{w})(1-\frac{p}{3})}{(1+\frac{w}{l})}$$

$$= \frac{280 * 16.5(1+\frac{13}{16.5})(1-\frac{0.808}{3})}{(1+\frac{16.5}{66})}$$

$$= 4806.4 \text{pcu/hr}$$

The practical capacity of the rotary using equation was calculated as 4806 PCUs which is well above the maximum value of sum of inflow and outflow volumes, i.e., 2717 PCUs. Hence the design can be considered adequate to handle the present approach traffic volumes and finally, the drawing of the proposed rotary intersection was prepared using AutoCAD as shown (Fig.6).

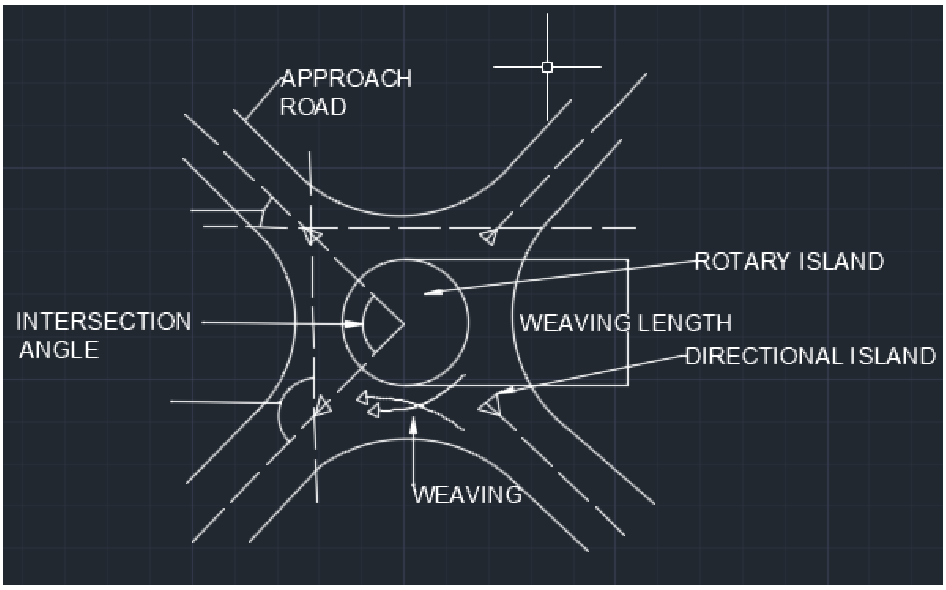

Figure 6 Showing the Design of Roundabout

4 Conclusion

Roundabouts are a type of circular intersection or junction that are becoming more common in surrounding communities as evidence of their benefits grows. As well as being safe, they improve traffic flow and are cost effective. Left-hand, right-hand (T-bone) and head-on collisions are virtually eliminated by a roundabout. The elevated roundabout separator at Porur junction is proposed for the following reasons,

- It can withstand heavier traffic congestion than a normal grade separator.
- It has more safety, functional performance, economic impact, environmental impact, traffic calming, pedestrian safety and aesthetic appearance than a normal grade separator.

- As there are four lane entrances and heavy right turning movements in almost all entrances, a raised roundabout is proposed.

The above problem can be solved by constructing an elevated roundabout. By reducing the chances of accidents, traffic congestion can be drastically reduced, which also helps to reduce pollution.

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