ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 5.2
IJAR 2017; 3(8): 452-462
www.allresearchjournal.com
Received: 06-06-2017
Accepted: 07-07-2017

Anirban Deshmukh
Post Graduate,
Department of Civil Engineering (Infrastructure),
Birla Institute of Technology & Science, Pilani, Rajasthan, India

Correspondence
Anirban Deshmukh
Post Graduate,
Department of Civil Engineering (Infrastructure),
Birla Institute of Technology & Science, Pilani, Rajasthan, India

The effects of vehicle traffic flow characteristics on capacity at Rotary in Bhubaneswar city (India)

Anirban Deshmukh

Abstract

Rotary or roundabouts are becoming more popular and efficient replacing signalized and stop controlled intersections around the world. Since its inception in in early 1960s, roundabouts are used to replace traditional traffic circles or channels. As roundabout forces the user to slow down the vehicle and enter the rotary, causing less congestion, accidents, decrease in conflict points and thus increase the vehicle traffic flow more smoothly and with better efficiency and sometimes beating that of signalized and stop-controlled intersections. Though with better vehicle flow, vehicle emissions due to fuel consumption will decrease, roundabouts which are congested due to poor capacity will instead increase the emissions and lead to congestion instead. Occurrence of unwarranted delays, queue formation and speed change cycles for approaching traffic have a significant impact on congestion and air quality in the adjacent areas. For study purpose, Master Canteen Chowk roundabout in Bhubaneswar city was selected. There are several analytical and statistical methods that allow the user to evaluate the capacity of a roundabout. This paper focuses on finding out peak hour and capacity of the rotary and thus analyze its reliability in providing the traffic flow service for present time and near future. Also, increase/decrease in emissions has a direct relationship with traffic flow characteristics. With the help of obtained results, a brief discussion has been included quoting past researches of reliable authors.

Keywords: Roundabouts, rotaries, traffic control, transportation engineering, infrastructural planning

Introduction

Roundabouts have several concepts and characteristics that are unique to its design and utility. Roundabouts consist of a circulatory roadway and three or more approaches with entry and/or exit lanes intersecting in a circular manner. When roundabouts operate at full capacity, they offer minimal vehicle delays than other intersection forms. Roundabout capacity for entry is the maximum rate at which vehicles can reasonably be expected to enter the roundabout from an approach during a given time period under prevailing traffic and geometric conditions. An operational analysis process considers a precise set of geometric conditions and traffic flow rates defined for a 10/15 minutes analysis period for each entry. While consideration of Average Annual Daily Traffic volumes (AADT) across all approaches it is useful for a planning purpose. Analysis of this shorter time period is critical to assessing the level of performance of the roundabout and its individual components. The capacity of the entire roundabout is not considered, as it depends on many factors.

A four-legged roundabout with roadways intersecting perpendicularly should provide that the traffic volumes are reasonably balanced and the geometry does not deviate substantially. The focus of this project is to compute the total and individual capacity of the roundabout for different motorized and non-motorized vehicles at peak hour on various types of lanes. In each case for consideration of lane, the capacity of the entry or approach is computed as a function of traffic on the other (conflicting) approaches, the interaction of these traffic streams and the intersection geometry. For a properly designed roundabout, the yield line is the relevant point for capacity analysis. Capacity provided at the yield line is called the approach capacity. Entry width and a number of geometric parameters decides approach capacity. It is important on multilane roundabouts to balance the use of each lane, because otherwise some lanes may be overloaded while others are underused. Poorly designed exits may influence driver behavior and lane imbalance and congestion at the opposite leg can be caused.

Literature Review: 30 mph or less speed can be achieved to slow down the vehicle using a good roundabout design. Vehicles paths can be deflected once within the circulatory roadway by using the central island. Figure 1 represents vehicles paths being deflected by Central Island.

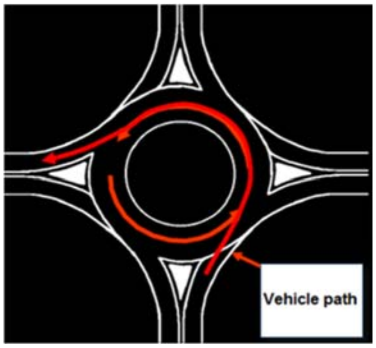

Fig 1: Deflections of Vehicle Path by Central Island

Almost all roundabouts except mini-roundabouts have provision for raised splitter islands. The traffic moving in opposite directions are splinted by design of Splitter Island as they approach and depart from the roundabout and to provide opportunities for pedestrians to cross in two stages. The characteristic of a mini roundabout is that it may consist of splitter islands. Previous researches have noted that roundabout decreases the conflict points and increase vehicle traffic flow more smoothly and with better efficiency and sometimes beating that of signalized and stop-controlled intersections. Generally, a roundabout consists of 8 conflict points (single-lane roundabout) as compared to 32 conflict points that of a traditional intersection (conflict points are for 4 single-lane approaches). Figure 2 gives a clear idea about conflict points for traditional sinter sections and roundabouts.

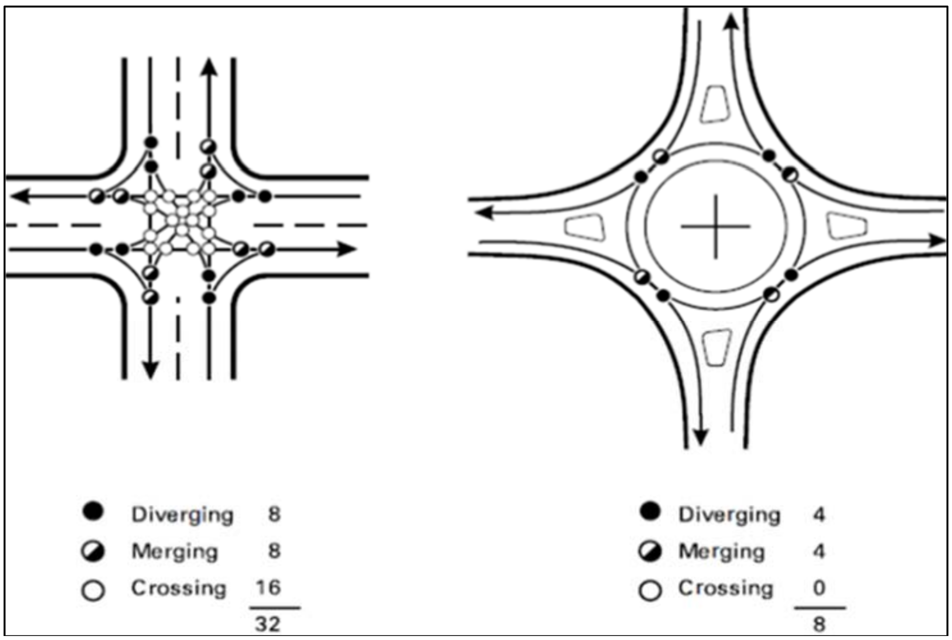

Fig 2: Conflict points for intersection with 4 single-lane approaches

Roundabouts have several of key benefits over traditional traffic signals depending on the conditions. As, conflict points are reduced from 32 to 8, it nearly eliminates the head-on collision chances, also reduce the crash severity. The reduced traffic speed at rotary provides a more controlled traffic over other options. Many researches have concluded that roundabouts can be more safe and efficient because of two characteristics - user has to enter traffic to yield to circulating traffic and geometric restraints slows down the vehicle before entering in it. The drivers need not to stop, only just requires to position the vehicle to the available acceptance gap to merge with circulating traffic. When a roundabout function at its peak capacity or lower, it offers lesser vehicle delays than the other type of intersections (Rahmi, A. 2009) [13]. It is not at all necessary the traffic to come to a total stop at a rotary when there is no conflict point. Whatever queues formed will continue to move, a luxury that is not present in either stop controls or traffic signal intersections.

A roundabout is made up of circular roadway with 3 or more approaches with entry and/or exit lanes. The vehicles entering the rotary is termed as “entering flow” and based on their lane occupancy, they are designated – on left or right lane. When the vehicles are on the circular roadway, passing in front of the approach are labelled as ‘circulating flow’ and they either occupy the inside or outside lane, the inside lane being the nearest to the center island. Figure 3 represents these definitions.

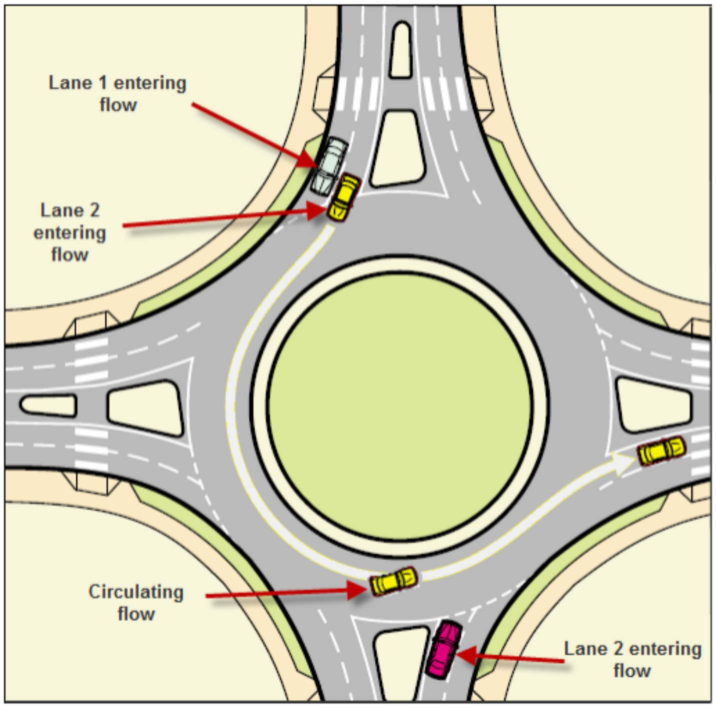

Fig 3: Entering flows and circulating flows at roundabouts

A "model" will relate to a simulation model that gauges various features and performances of an intersection or network. "Gap" is defined as the time and space that an entering vehicle requires to merge effectively and securely between two consecutive vehicles. (Flannery A. *et al*, 1996) [4]. This time and space is measured only when the ingoing vehicle is at the yield line when the gap starts. "Follow up time" is defined as the time between one parting vehicle from the minor pathway and next departing vehicle using the same gap under continuous queuing (Flannery, A. *et al*, 1996) [4]. Under a prevailing traffic condition and geometric feature, for a given time period, the maximum rate of vehicle that can reasonably be expected to enter the rotary from each entry leg gives the capacity for said rotary and each leg (FHWA, 2000) [3]. This capacity is obtained as a function of traffic on the conflicting approach which in this case is the circulating traffic. Figure 4 shows an example of roundabout pavement markings.

Geometric factors include entry width, circulating roadway width, number of lanes (entry and circulating roadway), and inscribed circle diameter and entry radius. Geometric dimensions and some definitions are illustrated in Figure 5.

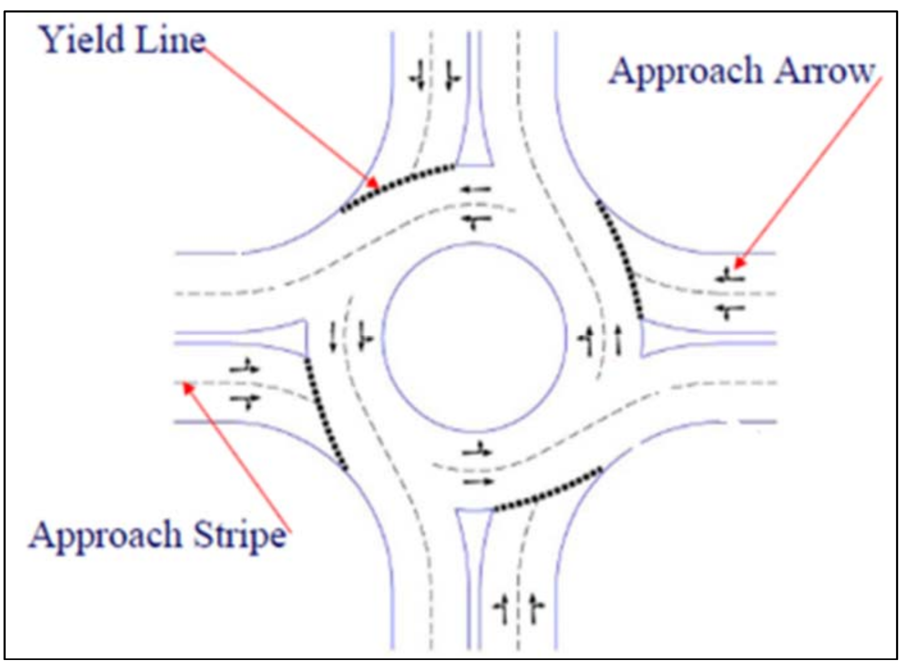

Fig 4: Roundabout pavement markings (Vaiana, R. 2007)

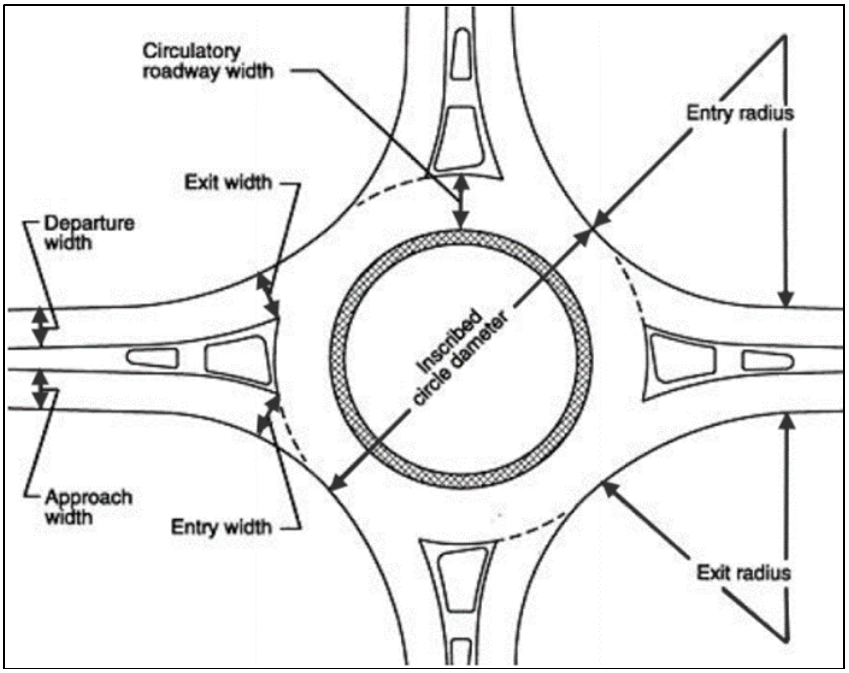

Fig 5: Basic geometric elements of roundabouts (NCHRP 3-65. 2004) [10]

Study Area: For the project, the best suitable study location in Bhubaneswar city was 'Master Canteen Chowk'- where the four-legged roundabout is situated. Figure 6 is provided below to give a detailed glimpse of the study location.

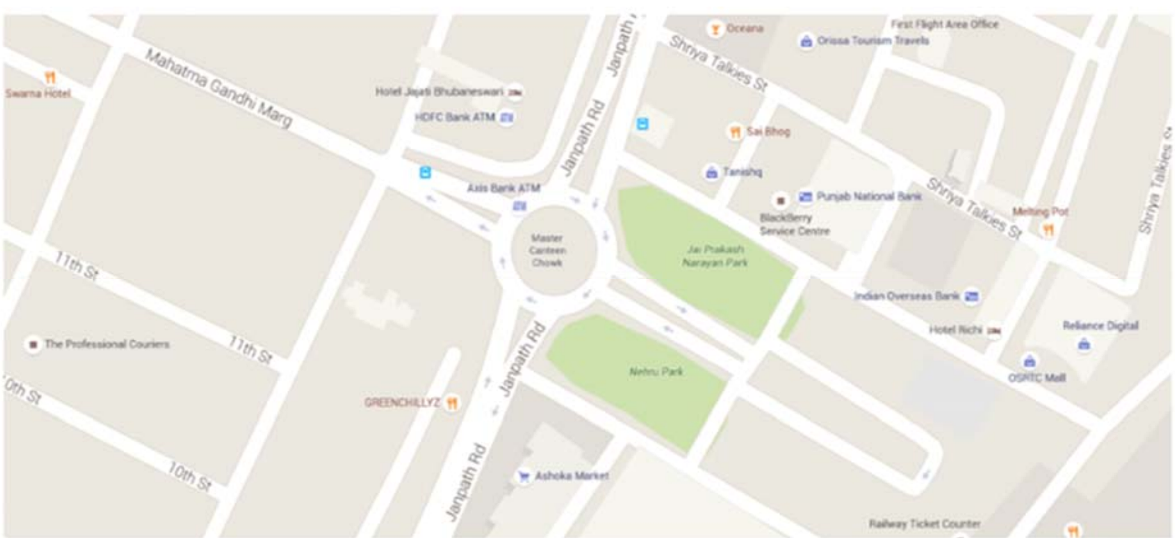

Fig 6: Master Canteen Chowk, Bhubaneswar (Google Maps)

From figure 6, it can be seen that opposite to Railway Station, the end of the rotary connects to Mahatma Gandhi Marg. The other two side of the rotary from the exit point of Mahatma Gandhi Marg leads to Janpath road, where the left side leads to Satya Nagar and the right-side leads to Airport.

Data Collection and Calculation

Peak Hour traffic flow: "Peak hour" is a part of the day during which traffic congestion on roads and crowding on public transport is at its highest. Normally, this happens twice every weekday—once in the morning and once in the afternoon-evening, the times during when the most people commute. Peak hour is valuable in case of traffic engineering as it gives the maximum traffic flow of a traffic section on a day, thus also helps in deciding the capacity of that section. The total peak hour for different kind of vehicles is computed in terms of Passenger Car Unit (PCU). A Passenger Car Unit is essentially the impact that a mode of transport has on traffic variables (such as headway, speed, density) compared to a single car. Capacity is measured in terms of PCU/hour only. Since this project is based on multi-lane rotary, the PCU Equivalents in the Draft Revision of IRC Guidelines for capacity was followed (pg. 519, table 21.3, *"Traffic engineering and Transport Planning"* by Dr. L.R. Kadiyali)

Table 1: Proposed PCU Equivalents in the Draft Revision of IRC Guidelines for Capacity

Vehicle Type	Multilane roads
Passenger car or pick up van	1
Bus	4.5
3-wheeler(auto-rickshaw)	1.6
Motorized 2-wheeler	0.5
Cycle	0.6
Cart/ carriages	4

Calculation to obtain Peak Hour traffic flow: The values that are obtained in the field are put into Microsoft Excel and the pick hour values are obtained. Table 2 gives a brief view at the readings and calculated results and table 3 gives results for all the routes.

Table 2: Vehicles coming from Airport [entering rotary]

		Car	**Buses**	**Auto Rickshaw**	**Motor Cycles**	**Carriages**	**Cycles**	**Others**	**Traffic Volume in PCU**	**Cumulative One Hour Traffic**	
From	To	1	4.5	1.6	0.5	4	0.6	1			
17:00	17:10	77	7	101	377	1	7	0	467		
17:10	17:20	91	4	93	368	2	8	6	461	3004	
17:20	17:30	89	6	105	375	5	11	4	502	3081	
17:30	17:40	108	9	115	389	2	10	2	543	3235	
17:40	17:50	99	5	105	417	0	7	1	503	3406	
17:50	18:00	118	6	103	432	0	4	0	528	3538	
18:00	18:10	121	8	101	447	0	1	1	544	3685	
18:10	18:20	144	7	117	465	2	11	5	615	3831	
18:20	18:30	161	5	142	501	1	8	3	673	3946	
18:30	18:40	187	6	129	465	2	14	6	675	3955	
18:40	18:50	169	7	112	490	4	9	4	650	3852	
18:50	19:00	181	6	128	481	3	11	2	674	3788	
19:00	19:10	172	5	131	472	2	12	4	659	3711	
19:10	19:20	157	5	117	467	3	11	5	624	3593	
19:20	19:30	126	4	123	431	1	13	1	569	3486	
19:30	19:40	166	6	127	409	1	7	3	612	3408	
19:40	19:50	145	9	111	395	1	8	4	573	3391	
19:50	20:00	136	6	120	382	0	7	5	555	3289	
20:00	20:10	127	5	131	375	0	5	3	553	3200	
20:10	20:20	131	4	117	379	2	14	4	546	3078	
20:20	20:30	113	6	129	362	3	9	7	552		
20:30	20:40	124	3	113	355	0	17	4	510		
20:40	20:50	104	4	115	337	0	11	3	484		
20:50	21:00	95	2	107	305	0	8	1	434		
Total at Peak Hour=		1027	34	759	2876	15	65	24	Max. Value of Peak Hour Traffic=		3955

Table 3: Maximum Peak Hour Traffic values for all routes

		Maximum Peak Hour Traffic
	Vehicles coming from Airport	3955
Entering Rotary	Vehicles coming from Mahatma Gandhi Marg	1847
	Vehicles coming from Satya Nagar	3978
	Vehicles coming from Railway Station	677
	Vehicles going towards Airport	3927
Leaving Rotary	Vehicles going towards Mahatma Gandhi Marg	1749
	Vehicles going towards Satya Nagar	3978
	Vehicles going towards Railway Station	704

From table 3, it can be seen that the peak hour is coming between 6pm to 7:30pm. As main concern is about peak hour for a given day, all the readings of morning to noon time were ignored as it was noticeably less than the readings in the evening to night time. Also, as the readings are taken on different days & 100% accuracy on vehicle count was not achieved, the no. of vehicles entering the rotary is not equal to the no. of vehicles leaving the rotary. But this should not be the case. So, the traffic that is entering the rotary is considered to calculate the capacity of the Master Canteen Chowk roundabout.

Rotary Capacity: It is the road's ability to accommodate ongoing traffic volume. The vehicles can reasonably be expected to cross at the maximum hourly rate. This traffic crosses on a roadway during s specific time period under prevailing traffic roadway and controled condition.

Fig 7: Traffic flow of a road section

The traffic operations at a rotary capacity are three types namely diverging, merging and weaving. All the other conflicts can be converted into these mentioned three types which are less severe conflicts. These movements are shown in the figure 8.

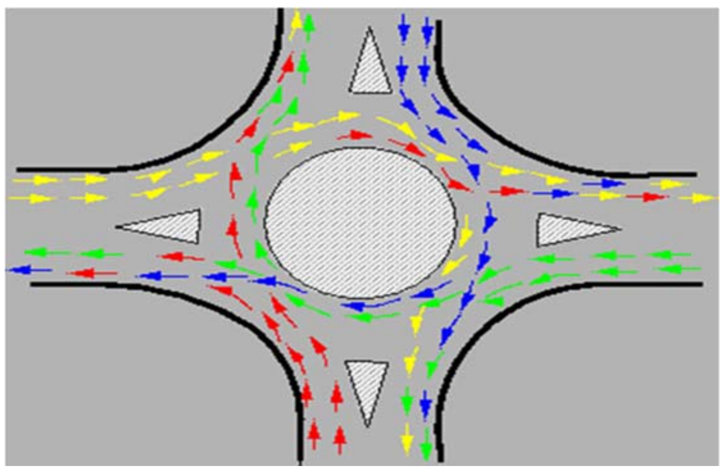

Fig 8: Traffic operations in a rotary

Formula associated with Capacity calculation: The capacity of each weaving section is directly used to determine the capacity of a rotary. Geometric layout including entrances, exits and the percentage of wearing traffic. A Typical rotary and the important design elements are shown in figure 9 (Kadyan S., 2016) [9].

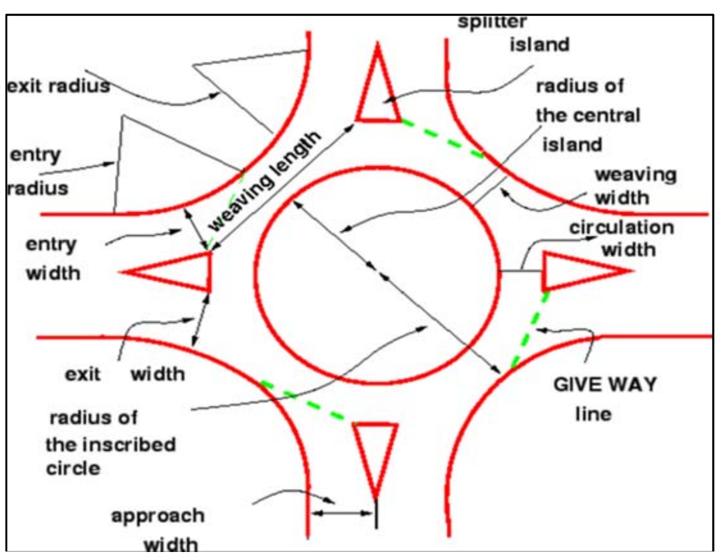

Fig 9: Design elements of a rotary

The following formula (which is the modification of the well-known Wardrop Formula) (page 259, L. R Kadiyali. “Traffic Engineering and Transportation Planning”. Khanna Publishers, New Delhi, 2016.) is proposed by the Transport and Road Research Laboratory (U.K.) which has pioneered research and development on this aspect :

$$Q_w = \frac{280w\left[1+\frac{e}{w}\right]\left[1-\frac{p}{3}\right]}{1+\frac{w}{l}}$$

where,
Q_w = practical capacity of the weaving section of the rotary in PCU/hour
e= the average entry and exit width, i.e., $\frac{e_1+e_2}{2}$
w = weaving width (within the range of 6-18 meters). The width of the weaving section should be higher than the width at entry and exit. Normally this will be one lane more than the average entry and exit width. Thus, weaving width is given as,

$$w_{weaving} = \frac{e_1+e_2}{2} + 3.5m$$

l= length of weaving section between the ends of the channelizing islands in meters
and
p= proportion of weaving traffic to the non-weaving traffic

Figure 10. shows four types of movements at a weaving section, a and d are the non-weaving traffic and b and c are the weaving traffic.

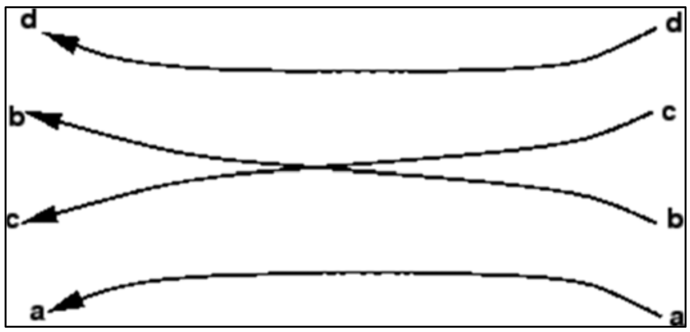

Fig 10: Weaving operation in a rotary

Therefore, $p = \frac{b+c}{a+b+c+d}$
Sample Notations for Capacity Calculation:

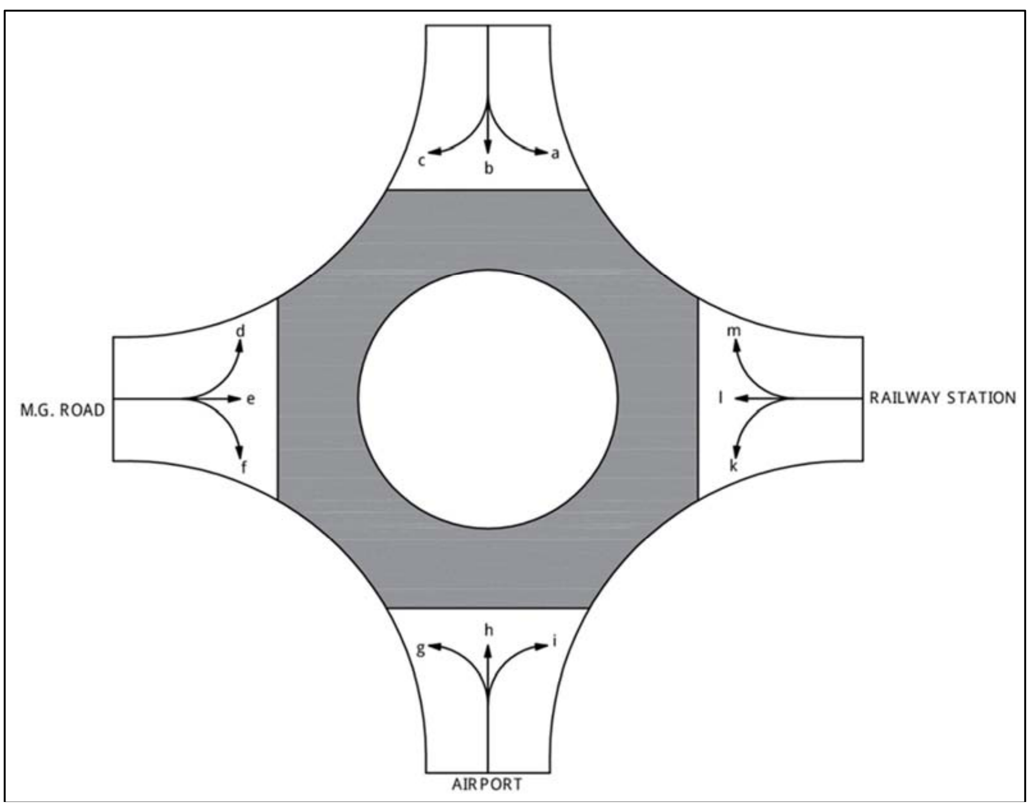

Fig 11: Sample Distribution of Vehicles

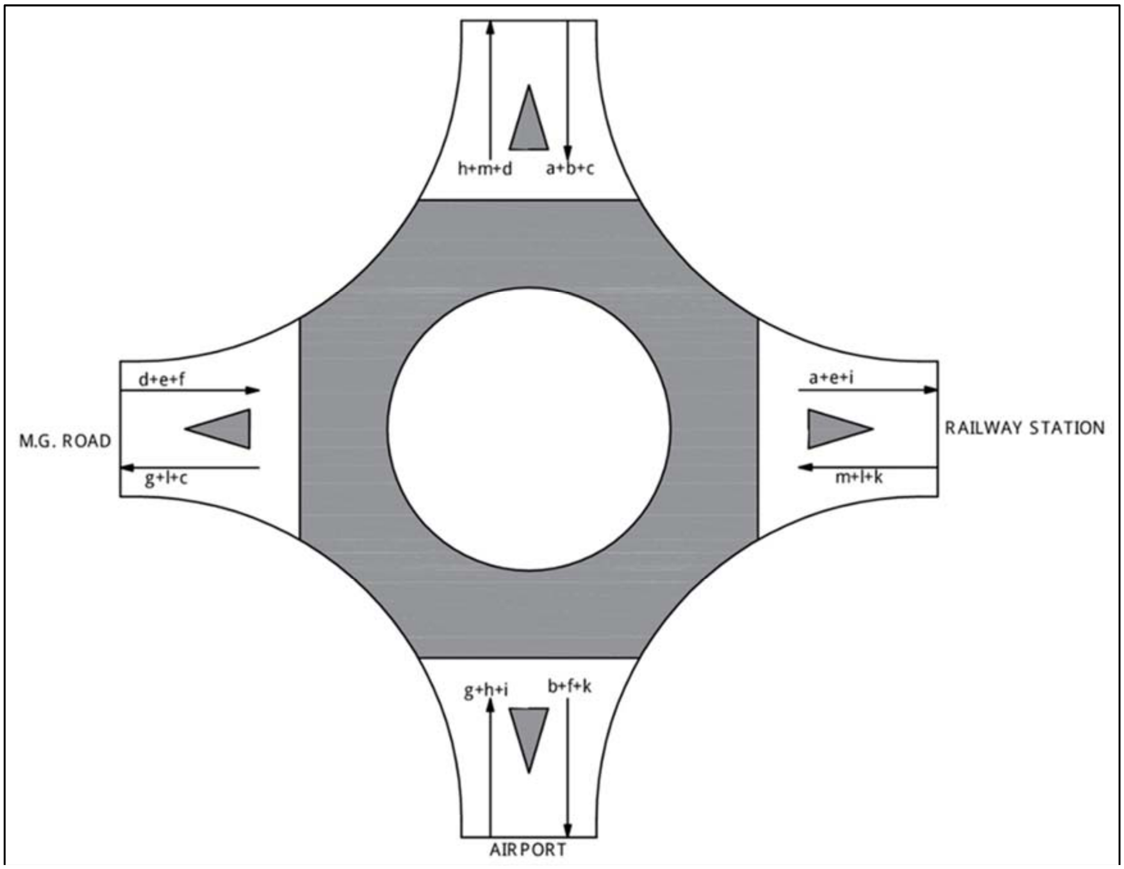

Fig 12: Sample Entering and Leaving Calculation

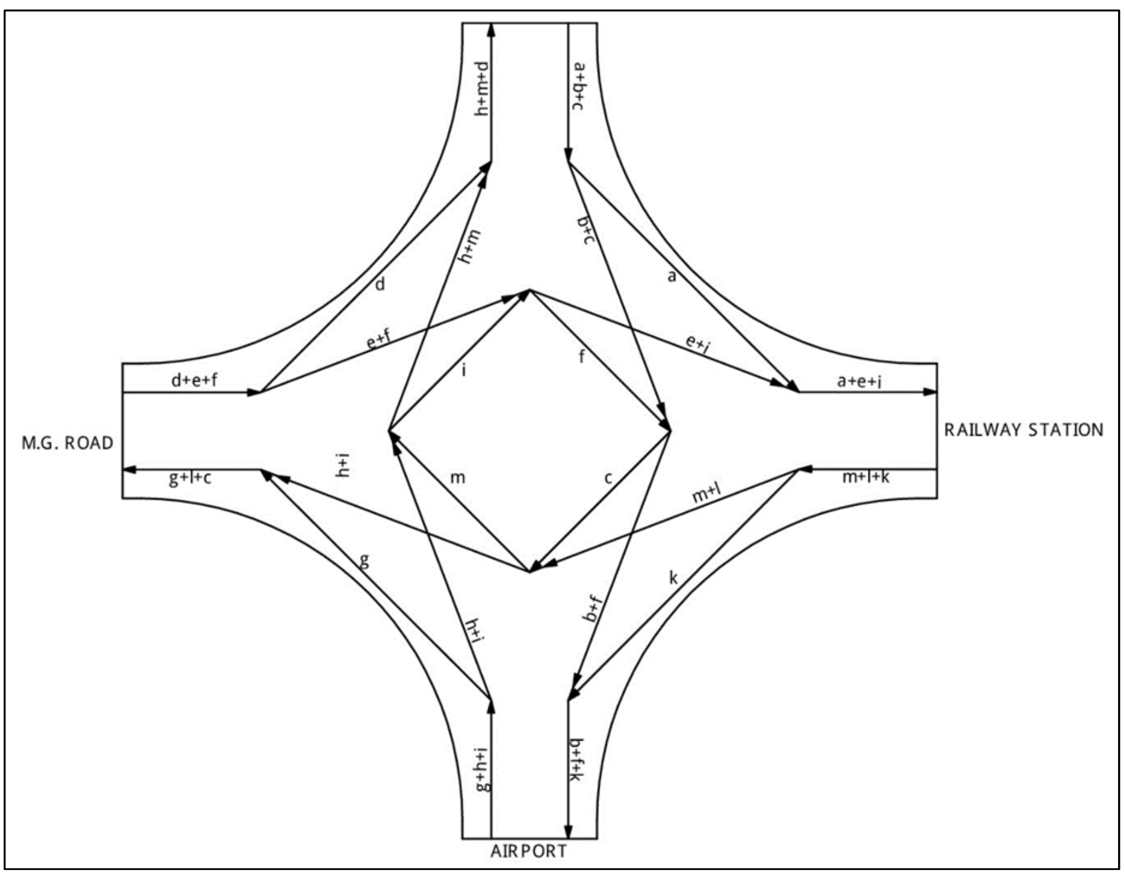

Fig 13: Sample Detailed Distribution of Vehicles

Capacity Calculation

Table 4: Capacity for Car in terms of PCU

Approach 1 (From Railway Station)			**Numerator Value in p**	
k value (Left)	l value (Through)	m value (Right)	Weaving Traffic 1	1231
82	31	86	Weaving Traffic 2	1234
			Weaving Traffic 3	1089
Approach 2 (From Airport)			Weaving Traffic 4	1106
g value (Left)	h value (Through)	i value (Right)		
197	747	83	Denominator Value in p	
			Total Traffic Crossing 1	1564
Approach 3 (From Mahatma Gandhi Marg)			Total Traffic Crossing 2	1544
d value (Left)	e value (Through)	f value (Right)	Total Traffic Crossing 3	1372
215	38	235	Total Traffic Crossing 4	1404
Approach 4 (From Satya Nagar)			Proportion of Weaving Traffic	
a value (Left)	b value (Through)	c value (Right)	p value 1	0.787
98	882	228	p value 2	0.799
			p value 3	0.794
	e1 Value		p value 4	0.788
Entry Width 1	12.00		p average	0.792
Entry Width 2	8.00			
Entry Width 3	10.67	e Average	Capacity of the Rotary (in PCU) =	3944
Entry Width 4	12.00	10.67		
Weaving Width	w Value			
W.W. 1	15.43			
W.W. 2	13.50			
W.W. 3	14.70	w Average		
W.W. 4	15.44	14.77		
Weaving Length	l Value			
W.L. 1	47.75			
W.L. 2	43.60			
W.L. 3	42.10	l Average		
W.L. 4	46.15	44.90		

Table 5: Capacity in terms of PCU

Type of Vehicle	Capacity of the Rotary (in PCU)
Auto Rickshaw	3993
Bus	3979
Car	3944
Carriages	3932
Cycle	3865
Motor Cycle	3898
Others	3905
Total Vehicle Count	3950

Results and Discussions

The capacity of rotary in terms of PCU/hour are found to be 3993 for auto rickshaw, 3944 for car, 3979 for bus, 3932 for carriages, 3865 for cycle, 3898 for motorcycle, 3905 for others and 3950 for mixed (total) traffic flow. A total volume of 3000 veh./hr is considered as the desired upper limit and a volume of 500 veh./hr is the lower limit. Since, roundabout at the study location can accommodate more than 3000 veh./hr for either mixed traffic flow or one particular type of vehicle, it safely regulates all the vehicles safely without causing congestion for any time period of the day and the situation is unlikely to change in the foreseeable future.

In India increasing traffic volumes and congestion are two quickly developing problems facing our modern society. As a consequence, traffic engineers are looking for new solutions to these problems. More and more, circular traffic control measures are being installed throughout the country due to the advantageous traffic flow and safety attributes. As cities grow and change, so too should the transportation infrastructure. As more vehicles use the road system each day, transportation management agencies have a civic obligation to evaluate and update existing infrastructures to meet the public demands of today and tomorrow. Currently, drivers in India appear to use roundabouts less efficiently than models suggested in other countries around the world. In addition, geometry in the aggregate sense has a clear effect on the capacity of a roundabout entry. Every method, when formulated, has to consider some aspects of roundabout circulation in comparison to others such as geometric elements (circulatory roadway width, inscribed circle diameter, and splitter island width), characteristics of traffic flow (approach speed, circulating flow and entering flow) and behavioral features (minimum gap, rejected gap and follow up time).

Also, vehicular emissions have shown an increment over the years with the increase in traffic volume. Modern roundabouts can be useful in improving traffic flow as well as reduction in vehicular emissions and fuel consumption by reducing the vehicle idle time at intersections. And hence, thereby a positive impact on environment can be created. A wide variety of pollutants can be found in vehicular emissions, principal elements of these pollutants are carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_X), particulate matter (PM_{10}), oxides of sulfur (SO_X) and hydrocarbons (HC) or volatile organic compounds (VOCs), which impact on air quality with severe effects. These emissions shows variations with the engine design, air-to-fuel ratio, and characteristic of vehicle operation. With increment in vehicle speed, there is a reduction in NO_X emissions in grams/mile up to a speed of 30-40 mph and then it shows increment above this limit. With increment in vehicular speed, there is a reduction in CO, PM_{10} and HC or VOCs emissions grams/mile. The emissions of CO_2 and SO_X shows variations directly with fuel consumption and for any reference vehicle and different fuel combination. Aggregate emission levels shows variations as per the distance traveled and the pattern of patterns (Russell *et al*., 2002). Road and street intersections results in congestion by forcing vehicular traffic to slow down and stop in complex patterns. The longer the duration of stops, the more fuel that will be consumed, and this will result in increased amount of vehicular emissions. With a properly designed rotary, this problem is avoided, saving fuel consumption and thus emission.

A research was carried out by Alper *et al*. (2001) on the effect of arterial traffic signal timing and coordination on the vehicle emissions quantity. The researchers found out that though the delay was a factor in the amount of emission released by vehicle, but the acceleration phase in the driving cycle generated more emissions than the emission released in during the idling phase. The roundabouts would cause the vehicles to slow down and sometimes forces them to a stop before accelerating and merging with the circulating traffic.

Not only that, a rotary has several other key advantages which was observed during the study at Master Canteen Chowk rotary. They are – 1) Traffic flow is regulated to only one direction, thus elimination of severe conflicts between crossing movements can be achieved efficiently. 2) Accidents and their severity can be reduced resulting because of lower speed of negotiation and elimination of severe conflicts. 3) Traffic Police control are not required as rotaries are self-governing bodies. Despite some of distinct advantages by rotaries, there are few specific *disadvantages* observed. 1) All the vehicles are forced down to slow and negotiate the intersection inevitably. Hence, the cumulative delay is much higher in time duration than that of channelized intersection. 2) Even in the situation of relatively low traffic, the vehicles are forced to reduce their speed. 3) Rotaries require large area of relatively flat profile and constructing them is costly in urban areas. 4) The vehicles do not usually stop at a rotary, instead they accelerate and exit the rotary at relatively high speeds. Therefore, they are not suitable to allow pedestrian movements due to safety concerns.

Also, there were few limitations for the project, like: 1) The reading was taken for each leg but on different days, therefore the vehicles entering the roundabout was not equal to the vehicles leaving the roundabout in this study. 2) There is not a constant peak time for the roundabout as a whole, as the four-leg connected to the roundabout connects to four different places in the city of Bhubaneswar therefore the peak hour time came different for each leg. 3) 100% accuracy in counting the vehicle was not achieved due to limitations in video reading caused by either low light at night or big vehicles obscuring the view.

Conclusion

Traffic rotaries results in reduction of complexity of crossing traffic by forcing them into weaving operations. Traffic volume and share of turning movements are used to determine the shape of rotaries. Capacity assessment of a rotary is done by the analysis of the section having the greatest proportion of weaving traffic.

The project looks into the movement of traffic, peak hour time and peak capacity about a roundabout. Also 4 different legs of the roundabout are separately analysed to note the congestion level at each leg.

We know that the urbanization and industrialization are two of the most important features of modern civilization where India is still one of the countries having low degree of urbanization. The existing transport network, which was adequate for the needs of the town of the past, becomes overloaded and turns out to be incapable of handling the newly created transport demand which often leads to relocation of activities at the edge of the town. Whatever be the stage in the evolution of a city, unplanned growth can lead to either severe congestion in the City Centre or to urban sprawl thus bringing extreme pressure on the transport capacity. Increase in urbanization and accelerated growth of traffic not only causes severe congestion but increases road accidents. The deterioration of the environment, noise in the streets, high pollutant level in the atmosphere, vibration of buildings and visual intrusion are some of the serious concern nowadays. This project basically focuses on calculating the total capacity at peak hour and discuss effects of emissions from different kinds of vehicles so that various factors causing increase in pollutant level in the atmosphere, traffic congestion etc. can be understood and steps be taken to reduce and control it.

Roundabouts were used as a replacement to traditional traffic circles and rotaries. With the distinct characteristics of entering traffic yielding in circulating traffic and geometric constraints that slow down the entering vehicles, roundabouts are found to be more efficient than traffic circles. In some cases they are found efficient even than the signalized and stop-controlled intersections. Roundabouts often require drivers to decelerate, and reaccelerate, and this process can involve one or multiple stops. In the final conclusion it can be said that the main advantage of introducing a Roundabout is that the traffic flow is regulated to only one direction of movement which eliminates the severe conflicts between crossing movements. As we are concerned in reducing the accidents; so, 1) more rotary construction should be encouraged where traffic flow is high and signalized intersection can lead to more delay. 2) Designing of a rotary should be done anticipating the future growth in transport and major developmental demands.

References

1. AASHTO. A policy of geometric design of highways and streets 5th edition, 2004.
2. Capiluppi GF, Vaiana R, Gallelli V. Roundabout intersection: analysis for scenarios by micro-simulation. 4th international SIIV congress-Palermo (Italy), 2007.
3. FHWA. Roundabouts: an information guide. Report n. FHWA-RD-00-067. US Department of Transportation, 2000.
4. Flannery A, Datta T. Operational performance measures of American roundabouts. Transp. Res. Rec. 1996; (1572):68-75.

5. Google Maps.
6. HCM. Highway Capacity Manual" Transportation Research Board. National research council, 2000.
7. Highway Capacity Definition, Types & Factors Affecting Highway Capacity: http://www.aboutcivil.org/highway-capacity-definition-types-factors.html last accessed, 2017.
8. Kadiyali LR. Traffic Engineering and Transportation Planning. Khanna Publishers, New Delhi, 2016.
9. Kadyan S, Ahuja VK. A Study of Rotary Intersection at Panipat International Journal of Enhanced Research in Science, Technology & Engineering. ISSN: 2319-7463. 2016; 5(7).
10. NCHRP 3-65 Applying Roundabouts in the United States. National cooperative highway research program., (3-65) status report to the committee on Highway Capacity and Quality of Service, 2004.
11. NCHRP. 572a. Roundabouts in the United States. National cooperative highway research program. 2007, (572).
12. NCHRP 572b. Roundabouts in the United States. National cooperative highway research program. (572) appendix B, 2007.
13. Rahmi A. A roundabout case study comparing capacity estimates from alternative analytical models. 2nd Urban Street Symposium (Anaheim, California), 2003.
14. Russell Eugene, Srinivas M, Margaret R. Phase II-Lawrence, Olathe, and Paola Roundabouts. K-TRAN Interim Report KSU-01-04. Kansas State University, 2002.
15. Vaiana R, Gallelli V. Roundabout intersection: evaluation of geometric and behavioral features with VISSIM. Transportation Research Board, national roundabout conference (Kansas City, Missouri), 2008.