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Gap acceptance behavior and vehicle speed on roundabouts: Case study in India

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Abstract

Roundabouts perform better than other types of uncontrolled intersections when traffic flow is low to medium. Research works on roundabouts have proposed different methods to estimate the entry capacity of an approach leg. One such approach is based on gap acceptance behavior of the entering vehicles. This approach requires estimation of critical gap using gaps accepted and rejected by entering vehicles and measurement of follow-up time. This paper discusses the gap acceptance behavior and vehicle speeds on roundabouts under heterogeneous traffic condition. Gaps accepted and rejected by entering vehicle have been extracted by vehicle type. These are used to estimate critical gap by using maximum likelihood method. The maximum likelihood method is reported to have better efficiency and accuracy above other methods of critical gap estimation. The circulating flow has been counted for every 10 minutes interval and is correlated with critical gap and follow-up time. Similarly, speed at entry of an approach and in the circulating area of the roundabout is also estimated and correlated.

Keywords:Roundabout; critical gap; follow-up time; speed

1. Introduction

Intersection is defined as a junction laid at same level and roundabout is a kind of intersection, which is laid with a big size circular island at the center of the

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layout of the crossing roads. The shape of a circular island in the center (usually circular) is modulated to synchronize the traffic flow around it, traffic signal is not required in that sort of intersection, and traffic follows the driving at reduced speed around the central island. The driving style is based on either left side (clockwise traffic flow) driving as per the British standards or right side (Counter clockwise flow) driving according to the American standards. Amount of engagement and collision gets heavily reduced in roundabouts as compared to the simple intersections without traffic signal. Insertion of an island in roundabout slows down the traffic and hence reduces the possibility of the accidents and thus increases the safety. The traffic enters a roundabout after seeking a suitable gap in the circulating stream of vehicles thereby, the crossing conflicts which are the most severe are completely eliminated and converted to merging and diverging. Quantitatively, the number of conflict point reduces from 32 in a Two-Way Stop Controlled (TWSC) intersection to 8 in the case of a roundabout. Besides, during low flows, there is less likelihood of crashes due to over speeding vehicles as there are inherent geometric features in the approaches to a roundabout which discourage high vehicle speeds in approaches.

Today it is common to see traffic congestion at intersections with roundabouts during peak morning and evening hours. Sometimes, the traffic police have to intervene in the situation to regulate traffic flow. Otherwise it would be practically difficult to have normal traffic flows, especially at intersections roundabout, which is more dependent on driver behavior and traffic flow balance between approaches. This problem will continue and can be more difficult in the future because of the rapid growth in population and vehicle ownership. Therefore, it is necessary to determine the performance of roundabouts for the proper operation of traffic. Some of the problems associated with the implementation of roundabouts are:

- Problem of visibility caused by the plant or elevated masonry while vehicles enterinto the roundabouts. Consequently, the entry capacity of the roundabout is affected.
- Slowing down of traffic flow in circulation area with speeds dropping down below 30km/hr (the standard speed for traffic operation on the roundabouts) as per IRC-65(1976).
- Formation of queue at the entry approaches due to non-availability of gaps between the vehicles in the circulating traffic stream.

Therefore, there is a need to analyze the performance of roundabouts in terms of operational speeds, gaps accepted or rejected by the entry vehicle and the follow-up time available which defines the opportunity available to the following vehicles to merge in the circulating flow.

2. Literature review

A vast amount of literature is available in the area of roundabout performance with respect to gap acceptance parameter and speed of the vehicles. An attempt is made to organize the available literature to develop an understanding about the advantages and limitations of the available methods of critical-gap estimation, and to examine the areas which are still to be explored. Ashworth and Green (1966)measured gap from the rear of one vehicle to the front of the following vehicle. Adebisi (1982)defined gap as the major stream headway wholly available to a waiting vehicle from the minor road. Polus (1983)defined it as the time interval between two successive vehicles in the major road stream. Critical gap is an important parameter in gap acceptance behavior. A small variation in the critical gap would result in significant variation in the entry capacity Velan and Van Aerde (1996). Vasconcelos et al. (2012)reported that “a 0.5 s difference in the critical gap can result in capacity difference of up to 15%”. Raff and Hart (1950) defined critical gap as the size of the gap whose number of accepted gaps shorter than it is equal to the number of rejected gaps longer than it. HCM (Highway Capacity Manual, 2000)defined critical gap as the minimum time interval in the circulating flow that allows intersection entry for one entry vehicle. A particular driver would reject any gaps less than the critical gap and would accept gaps greater than or equal to the critical gap. All gaps less than the critical gap would be rejected and all gaps greater than or equal to the critical gap would be accepted. Another definition is that the critical gap is the gap that has an equal probability of being accepted or rejected (Polus et al., 2005).

Miller (1972) developed a simple gap acceptance model to compare nine different methods of critical gap estimation. Simulation study was used to generate artificial data and comparison was based on the central value estimated by each method. The study found that Ashworth method and maximum likelihood technique gave satisfactory results. Brilon et al. (1999)concluded that the maximum likelihood procedure and Hewitt’s method for estimation of critical gap give the best result and recommended to use these two methods for practical application. Guo (2010) found on the base of video survey of Shuma Square roundabout in Dalian, China that Ashworth’s method gave the highest value and other methods had a little difference.It is because Ashworth’s method uses only accepted gap, but modified Raff’s method and maximum likelihood methods use both accepted and rejected gaps.

Another aspect taken up in this paper is vehicle speeds on roundabouts. Federal Highway Administration proposed that merging traffic in the roundabout should reduce their speeds so that they can make it easily and safely inside the roundabout and synchronize easily with the other drivers(FHWA, 2000). Coelho et al. (2006) discovered that drivers are compelled to reduce their speedat the entry approach and accelerate the speed at the exit approach due to geometry of the roundabout, producing different speed profiles as compared with other types of intersection.

Hels and Orozova-Bekkevold (2007) have observed that probability of an accident is higher at roundabouts with bigger drive curves allowing higher driving speeds. Montella et al. (2012) proposed that the main variables controlling the roundabout speed are, deviation angle (angle between straight vehicle and the tangent along that curve), the deflection radius (shift in the path of the vehicle while moving from the road link), and the entry path radius.

Conclusively,it can be said that the above studies have helped to establish a firm base to study performance of roundabout in terms of gap acceptance and speed of the vehicles. The above studies of the research articles explain that best suited method for estimating the critical gap is MLM (Maximum Likelihood Method).

3. Data collection and extraction

Data collection is a very important part of any traffic engineering study and the success of the effort is heavily dependent on the quality of data. Proper identification of study sites is very important for gathering useful data. The requirement of the study was a roundabout located in an urban or sub-urban area. The city of Chandigarh was chosen for the study as it had some well-designed roundabouts. Chandigarh, capital of both the Indian states of Punjab and Haryana, is a union territory with well-planned roads and buildings. The population of the city has crossed the designed population and this has resulted in traffic problems. It is visible on the roundabouts in the form of slowing down of the traffic and the formation of queue. The city is divided into sectors from 1 to 47 of almost equal size. Most of the intersections of roads have four legged approaches. Two roundabouts were selected for the study purpose. The traffic and operational conditions of the two roundabouts are shown in Figure 1. The roundabouts are named as R25 and R37, where ‘R’ stands for a roundabout and number (25 or 37) represents the diameter of the central island in meters.

(a) R 25 **(b) R 37**

Figure1: Traffic and operational condition of roundabouts

Following points were considered in the selection of a roundabout:

- The roundabout preferably has fourapproaches which are mutually perpendicular to each other.
- The roundabouts are uncontrolled.
- There should be minimum interference from cyclists and pedestrians.
- No gradient should be present at any of the approaches.
- The parking bays or bus bays should be sufficiently away from the intersection.

The data collected at the roundabout can be classified broadly into two categories, inventory data and volume data. The inventory data includes the geometric details of the roundabout like central island diameter, entry width, approach width, etc. Volume data is about the volume of circulating traffic and its composition. This was done by using a video camera. The video was captured from 8 a.m. to 12 a.m. in the morning and 3 p.m. to 7 p.m. in the evening on a typical clear weekday. The inventory data of the selected roundabouts is shown in Table 1.

Table 1: Geometric Data of the Selected Roundabouts (in meters)

Geometric Parameters	*R25*	*R37*
Entry Width	7.0	8.5
Exit Width	7.0	8.5
Approach Width	6.7	7.5
Departure Width	6.7	7.5
Circulating roadway width	8.0	7.0
Central island diameter	25.0	37.0

Data was collected using video camera placed at a suitable location from where a complete view is obtained. A nearby multi-storey building served the purpose. The duration of the video was such that it could take into account the morning peak as well as the evening peak hour traffic. The video was analyzed to compute the circulating traffic in front of approach, the gap accepted or rejected, follow-up time, and entry speed on an approach section and within circulating section. This gap acceptance behavior of the entering driver is assumed to be homogeneous and consistent where in actual practice, it is not so. Therefore, the pcu values for converting the heterogeneous traffic into a homogeneous one are taken from IRC-65 (1976).PCU formotorized two-wheelers (2W)is 0.75, motorized three-wheeler (3W)is 1.0 and buses and trucks (HV) are 2.8. The composition of traffic flow on roundabout R25 and R37 are shown in the form of a pie-chart in Figure 2 and Figure 3, respectively.

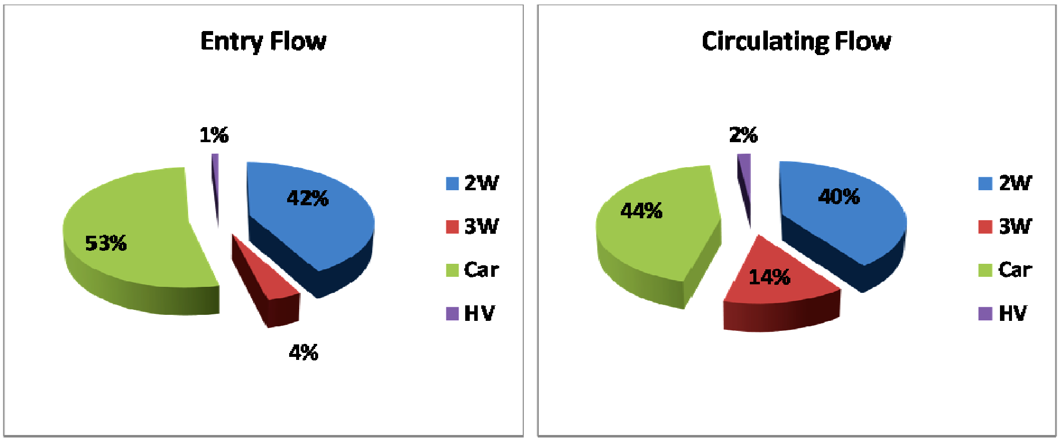

Figure2:Mean Composition of traffic flow on roundabout R 25

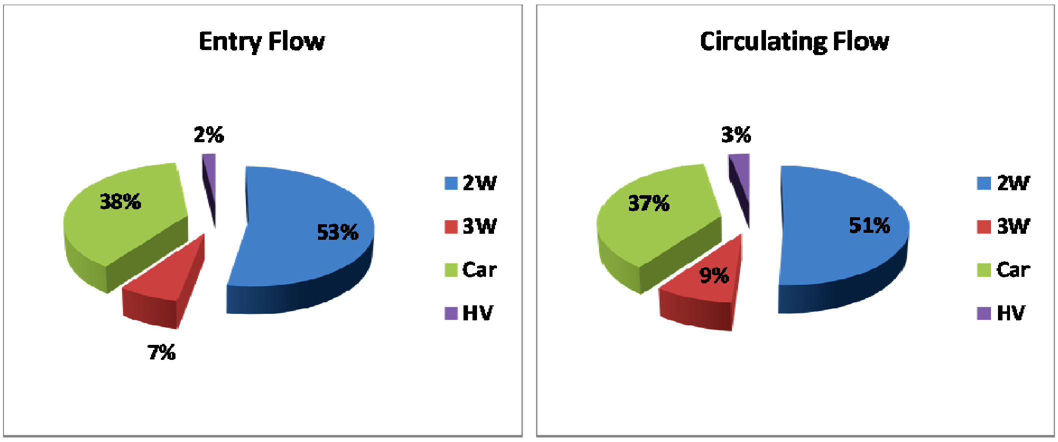

Figure3: Mean Composition of traffic flow on roundabout R 37

4. Analysis and results

Critical gap, follow up time and speed are important parameters on the roundabout. Accepted gaps and maximum rejected gaps are extracted for the estimation of critical gap. The follow-up time and speed of the vehicles are also extracted from the captured video.

4.1 Estimation of critical gap and follow-up time

The critical gap is estimated using accepted gap data and maximum rejected gap data by entering vehicle. The method is used for estimation of critical gap is maximum likelihood method. In this study, only car and motorized two-wheeler is considered,because the percentage of others vehicle is not sufficient so as to extract the data for estimating the gap acceptance parameters. The whole study period is divided using 10 min interval time period to see the variation of gap acceptance parameters and speed of the vehicles with circulating traffic flow. The estimated critical gap of car and motorized two-wheeler on both the roundabouts is given in Table 2. The critical gap value for car and motorized two-wheeler at roundabout R-25 is higher than the critical gap value for car and motorized two-wheeler at roundabout R-37. As can be seen, mean value of critical gap for car is 2.32 s and for motorized two-wheeler is 1.65 s on roundabout R-25. While, the mean value of critical gap for car is 2.13 s and for motorized two-wheeler is 1.55 s on roundabout R-37.

Table 2: Summarizes Critical-gap (in sec.) for car and motorized two-wheeler

	R-25m		*R-37m*	
	Car	*2W*	*Car*	*2W*
Mean	2.32	1.65	2.13	1.55
S.D	0.05	0.02	0.01	0.02
Min	2.23	1.62	2.11	1.52
Max	2.40	1.70	2.17	1.59

The follow-up time of car and motorized two-wheeler on both roundabouts are given in Table 3. The mean value of follow up time for car is 1.53 s and for motorized two-wheeler is 1.16 s on roundabouts R-25 and the mean value of follow up time for car is 1.56 s and for motorized two-wheeler is 1.11 s on roundabouts R-37. The follow up time of the vehicles are almost equal on both the roundabouts.

Table 3: Summarized Follow-Up Time (in sec.) for car and motorized two-wheeler

	R-25m		*R-37m*	
	Car	*2W*	*Car*	*2W*
Mean	1.53	1.16	1.56	1.11
S.D	0.10	0.12	0.19	0.13
Min	1.40	0.98	1.27	0.92
Max	1.71	1.35	1.90	1.41

4.2 Relationship between critical gap and circulating traffic

The critical gap for car and motorized two-wheeler are plotted against the circulating traffic volume for successive 10 min intervals. The traffic volume was converted into pcu using the values given in IRC: 65-1976. The variation of critical gap with circulating traffic flow on both the roundabouts is shown in Figure 4 and 5.

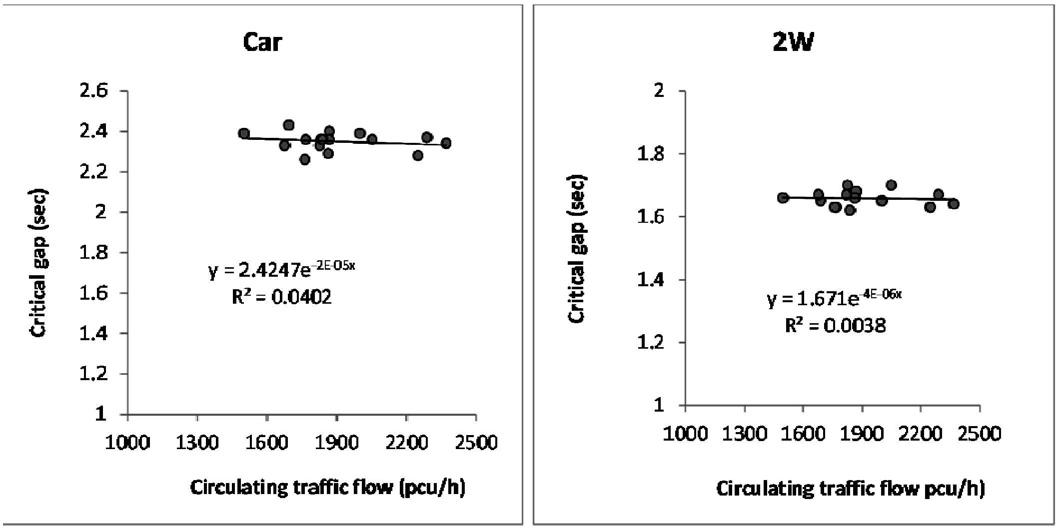

Figure4: Critical gap v/s circulating traffic flow at roundabout R-25

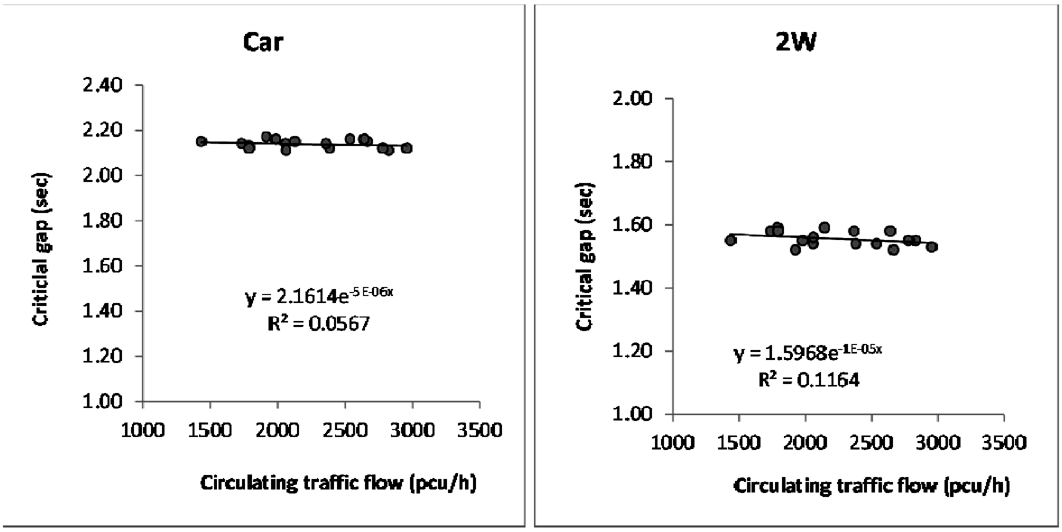

Figure5:Critical gap v/s circulating traffic flow at roundabout R-37

Various types of distributions have been examined to arrive at the best relationship between estimated critical gap and circulating traffic flow. The one which gave better results based on R^2 values is reported here. The best fit is in the form of exponential function between critical gap and circulating traffic volume. Figure 4 and 5, shows that the critical gap decreased with the increase in circulating traffic flow. Table 4 shows the equation and correlation between the critical gap and circulating volume on both the roundabouts. Based on the R^2 values and P-values, it has been concluded that there is no effect of the circulating traffic flow on the critical gap since, these equations are not statistically significant.

Table 4: Equation for critical gap (t_c) and circulating traffic flow (q_c)with statistical parameter

Roundabouts	*Vehicle*	*Equation*	*R^2*	*P-value*
D-25	Car	t_c = 2.4247*e-2E-05*q_c	0.0402	0.339
	2W	t_c= 1.671*e-4E-06* q_c	0.0038	0.609
D-37	Car	t_c= 2.1614*e-5E-06* q_c	0.0567	0.327
	2W	t_c= 1.5968*e-1E-05* q_c	0.1164	0.195

4.3 Relationship between follow up time and circulating traffic

The follow up-time of the entering vehicles under queue condition has been estimated by considering a 10min time period in succession. This helped in getting the follow-uptime value for car and motorized two-wheeler with respect to the circulating traffic flow in that time period. The follow up-time for car and motorized two-wheeler is plotted against the circulating flow for both the roundabouts and are shown in Figure 6 and 7.

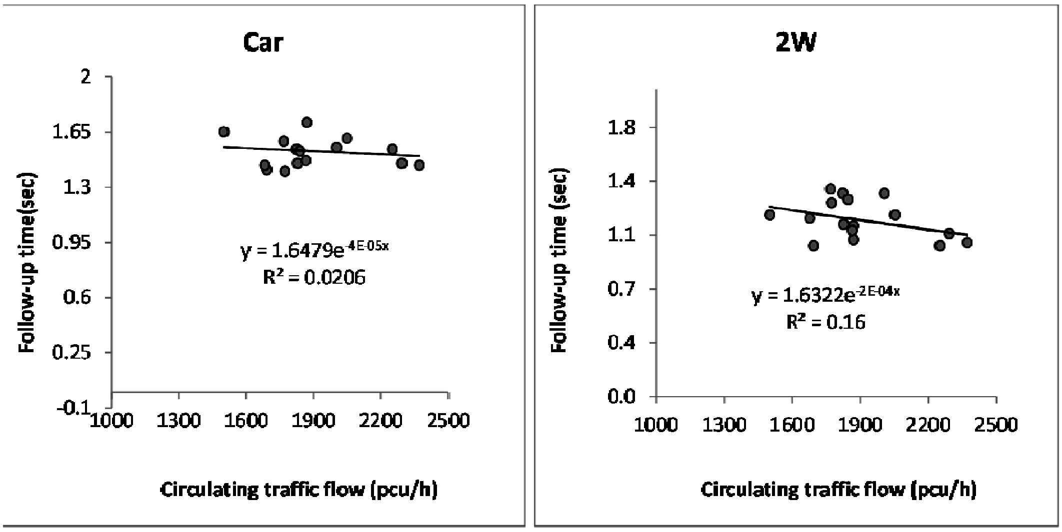

Figure6:Follow up time v/s circulating traffic flow at roundabout R-25

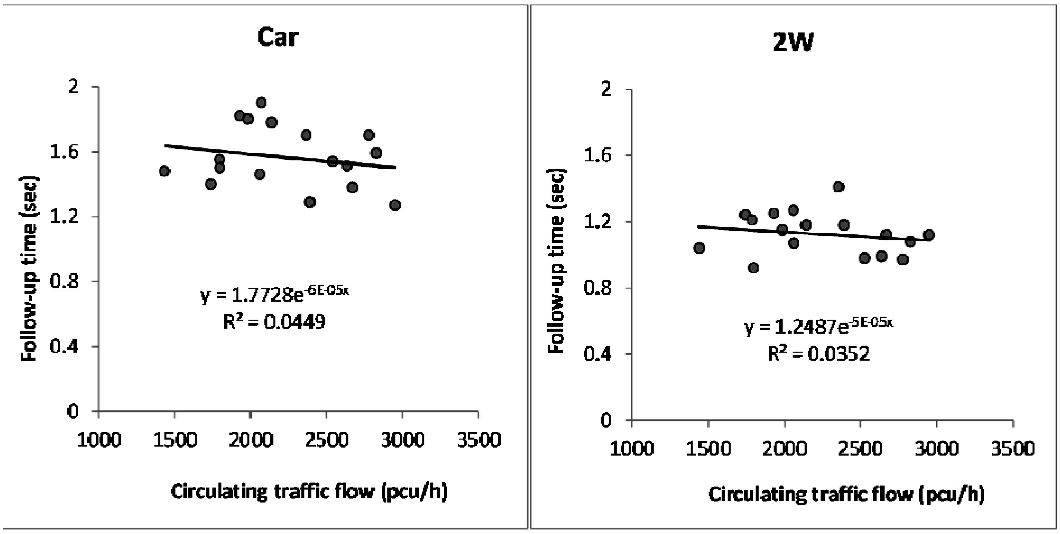

Figure7:Follow up time v/s circulating traffic flow at roundabout R-37

To examine the relationship between the two, various types of distributions have been examined and the one which gave better result based on R2 values is reported here. The best fit is in the form of exponential function between follow-up time and circulating traffic flow. Table 5 shows the equation and correlation between the follow-up time and circulating traffic flow on both the roundabouts. Based on the R2 values and P-values, it has been concluded that there is no effect of the circulating traffic on follow-up time since, these equations are not significant.

Table 5: Equation for follow-up time (t_f)and circulating traffic flow (q_c) with statistical parameter

Roundabouts	*vehicle*	*Equation*	*R^2*	*P-value*
D-25	Car	t_f = 1.6479*e-4E-05 * q_c	R^2 = 0.0206	0.552
	2W	t_f= 1.6322*e-2E-04 * q_c	R^2 = 0.1600	0.228
D-37	Car	t_f= 1.7728*e-6E-05* q_c	R^2 = 0.0449	0.384
	2W	t_f= 1.2487*e-5E-05* q_c	R^2 = 0.0352	0.447

4.4 Estimation of entry speed and circulating speed

The speed of car and motorized two-wheeler has been estimated at entry and in the area of circulating section. The average circulating speed and entry speed of car and motorized two-wheeler on the roundabouts have been given in the Table 6. The speed of car and motorized two-wheeler at entry and in the area of circulating section is higher for roundabout R-37 than for roundabout R-25. The speed of car is lower than the speed of motorized two-wheeler at entry of an approach and in the circulating area.

Table 6: Summarize circulating and entry speed (km/h) for car and motorized two-wheeler

	R-25				*R-37*			
	Circulating speed		*Entry speed*		*Circulating speed*		*Entry speed*	
	Car	*2W*	*Car*	*2W*	*Car*	*2W*	*Car*	*2W*
Mean	11.63	15.91	18.89	22.52	27.14	28.41	19.26	27.47
S.D	2.06	1.96	2.09	1.58	2.77	2.95	1.56	3.10
Min	8.35	13.11	15.19	20.23	24.23	25.05	17.25	22.97
Max	14.69	19.12	21.97	25.21	32.35	33.41	22.11	33.37

4.5 Relationship between entry speed and circulating traffic

The speed of car and motorized two-wheeler are estimated at entry of an approach and in the area of circulating section. Circulating traffic flow for consecutive 10 minutes intervals have been counted. The 10 minutescounts were converted to the hourly volumes. The scatter plot for entry speed of car and the motorized two-wheeler with the circulating traffic volume is shown in Figure 8 and 9 for both roundabouts R-25m and R-37m, respectively.

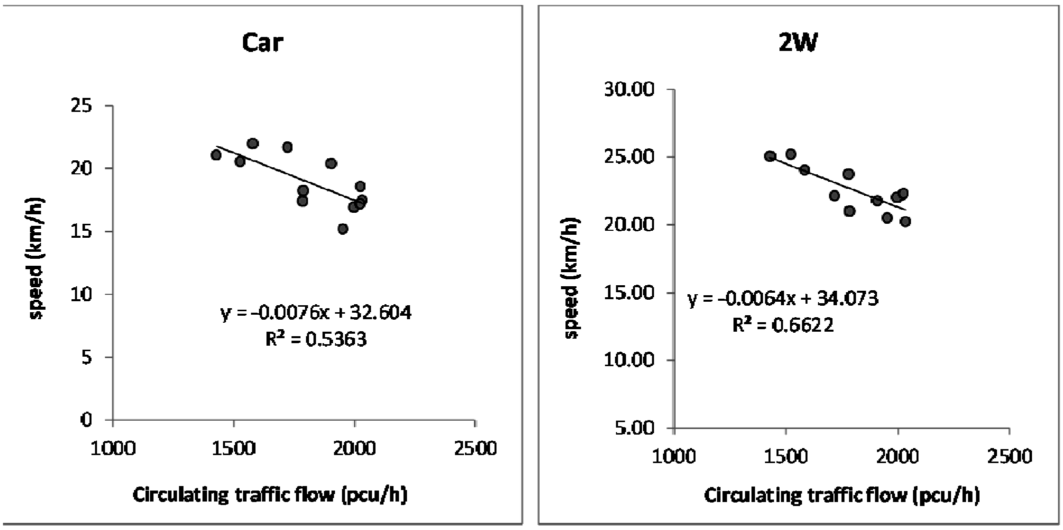

Figure8: Entry speed v/s circulating traffic flow at roundabout R-25

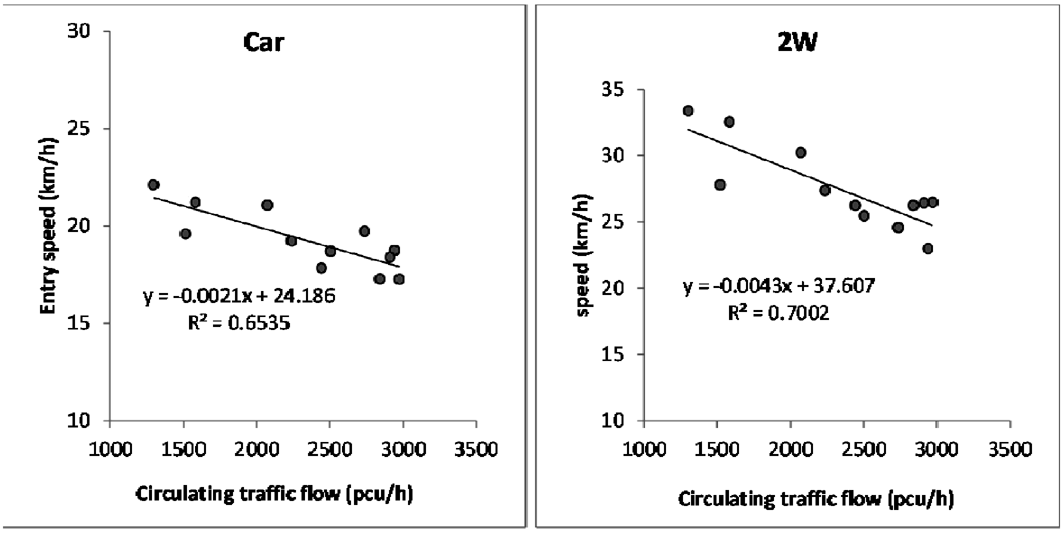

Figure9: Entry speed v/s circulating traffic flow at roundabout R-37

The entry speed of vehicles at approaches is found to be decreasing with an increase in circulating traffic flow for both types of vehicles. The trend of decreasing speed is found to be similar for both vehicles on a roundabout. But across the roundabouts as the size of the roundabouts increased, the rate of decrease in vehicle speed at entry of an approach decreased. Table 7 shows the equation for entry speed and circulating volume with statistical parameters. Based on the R2 values and P-values, it has been concluded that there is satisfactory relationship between the circulating traffic flow and the speed of vehicles at entry.

Table 7: Equation ofentry speed (V_e) and circulating traffic flow (q_c) with statistical parameter

Roundabouts	*Vehicle*	*Equation*	*R^2*	*P-value*
D-25	Car	V_e= -0.0076*q_c + 32.604	R^2 = 0.5363	0.0067
	2W	V_e = -0.0064* q_c+34.073	R^2 = 0.6622	0.0013
D-37	Car	V_e = -0.0021* q_c+24.186	R^2 = 0.6535	0.0016
	2W	V_e = -0.0043* q_c+37.607	R^2 = 0.7002	0.0007

4.6 Relationship between circulating speed and circulating traffic

The scatter plot for circulating speed of car and the motorized two-wheeler with the circulating traffic volume is shown in Figure10 and 11 for both roundabouts R-25m and R-37m, respectively.

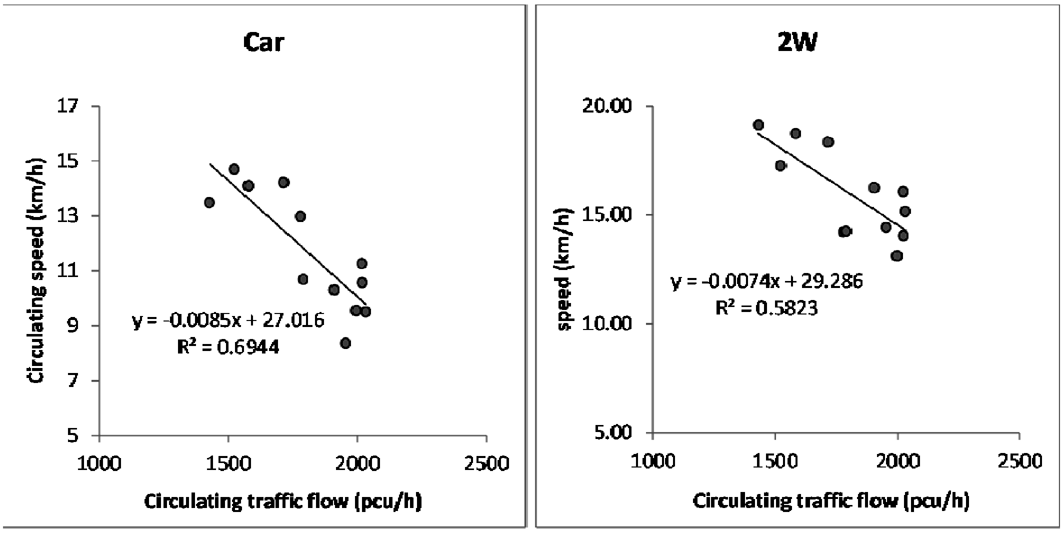

Figure10: Circulating speed v/s circulating traffic flow at roundabout R-25

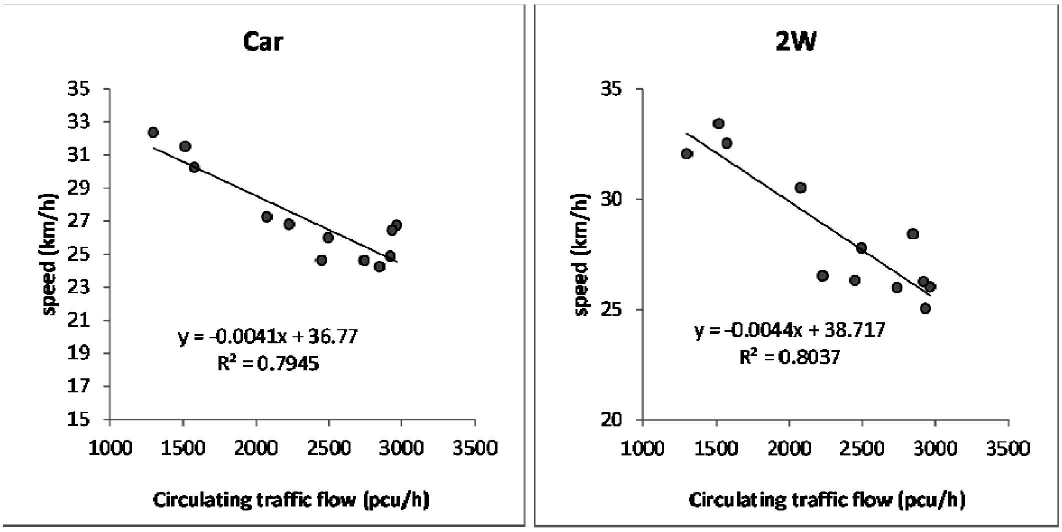

Figure11: Circulating speed v/s circulating traffic flow at roundabout R-37

It is clear from the Figure 10 and 11 that circulating speed for car and motorized two-wheeler is linearly decreasing, with an increase in the circulating traffic flow. The relationship has reasonable coefficient of determination. The reduction in the circulating speed is found to be lower on the bigger size roundabout as compared to smaller size roundabouts. Table 8 shows the equation for circulating speed and circulating volume with statistical parameters. Based on the R^2 values and P-values, it has been concluded that there is satisfactory to good relationship between the circulating traffic flow and the speed of vehicles in the area of circulating section of the roundabout.

Table 8: Equation of Circulating speed (V_c) and circulating traffic flow (q_c) with statistical parameter

Roundabouts	*vehicle*	*Equation*	*R^2*	*P-value*
D-25	Car	V_c= -0.0085* q_c+27.016	0.6944	0.0007
	2W	V_c= -0.0074* q_c+29.286	0.5823	0.0039
D-37	Car	V_c = -0.0041* q_c+36.770	0.7945	0.0001
	2W	V_c = -0.0044* q_c+38.717	0.8037	0.0001

5 Conclusions

Following points emerged from the analysis of the two roundabouts, one with diameter of central-island as 25 m and other with 37 m. The entry approach and circulating section are both classified as two-lane systems though there is some difference in the widths.

- The majority of the traffic composition on the two roundabouts was constituted of cars and motorized two-wheelers. The percentage of motorized two-wheelers in the total traffic volume on both the roundabouts is around 40-50percent, together they constitute more than 80% of the traffic.
- The critical gap and follow-up time are found to be lower than the critical gap and follow-up time values as being reported in literature from other countries. This might be due to the aggressive or impatient behaviourof drivers in India under the highly congested traffic conditions. Therefore, the critical gap and follow-up time values as recommended by other countries are not applicable to traffic flow conditions in India.
- The critical gap of car is greater than the critical gap of motorized two-wheeler on both the roundabouts. This is logical as car drivers are more conscious regarding safety of their vehicle as compared to the motorized two wheelers. Owning to the small size, the motorized two wheelers just enter using any small gaps.
- The critical gap and follow-up time of car and motorized two-wheeler at the roundabout with smaller diameter central-island is found to be more than that onthe roundabout with larger diameter central-island.
- It has been found that there is no statistically significant relationship between the critical gap or follow-up times and circulating traffic flow on the two roundabouts. Therefore, it can be inferred that critical gap and follow-up time do not get influenced solely by circulating traffic flow on a roundabout.
- The speed of car and motorized two-wheeler at entry and in the area of circulating section is higher for roundabout R-37 than for the roundabout R-25. The speed of car is lower than the speed of motorized two-wheeler at entry of an approach and in the circulating area. This again can be attributed to the effect of

relative sizes as well as the opportunities available to the vehicles to enter the traffic stream.

- The entry speed of vehicles at approach is found decreasing linearly with an increase in the circulating traffic flow. Similarly, the circulating speed of the vehicles is found to be decreasing linearly with an increase in the circulating traffic flow.

Based on the above it is recommended that the estimated values of critical gaps and follow-up times for the cars and motorized two wheelers on roundabouts shall be used in the developing countries.

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