Calibration of Performance of Roundabouts Based on Gap Acceptance Parameters Using Simulation for Indian Scenario

Shweta Rao[1],

Assistant Professor, Department of Civil Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad

Yadu Krishna[2],

Assistant Professor,

Atmakuri Priyanka[3],

Research Scholar (PhD), IIT Chennai

Prasanta Kumar Bhuyan[4]

Assistant Professor, Department of Civil Engineering, National Institute of Technology Rourkela, India

Abstract: Indian traffic is characterized by wide range of variations and heterogeneous composition. This makes the driver behaviour a prominent feature for developing traffic models and simulations. In this study, detailed analysis is carried out to simulate a traffic model for roundabouts using the entry and the circulating flow values to calculate the gap acceptance parameters like critical gap and follow-up time. To measure the critical gap of entry of roundabouts incorporating distribution of headways, statistical techniques like equilibrium of probabilities and cumulative probability density function are used. The equilibrium of probabilities method was found to overcome few assumptions relating to homogeneity used by several methods. The simulation was carried out using VISSIM software taking the vehicle dimensions and flow values as input parameters. Deceleration and minimum headway were used as calibrating parameters to simulate the model. The values of critical gap and follow-up headway showed less variation with those obtained using equilibrium of probabilities method.

1. INTRODUCTION

Intersection took about a century to evolve from human powered traffic control through traffic rotaries to modern roundabouts. It is still evolving nurturing the need of the people and nature of the traffic from site to site. Study and research on roundabouts as an intersection alternative for better and smooth flow of the traffic is something that started a couple of decades ago in developed nations.

Intersections have always been a primary concern for people involved in traffic engineering as the number of conflict points is comparatively higher at those places. The present day roundabouts have proved effective in increasing safety by reducing conflicts and also as less overall delay leading to many environmental benefits, less maintenance charges and U – turn facility without affecting free flow of traffic. When it comes to performance of roundabouts in Indian cities, the traffic at the sites is heterogeneous and the composition varies with the location of site within the city. This diversity in traffic leads to varied driver behaviour and his response to traffic.

The main objective of this study is to obtain the gap acceptance parameters and the variation of these parameters with change in flow values at the roundabout. The code which is under use for design of roundabout in India is IRC: 65-(1976, which is purely outdated and is incapable of representing the driver behaviour on roads as only the geometrics and proportion of weaving traffic are considered determine the capacity. For this purpose, a study was carried out to analyse the driver behaviour pattern. A detailed framework of the study is given below in Fig 1.

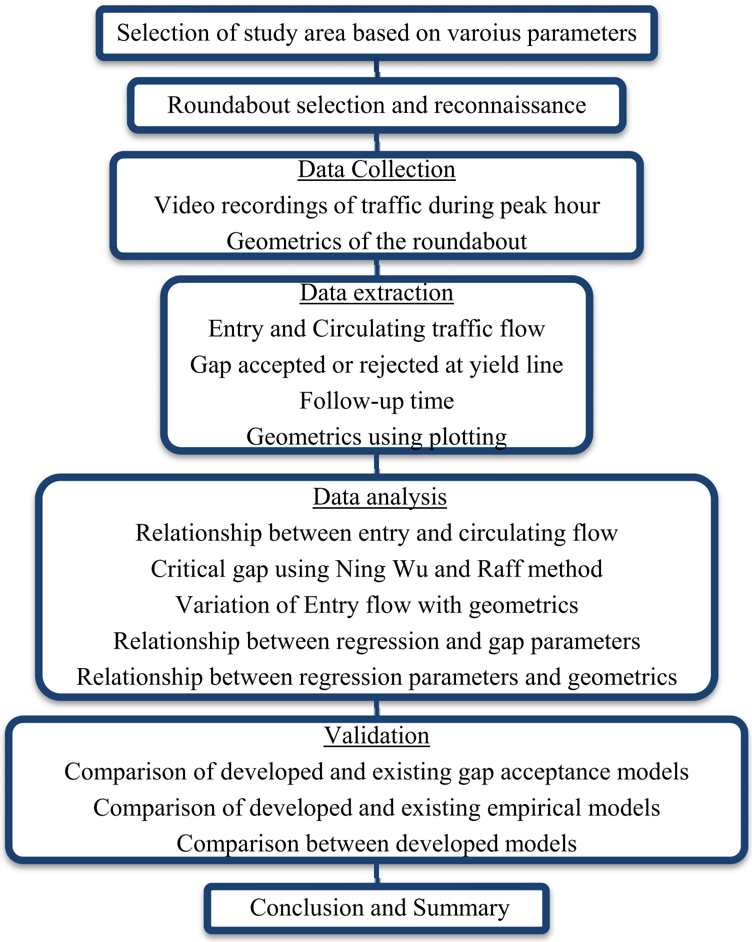

Fig.1: Detailed framework of study

2. BACKGROUND

Generally, there are three main methods to analyse the performance of roundabouts, i.e. empirical, analytical (gap acceptance) and micro simulation. Many researches have been done since 1950 regarding the procedures to calculate driver behaviour characteristics, i.e. critical gap and follow-up time. The methodology to determine critical headway was first determined by Raff (1950), in which the cumulative probabilities of accepting and rejecting gaps were used to find critical headway as a point of intersection of accepting and rejecting headway graphs. But this procedure gave random values in case of small data sets.

Many reforms were made in these methods giving rise to more accurate measurements like Ashworth method (1969), Maximum likelihood method by Troutbeck (1992) and Equilibrium of probabilities method by Ning Wu (2012). Among all these methods, Ning Wu method is the most recent method and it overcomes the drawbacks of earlier methods by considering the probability distribution function (PDF) of accepted and rejected gaps for calculating critical gap. And also it doesn't take into consideration homogeneous nature of driver behaviour, neither has it required predefined distribution nor it is not necessary for an accepted gap to be always greater than the rejected gap. This method was thus found reliable for Indian traffic conditions.

To study the driver behaviour more precisely and individually, tools like micro simulation are used. Many softwares like VISSIM, PARAMICS, etc. are developed for simulating traffic in various parts of world. One such analysis was done by Zhixia *et.al* (2013) by initially conducting a sensitivity analysis on the various parameters like flow and speed to check the effect of these parameters on the change in driver behaviour characteristics. Similarly, Arroju et.al (2015) performed a simulation test for the roundabouts in Delhi, India using VISSIM tool by considering deceleration for sensitivity analysis. It was found that the roundabout geometry and the speed played an important role in predicting gap acceptance behaviour of the driver.

As far as Indian scenario is considered, IRC65 (1976) provides a basic information about the rotary geometry, shapes, PCU (Passenger Car Unit) conversion factors and an equation for the determination of weaving capacity. The capacity equation is based on entry width, width and length of weaving section and the proportion of weaving traffic. But no improvisation had been made since then taking into consideration the various changes that has occurred in road design aspects as well as traffic characteristics such as vehicle engine efficiency, weight, dimension and rising user's demand.

3. DATA COLLECTION

The complex nature of the traffic in India accounts for careful selection of site for the study. Roundabouts have been selected considering many factors like the difference in geometry, traffic composition, its strategic location and nature of the city where it is located. Of the many available roundabouts in India, a few of which satisfied these requirements are sorted and data is finally collected from five cities (Trivandrum, Nagpur, Rourkela, Bhubaneswar and Ranchi) from four different states.

A field reconnaissance survey is carried out to observe the site condition, geometrics and inventory details. The traffic flow data is collected during the peak hours for three hours duration, which varied from city to city depending on the various business and school hours. The video camera is placed on high raised buildings or elevated structures in such a way that it records the traffic flow of all approaches. The cameras had been so adjusted that the entry flow, circulating flow, headways and follow-up time could be easily extracted later.

The speed data is also collected at site to measure the deceleration of the vehicles at the entry. For this purpose, the spot speed of the vehicles is collected using the radar guns at two positions, one at a distance of 100m from the entry and other at 20m from the entry. The first one gives the free flow speed of the vehicles whereas the second one gives the decelerated speed due to yielding at entry. This spot speed data was then used to calculate the 85th percentile speed of the vehicles.

To develop a simulation model, geometry of the roundabout is needed to create a replica in VISSIM. Thus, the geometric elements like central island diameter, entry width, circulating width, entry radius were measured during off peak hours using a measuring tape and further verified using external referencing in AutoCAD as shown in Fig 2. This is done to eliminate the error due to approximation during filed measurements.

Fig 2: External Referencing of Panposh Chowk map in AutoCAD

4. METHODOLOGY

For simulating a model based on gap acceptance parameters, it is necessary to calculate the entry and the circulating flow values along with the driver behaviour parameters, gap and follow-up time. So, initially data was extracted for all the sites to as to develop the model.

4.1. Entry and circulating flows

The flow data had been extracted from the videos, taking heterogeneity into consideration. This heterogeneity aspect is emphasized by counting bicycles, two- wheelers, light motor vehicles and heavy vehicles separately and converting them into PCUs. The PCU conversion provided in IRC65 (1976) i.e. 0.5 for bicycles, 0.75 for 2-wheelers, 1 for cars(LMV), 2.8 for heavy vehicles and 5 for animal drawn vehicles, has been used in this case. The average flow of traffic entering and circulating around Ram Nagar Square, Nagpur is shown in Table 1.

Table1. Details of Entry and Circulating traffic flow at Ram Nagar Square, Nagpur

ENTRY TRAFFIC VOLUME							
Leg Direction	Heavy Vehicle	Light Motor Vehicle	Motor Cycle	Bicycle	Animal Drawn	Total Vehicles	Traffic Volume (PCU/h)
NE	22	437	999	60	5	1523	1303
NW	13	235	710	33	6	997	850
W	0	123	690	72	17	902	762
SW	13	424	1162	82	4	1685	1393
CIRCULATING TRAFFIC VOLUME							
NE	12	363	1423	170	23	1991	1645
NW	13	599	1820	180	21	2633	2195
W	19	687	1812	128	8	2654	2203
SW	11	374	1247	241	14	1887	1531

4.2. Estimation of Critical Gap (t_c)

Gap is defined as headway maintained between two consecutive vehicles in the conflicting stream. The value of critical gap varies with the composition, like, it would be smaller if the traffic comprised mostly of motorcycles.

For the purpose of estimating the critical gap, gaps accepted and rejected by driver at the entry of roundabout are extracted from the videos. To obtain these, two imaginary lines are considered, one at the entry of the lane (L1) and another at the line of conflict on the circulating lane (L2) as shown in Figure 3(a). The time when front bumper of a vehicle in minor stream (entry flow) touches the imaginary line L1 is considered t_1, as shown in Fig. 3(d). The time at which the front bumper of the vehicle in the major stream touches L2 is considered as t_2, as shown in Fig. 3(e). The gap is then calculated as the difference between the time stamps t_2 and t_1. The value of critical gap is then estimated from the obtained data using two methodologies, Raff and Equilibrium of Probabilities for all the sites.

Fig. 3(a). Conflict Lines L1 and L2 under consideration

Fig. 3(b). First follow-up time stamp Ft1

Fig. 3(c). Second follow-up time stamp Ft2

Fig. 3(d). First Critical gap time stamp T1

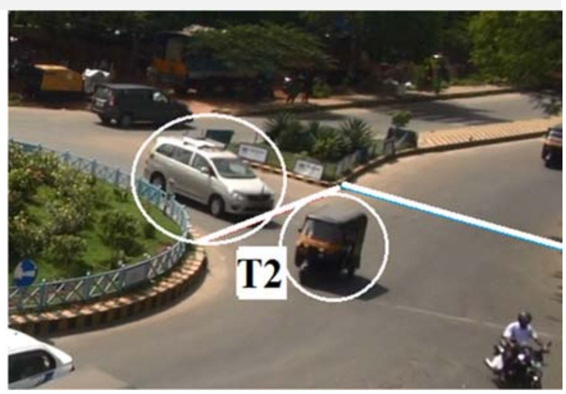

Fig. 3(e). Second Critical gap time stamp T2

Fig 3. Calculation of headway and follow-up time

4.2.1. Raff method

According to this method developed by Raff (1950), the critical gap is the value of time (t) at which the functions of 1- $F_r(t)$ and $F_a(t)$ intersect. To obtain this intersection point initially cumulative density function of accepted ($F_a(t)$) and rejected gaps ($F_r(t)$) is calculated. 1- $F_r(t)$ is a function which denotes that the gap is not rejected. Minimum of 400 headway values were extracted to obtain accurate results of critical gap. Table 2 shows the data analysis to estimate the critical gap using Raff method. A graph is plotted for these values of 1- $F_r(t)$ and $F_a(t)$ against the headway in major stream for the data extracted from Albert Ekka Chowk as shown in Fig 4. The point of intersection of these two curves is then estimated as critical gap i.e. 1.11 sec in this case.

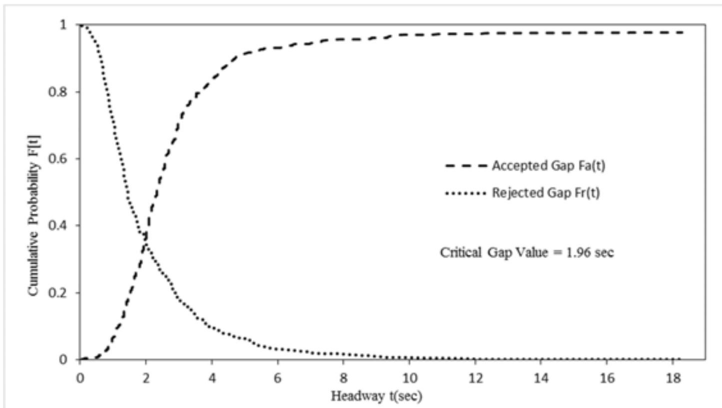

Fig 4. Cumulative probability distribution vs. Headway using Raff Method

Table 2. Estimation of critical gap using Raff Method

Time (sec)	C= A or R	If C=R, N_R=N+1	If C=A, N_A=N+1	$F_R = \frac{NR}{NRmax}$	Accepted Probability	Rejected Probability
0.12	R	2	1	0.003766	0.002294	0.996234
0.28	R	3	1	0.00565	0.002294	0.99435
0.32	R	4	1	0.007533	0.002294	0.992467
-	-	-	-	-	-	-
0.8	R	100	13	0.188324	0.029817	0.811676
0.88	A	121	19	0.227872	0.043578	0.772128
-	-	-	-	-	-	-
0.96	R	144	27	0.271186	0.061927	0.728814
1	A	144	28	0.271186	0.06422	0.728814
-	-	-	-	-	-	-
8.84	A	517	418	0.973635	0.958716	0.026365
8.92	R	518	418	0.975518	0.958716	0.024482
9.16	R	519	418	0.977401	0.958716	0.022599

4.2.2. Equilibrium of Probabilities Method

This method developed by Ning Wu (2012) is based on equilibrium of probabilities of accepted and rejected headways. According to the PDFs of the accepted ($F_a(t)$) and rejected ($F_r(t)$) gaps, the observed probability that a gap of length t is accepted is $F_a(t)$ and that it is not accepted is

$1 - F_a(t)$. The observed probability that a gap of length t is rejected is $F_r(t)$ and that it is not rejected is $1 - F_r(t)$. The PDF of critical gaps thus estimated is denoted by $F_{tc}(t)$.

To estimate critical gap by this procedure, CDFs of accepted and rejected gaps were initially calculated for the available gap data set. The CDF of critical gap is then estimated as

$$F_{tc}(t_j) = \frac{F_a(t_j)}{[F_a(t_j)+1-F_r(t_j)]} \quad (1)$$

Then, the frequencies of the estimated critical gap, $p_{tc}(t)$ were calculated as

$$p_{tc}(t_j) = F_{tc}(t_j) - F_{tc}(t_{j-1}) \quad (2)$$

Finally the average value of critical gap was estimated as the sum of multiplication of the class mean of the time gaps ($t_{d,j}$) and the frequencies of estimated gaps.

$$t_{c,avg} = sum[p_{tc}(t_j) * t_{d,j}] \quad (3)$$

The graphs of the CDFs of accepted, rejected and critical gap are plotted against the values of conflicting headway for an entry of Albert Ekka Chowk as shown in Fig 5. And the calculations for the same are shown in Fig 6.

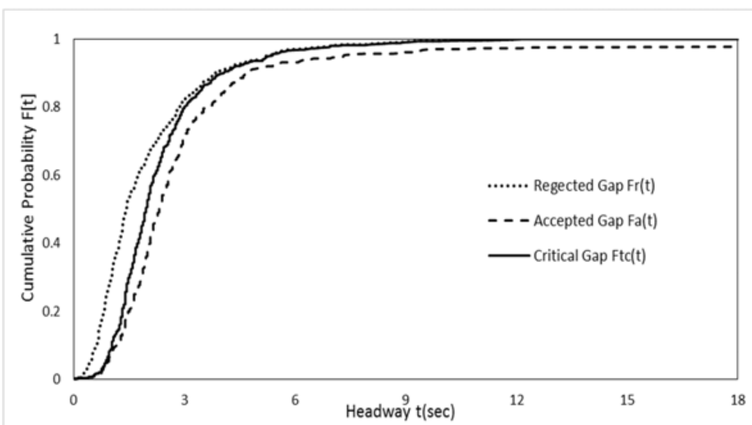

Fig 5. Cumulative probability distribution vs. Headway graph using probability of equilibrium method

Critical gap of different sites obtained using these three existing methods has been estimated and tabulated in Table 4.

1	2	3	4	5	6	7	8	9	10	11	12
Time Interval (sec)*10	A/R	IF '2'=R, nr=n+1	IF '2'=A, na=n+1	Rejected gap, Fr(t)	Accepted gap, Fa(t)	Critical Gap, Ftc(t)	Pc=Ftc(t)-Ftc(T-1)	Td,j=(Tj+Tj-1)/2	Tc,mean=Pc*Td,j	Pc*Td,j^2	(Pc*Td,j)^2
0.208333	R	10	2	0.045249	0.009804	0.010164191	4.74593E-05	0.48	2.27804E-05	1.09346E-05	5.18949E-10
0.192308	A	10	3	0.045249	0.014706	0.015169195	0.005005004	0.5	0.002502502	0.001251251	6.26252E-06
.	.	.	.	.	.	.	.	.	.	.	.
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0.078125	R	84	30	0.38009	0.147059	0.191740413	0.001124577	1.28	0.001439459	0.001842507	2.07204E-06
0.078125	R	85	30	0.384615	0.147059	0.192878338	0.001137925	1.28	0.001456544	0.001864377	2.12152E-06
0.069444	A	98	41	0.443439	0.20098	0.265306122	0.00478508	1.44	0.006890516	0.009922343	4.74792E-05
0.067568	A	98	42	0.443439	0.205882	0.270029674	0.004723551	1.46	0.006896385	0.010068722	4.75601E-05
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
0.060976	R	111	55	0.502262	0.269608	0.351351351	0.002059705	1.62	0.003336722	0.00540549	1.11337E-05
0.059524	A	111	56	0.502262	0.27451	0.35546875	0.004117399	1.66	0.006834882	0.011345904	4.67156E-05
0.044643	R	153	104	0.692308	0.509804	0.623616236	0.00343275	2.24	0.00768936	0.017224166	5.91263E-05
0.04386	A	153	105	0.692308	0.514706	0.625859697	0.002243461	2.26	0.005070222	0.011458703	2.57072E-05
0.007987	A	221	203	1	0.995098	1	0	11.84	0	0	0
0.007987	A	221	204	1	1	1	0	12.52	0	0	0
							1.000000117		2.271323866		0.026145517

Fig 6. Estimation of critical gap using Equilibrium of probabilities method

The value of critical gap and follow-up time obtained for various sites is shown in Table 3.

Table 3. Values of Critical Gap and Follow-up Time

Site	Critical Gap (sec)		Follow-up time
	Equilibrium of probabilities	Raff	
Chacka Junction	2.271	1.94	1.1353
Panposh Chowk	2.285	2.00	1.0499
Ramnagar Square	2.353	1.96	1.5976
Master Canteen	1.320	1.12	1.0053
Albert Ekka Chowk	1.352	1.11	0.9229
Medical Square	2.455	2.22	1.2236

4.3. Estimation of Follow-up Time (t_f)

The follow-up time is the time gap between the two consecutive vehicles in the entry stream. To calculate the follow-up time, an imaginary line has been considered along the entry of roundabout, as shown in Figure 3 (b and c), and at which the back bumper of the vehicle touches the line is noted as t_1 and the time at which the front bumper of following vehicle touches the line is taken as t_2. The follow up time is the difference between these two times. The average value of the readings is taken as the net value. Follow-up time of each site considered for model development has been tabulated in Table 3.

4.4 Speed data

For inputs in VISSIM, the speed data is collected at the sites and the 85th percentile speed are calculated. The speeds obtained for different types of vehicles at various sites are given below in Table 4 and the graph showing 85th percentile speed of Ramnagar square is shown in Fig 7. The deceleration on average of motorcycles is found to be 1 km/h^2, while that of LMV and heavy vehicles is 0.9 km/h^2 and 0.8 km/h^2 respectively.

Table 4. Speed and deceleration of various vehicle types

Site	85th percentile Speed of vehicles (km/h)		
	Motorcycles	LMV	Heavy vehicles
Chacka Junction	22.58	25.81	12.14
Panposh Chowk	21.82	34.34	11.75
Ramnagar Square	20.24	35.26	11.28
Master Canteen	18.98	28.49	10.69
Bisra Chowk	18.26	26.92	10.86
Medical Square	19.32	25.46	11.12

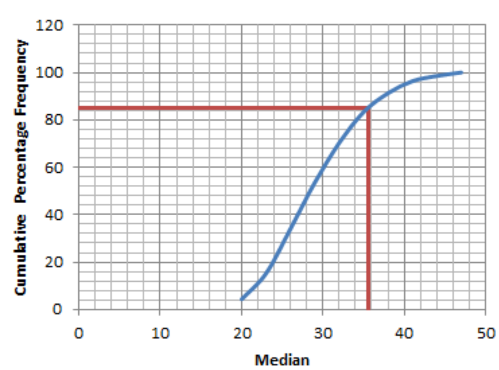

Fig 7. 85th percentile speed of LMV at Ramnagar Square

5. VALIDATION USING VISSIM

The flow data and the speed data obtained from the survey are then provided as inputs for the simulation modelling of roundabouts using VISSIM. The dimensions of various categories of vehicles are provided as per Indian conditions to comply the situations on site. The entry and the circulating flow for the saturated legs of roundabouts were calculated for every one minute interval, when the queuing is observed. The cloud showing relation between the entry and the circulating flow showed the exponential fit for the data as shown in Fig 8.

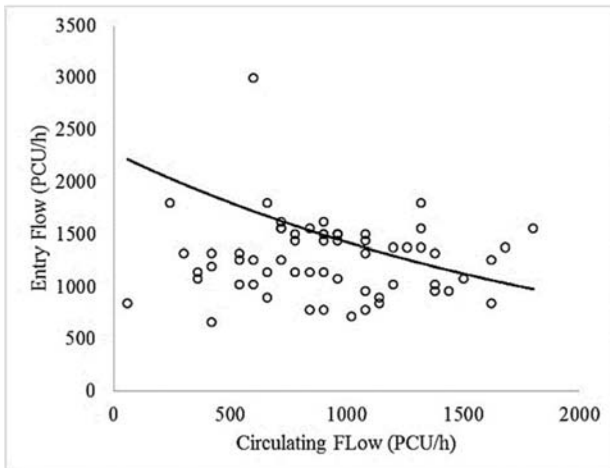

Fig 8. Scatterplot showing relationship between entry and circulating flow

The simulation run is conducted for the same one hour data in time steps of ten minutes each in VISSIM, which verified the relationship of circulating flow with the entry flow as exponential. Now, initially the values of circulating flow differed for ever simulation run, giving a higher error. For this purpose of reducing the error, few of the default parameters taken as inputs are changed. In this case, the deceleration in lane changing parameters and minimum gap in priority rule parameters, are used for calibration.

Two time stamps, as in case of field data are inserted in VISSIM model to calculate the value of gaps and follow-up time for the vehicles yielding at entry. This yielding is considered as priority rule where the driver at the entry waits for the suitable gap before entering into weaving section. The value of critical gap is obtained by varying the values of calibration parameters such that they portray the real time situation. The simulation model for Panposh Chowk is shown in Fig 9. The values of critical gap and follow-up time using the simulation model are shown in Table 5.

Table 5: Critical gap and follow-up time values using VISSIM

Site	Critical Gap(secs)	Follow-up time (secs)
Chacka Junction	2.26	1.18
Panposh Chowk	2.29	1.1
Ramnagar Square	2.41	1.63
Master Canteen	1.36	1.01
Albert Ekka Chowk	1.41	0.96
Medical Square	2.52	1.28

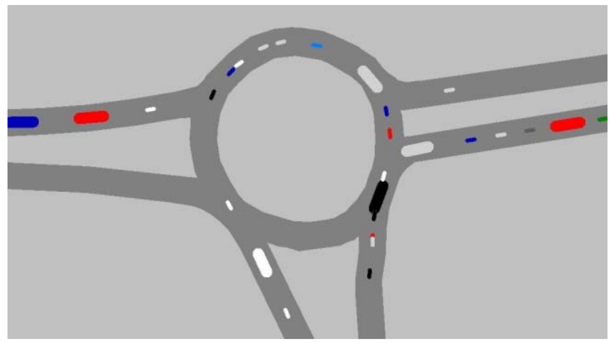

Fig 9: Simulation model of roundabout using VISSIM

Further, sensitivity analysis is carried out to measure the consequences of change in calibration parameters over gap acceptance parameters. For this purpose, the values of minimum gap and the deceleration are changed one at a time, keeping the other parameter constant, and the value of critical gap is measured for each change. Critical gap showed a wide variation with change in values of minimum gap. The variation followed a linear trend with R value of 0.85.

6. CONCLUSION

From the study, the following conclusions are drawn:

i) It is observed that the driver behaviour varied from site to site with the change in traffic composition, which in turn affected values of gap acceptance parameters.

ii) Critical gap is computed using two methods namely, Raff and Wu and the values of critical gap obtained from these methods had standard deviation of 10-23%. The equilibrium of probabilities proved to fit better for Indian traffic conditions as it took heterogeneity into consideration.

iii) Regarding the traffic flow, the entry flow of roundabouts is found to vary exponentially with the circulating flow when plotted using one minute interval data.

iv) The critical gap and follow-up time calculated using simulation model in VISSIM are almost similar to the values obtained using Probabilities of equilibrium method.

v) The sensitivity analysis for the gap acceptance parameters in VISSIM revealed that the value of minimum gap had a significant effect as compared to deceleration.

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