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Performance Analysis and Modeling of Entry Capacity of Roundabout Under Heterogeneous Traffic

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Abstract: Emerging traffic in medium and large cities is of major concern to develop a network which would be able to satisfy the needs of traffic. Intersections are a very important part of this network and are to be designed properly to handle the traffic efficiently. Un signalized intersections have a drawback of a large number of conflict points. Introduction of roundabouts at intersection had many advantages. Roundabouts eliminate the conflict points which lead to perpendicular crashes. It reduces driver confusion associated with perpendicular junctions and also reduces the queuing caused due to signalization. It is crucial to measure the performance of existing roundabouts in terms of its ability to handle the present traffic scenario. The entry capacity is found to vary immensely with the changing geometrics of the roundabout and circulating flow. A model can be developed using empirical analysis based on five such geometric parameters circulating flow and exit flow which proved to be significant for estimating the capacity. The model can be validated with the site data for checking its practicality. Performance analysis of rounabouts were also done by estimating entry capacity and capacity of weaving sections. And also level of service of both weaving sections and entry sections were found out as per HCM (2010) and IRC (65) respectively.

Keywords: Entry flow, Model, Level of service, HCM, IRC

I. INTRODUCTION

Road network is a very important aspect of transportation system as it connects even the smallest villages and cities. Emerging road traffic is of major concern to develop a network which would be able to satisfy the needs of traffic. Intersections are very important part of this network and are to be designed properly to handle the traffic effectively. Unsignalized intersections also play an important role in road network. They help in free movement of traffic without any constraint as in case of signalized intersection. Unsignalized intersection has a drawback of large number of conflict points. As the number of lanes increase, the unrest at the intersection also increases drastically. Over the years, many reforms have been made to reduce this. Initially, the traffic at intersection was controlled by policemen. Then in later years, rotaries were introduced. The concept of rotaries was then modified to what we call as roundabouts. A roundabout is a type of circular intersection or junction in which road traffic flows almost continuously in one direction around a central island. Introduction of roundabouts at intersection had many advantages other than eliminating the conflict points which lead to perpendicular crashes.

II. LITERATURE REVIEW

H.M.N.Al-Madani [1]developed a multivariate model for the prediction of roundabout maximum entry flow during forced flow condition is developed considering the circulating flow, exiting flow and roundabout geometric characteristics. None of the current available methods are specifically developed for forced flow conditions. The data were collected from 13 large roundabouts.Beside circulating and exitingflows, number of lanes and lateral position of the vehicles, as they approach and cross the roundabout,showed significant influence on roundabout entry capacity. RamuArroju [2] determined the capacity of the roundabout using various capacity formulas such as gap acceptance models given by Highway Capacity Manual 2010 (US), German model (2001); empirical regression models given by TRRL (UK) and weaving models given by IRC: 65–1976 (India). In addition, microscopic simulation model like VISSIM (PTV Germany) is also used to derive capacity values.

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Stephen Agyeman [3] analyzed capacity and performance of 3 major roundabouts (Jubilee Park, Cocoa House and Post Office) in Sunyani,Ghana.Traffic data were collected manually during peak hours in the interval of 15 minutes. Geometric data of the roundabouts were measured in the field. Synchro plus SimTraffic 7 software's were used to run computer simulations to estimate the capacities and performances of the roundabouts.Results showed that the Jubilee Park and Post Office roundabouts were performing above capacities based on the overall volume to capacity ratios of 0.78 and 1.13 respectively, with intersection capacity utilization (ICU) level of service H. The roundabouts were at least 9% above capacity and were being subjected to congestion periods in excess of 120 minutes per day.

Abdullah Ahmad [4] produced Regression model for entry capacity of a roundabout under mixed traffic condition – an Indian case study dealt with a regression model which is developed to estimate entry capacity of an approach on a roundabout for Indian traffic conditions.11 roundbouts are taken and 1 for validation of the model. Geometric details of the roundabout like circulating roadway width (CW), entry width (EW), central island diameter (C.I. Dia.) were colleted.Entry and circulating flow extracted from video graphic survey.The analysis also indicated that the widths of circulating roadways and central island diameters have a significant influence on the entry capacity. The circulating traffic flow versus entry capacity charts were made with the purpose of comparing the results of the proposed model with the existing models available in the literature, namely Jordanian, Malaysian, and Indian. The results of the proposed model have shown very good relationship with the field entry flow data, as compared to other models.

Ashish K Patnaik [5] was developed a model using empirical analysis based on five geometric parameter and circulating flow which proved to be significant for estimating the capacity.The developed model satisfied the practicality when validated with the site data.Ten roundabouts from these five states had been used for developing and validating the model. The flow of traffic in each leg was collected using a video camera.The geometric features like diameter of central island, length and width of weaving sections, width of lane are also required for the analysis of roundabout. These dimensions were also measured.The flow data comprising entry and circulating flow were extracted from the video data-set for one-minute interval.Relationship between entry flow and circulating flow was developed. Relationship between entry flow and various geometric features. Finally, taking into consideration the geometric variables and circulating flow, an equation was developed using multiple regression analysis.Validation of the model proved that the proposed model provided a good fit for the saturated flow conditions for maximum in all the sites. Liang Ren [6] evaluated the performance of the capacity estimation for single-lane roundabouts using analytical models [including the highway capacity manual (HCM) 2000 model, the German Highway Capacity Manual (GHCM) model, the signalized and unsignalized intersection design and research aid (SIDRA) model and a new roundabout capacity (NRC) model]and an empirical model(the HCM 2010model Based on field data collected at nine roundabouts in Gold Coast, Australia.

III. DATA COLLECTION AND EXTRACTION

A. Data Collection

Three suitable sites were recognized for the purpose of data collection. The selected sites are aswinijunction, patturakkal junction and kizhakkekotta junction. data of first two junctions were used to develop model and the third one was used for validation of the model. The details of each site is shown in table 1 and in figures fig 1,fig 2. The flow of traffic in each leg was collected using a video camera placed in such a position so as to prove convenient to collect the data. Geometric features were collected using total station.

Table. 1 Details of roundabouts

Sl No	Intersection	Number of Approaches
1	Aswini Junction	4
2	Patturakkal Junction	4

Tripods were used to place the camera in a perfect position to record the data in clear way. The data of all sites were collected during morning one hour peak hour and evening one hour peak hour. The video, thus recorded, provides the data of number of lanes of the roundabout, their direction, entry flow through each lane, circulating flow for each lane, and also the exit flow. The geometric features like diameter of central island, length and width of weaving sections, width of lane are also required for the analysis of roundabout. These dimensions were measured using total station survey and were obtained by importing maps of the site into AutoCAD.

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Fig. 1 Aswini Junction

Fig. 2 Patturakkal junction

B. Data Extraction

The flow data comprising entry and circulating flow were extracted from the video data-set for one-minute interval during continuous flow of traffic. The numbers of vehicles counted were converted into Passenger Car Unit/hour (PCU/h) considering the conversion factors mentioned in IRC-65 (1976). The PCU conversion for car is one, two-wheelers (motor cycle) is 0.75, bicycles is 0.5, heavy vehicles is 2.8, and for animal-drawn vehicles is 5. The details of traffic volume for each approach of two roundabouts are shown in Table 2.The details of geometric features for each approach of two roundabouts are shown in Table 3 and 4.The geometric features include, Central island diameter (D),Weaving Width (WW), Weaving Length(WL), Entry Width(EW), Departure Width(DW), Entry Radius(ER).

Table. 2 Traffic volume

Sl No	Leg Direction	Leg Notation	Mean entry flow	Mean circulating flow	Mean Exit flow
Aswini junction					
1	N-E	A1	2634	1645.6	2205
2	N-W	A2	1764.275	2087.05	2098
3	S-W	A3	1459.8	2725.825	1788
4	S-E	A4	2832.025	1682.6	2597
Patturakkal junction					
1	N-E	P1	1834.8	1426	1506
2	N-W	P2	2735.4	196.8	2446
3	S-W	P3	979.3	1664.1	1118
4	S-E	P4	977.9	1805	1455

Table. 3 Geometric parameters

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Intersection	Leg	Central island diameter(D)	Weaving length (WL)	Weaving Width (WW)
Aswini junction	A1	14.8354	23.7997	17.6191
	A2	14.8354	22.9231	13.9738
	A3	14.8354	25.2121	23.6179
	A4	14.8354	24.671	21.5189
Patturakkal junction	P1	14.0219	43.9178	9.6213
	P2	14.0219	23.97	28.1463
	P3	14.0219	34.2133	22.7391
	P4	14.0219	30.1938	15.869

Table. 4 Geometric parameters

Interection	Leg	Entry width (EW)	Departure width (DW)	Entry radius (ER)
Aswini junction	A1	10.121	10.1623	32.2302
	A2	8.1164	18.0488	19.2595
	A3	16.2431	16.0974	127.082
	A4	13.5862	11.7895	28.0127
Patturakkal junction	P1	9.50025	9.50025	38.589
	P2	15.5	16.9149	17.1992
	P3	8.3912	8.3912	12.0536
	P4	6.34145	6.34145	192.778

IV. DATA ANALYSIS

A. Estimation of Entry Capacity and Level of Service as per HCM(2010)

The capacity of a single entry lane conflicted by one circulating lane is based on the conflicting flow as per HCM(2010).The equation for estimating the capacity is given as equation,

$$C_{e,pce} = 1130e^{(-1*10^{-3})Vc,pce} \quad (1)$$

Ce,pce = lane capacity ,adjusted for heavy vehicles (PCU/h),and
Vc,pce = Conflicting flow rate(PCU/h)

Table. 5 The level of service(LOS) criteria for automobiles in roundabouts

Control delay (s/veh)	LOS by volume to capacity ratio	
	v/c ≤ 1.0	v/c >1.0
0-10	A	F
>10-15	B	F
>15-25	C	F
>25-35	D	F
>35-50	E	F
>50	F	F

Ce,pce is estimated for all approaches of two roundabouts and is tabulated in Table 6.

Table 6.Entry Capacity and LOS of All Approaches of Roundabouts

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Intersection	Leg	Ce, pce (PCU/h)	LOS
Aswini junction	A1	1129.981	F
	A2	1129.976	F
	A3	1129.969	F
	A4	1129.981	F
Patturakkal junction	P1	1129.984	F
	P2	1129.998	F
	P3	1129.981	D
	P4	1129.979	D

Control delay is foundout using the equation,

$$d=3600/c+900T[x-\sqrt{(x-1)2+(3600/c)x/450T}]+5*[x,1] \quad (2)$$

d = Average control delay(s/veh)
x = Volume to capacity ratio of the subject lane
c = Capacity of the subject lane (veh/h)
T = Time period (h)

B. Estimation of Entry Capacity and Level of Service as per IRC(65)

The practical capacity of a rotary is really synonymous with the capacity of the weaving section which can accommodate the least traffic. Capacity of the individual weaving sections could be calculated from the following equation,

$$Qp = \frac{280w\left(1+\frac{e}{w}\right)\left(1-\frac{p}{3}\right)}{1+\frac{w}{l}} \quad (3)$$

Qp = Practical capacity of the weaving section of the rotary in PCU per hour
w = Weaving width in metres
e = Average entry width in metres
l = Weaving length
p = proportion of weaving traffic i.e.,ratio of sum of crossing streams to the total traffic on the weaving section.

Table 7. LOS of weaving sections

Intersection	Weaving section	Capacity of weaving section (PCU/h)	(LOS)
Aswini junction	S-W	4206.79	A
	S-W	2677.109	D
	N-W	3555.631	B
	N-E	4077.58	A
Patturakkal junction	S-E	900	F
	S-W	150	F
	N-W	1400	F
	N-E	1000	F

C. Model Development and Validation

Linear relationship is obtained between entry and circulating flow. Similarly The geometrics play a key role in determining the capacity of roundabout. Thus, it is of prime importance to check variation in entry flow with geometry. The variation in diameter, ER, WW, weaving length, EW, DW and exit flow with respect to entry flow was in cubes for the best fit.

All independent variables taken for model development are found to be significant. Taking into consideration the geometric variables and circulating flow and exit flow an equation was developed using multiple regression analysis

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using SPSS software. The regression value of 0.794 was obtained and the parameters were also found to be significant even when considered all together. Model summary obtained for this model is shown in Table 8.ANOVA table obtained from SPSS for this model is shown in Table 9.Coefficients of different parameters of model are shown in Table 10.

Table. 8 Model summary

Model	R	R Square	Adjusted R Square	Std. error of the estimate
1	0.794	0.63	0.627	9.391565811

Thus the equation obtained for capacity by this method is as follows:

$$q_e=672.377+0.251q_c^3+0.169qexit^3-35.452D^3\ 3.269WL^3-3.597WW^3+6.126EW^3-2.926DW^3-0.183ER^3 \quad (4)$$

qe = Entry capacity in PCU/h
qc = Circulating flow in PCU/h
qexit = Exit flow in PCU/h
D = Central island diameter in meter
WL = Weaving length in meter
WW = Weaving width in meter
EW = Entry width in meter
DW = Departure width in meter
ER = Entry radius in meter
For validation of the model data of 3 roundabouts(Eastfort junction) were used,RMS value of 0.11 is obtained.so we can conclude that the model developed is representing the actual condition.

Table. 9 Coefficients of different parameters of the model

Parmeters	Unstandardized Coefficients	t	Sig.
Constant	672.377	16.39	0
Circulating flow	0.251	7.178	0
Exit flow	0.169	5.388	0
Center island diameter(D)	-35.452	-14.7	0
Weaving length(WL)	-3.269	-19.18	0
Weaving width(WW)	-3.597	-19.88	0
Entry width(EW)	6.126	22.69	0
Departure road width(DW)	-2.926	-19.14	0
Entry Radius (ER)	-0.183	-22.42	0

V. CONCLUSIONS

Unlike the traffic in other countries, the traffic in India has been found to be heterogeneous and had great variation in its content from place to place. The amalgam of vehicles consisted varying number of two-wheelers, cars, heavy vehicles, bicycles and animal-drawn vehicles. The study showed the increase in roundabout numbers over the past few years. The method used to estimate the capacity of roundabouts was very primitive, thus a new model defining the capacity of roundabouts was to be developed. An empirical model was finally developed for capacity of roundabouts with the geometric parameters, exit flow and circulating flow as explanatory variables. The relationship between the entry and the circulating flow was found to be exponential for the best fit. And the relationship between the entry flow and the exit flow, between entry flow and geometric parameters were found to be cubic for best fit. Validation of the model proved that the proposed model provided a good fit for the actual field conditions.

LOS of entry capacity of all approaches of Aswini junction were found to be F, indicating very poor performance of all approaches.LOS of weaving sections of Aswini junction were A,D,B and A. But that for Patturakkal roundabout is

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F(poor) for all of it's weaving sections. So the Patturakkal junction has poor performance in case of weaving capacity.2 legs of Patturakkal junction has poor performance and LOS F in case of entry capacity. The remaining 2 legs of Patturakkal junction has LOS D and average performance for entry capacity. In the case of Aswini junction, it's weaving capacity of all sections are satisfactory but entry capacity is very poor.

Some improvements in terms of geometry could lead to much better performance. The data collected for the empirical analysis was from three different sites and one was used for validation. More data can be used to obtain more accurate relationship. On the other hand, the model only takes into consideration the geometry, circulating flow and exit flow as explanatory variable for capacity, whereas the driver behaviour characteristics also decide the capacity. Thus a revised model could be developed using gap acceptance concept along with the geometric elements to develop a robust model for heterogeneous traffic conditions. The study was conducted only for the unsignalized roundabout intersections, thus a study could be done for the capacity evaluation for the signalized roundabouts. Along with it, the parameters like pedestrian behaviour and sidewalks could be studies.

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