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AN EMPIRICAL CAPACITY MODEL FOR ROUNDABOUTS UNDER HETEROGENEOUS TRAFFIC OF HYDERABAD

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Abstract—Roundabouts are generally used as a means of intersection control for moderate traffic flows condition. It is important to measure the performance of existing roundabouts in terms of its ability to handle the present traffic condition. The capacity of an entry flow is found to vary considerably with the vary in geometrics of the roundabout. A study was conducted to collect the data from three different roundabouts in Hyderabad with different geometry and traffic characteristics. A model was developed using empirical analysis based on four geometric parameters of roundabout (Entry Width, Weaving Width Central Island Diameter, and Weaving Length) which are significant for estimating the capacity of roundabout. Each geometric have been tested individually for its influence on capacity, by keeping the traffic flow conditions unchanged. The developed model validated with the site data. A comparative study with some existing empirical models indicated that the capacities of roundabouts are underestimated or overestimated for Indian heterogeneous traffic condition.

Keywords: Roundabouts; Capacity; empirical analysis; heterogeneous flow; modeling

Introduction

Road network is one of the important aspect of transportation system as it connects even the smallest towns and cities. Increase in road traffic in medium and large cities is of big concern to develop a network which would be able to satisfy the traffic needs. Intersections are important part of this road network and are to be designed properly so as to handle the traffic condition effectively. Unsignalized intersections play an vital role in road network to divert the traffic to respective lanes. They provide free movement of traffic without any constraint as in case of signalized intersection. But it has a drawback of large number of conflict points. As number of lanes increase, the number of conflict points at the intersection also increases drastically. To Overcome this many reforms have been made for years. At Initial stages, 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. Introduction of roundabouts at intersection had many advantages other than eliminating 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. They allow U-turns within the normal flow of traffic, which often are not possible at other forms of junction. Moreover, roundabouts prove to be eco-friendly as it causes less pollution, since vehicles on average spend less time at roundabouts than at signalized intersections.

The road network with rapid-growing traffic has increased the uncertainty of traffic behavior. The models so developed to analyses the traffic behavior assumed homogeneous nature of traffic, while the traffic flow considered in this study is fully heterogeneous. Small studies have been made on the operational behavior of road traffic under mixed traffic flow with change in geometrics of roundabouts. A guide line which provides basic information about the rotaries in India was developed by Malhotra et al. (1976) and published in the Indian Roads Congress (IRC) code of practice 65. It summarizes the basics of the rotary intersections including the definition, geometric aspects, capacity, and various shapes of the rotary like radii, curvature, weaving length, grades, cambers, and sight distance. It also provided the signs, pedestrian crossing, and marking of the rotary intersection. Formula to determine the weaving capacity of the rotary using its geometric characteristics and the traffic flow on respective approach legs is provided. There is a immense need for improvement in the specific code to give proper way to estimate the capacity of roundabouts for heterogeneous traffic condition in India. Improved formulas for estimate the performance of roundabouts need to be developed. Thus, a method to determine the capacity of roundabouts depending on entry and circulating flows is proposed in this study keeping in view the heterogeneity of traffic flow in Indian constrains. The influence of various geometric parameters on the capacity of roundabouts is also observed through the application of the proposed model.

Literature Review

Roundabouts have been the area of interest for many of the engineers since long back. Significant studies have been conducted on traffic behavior at roundabouts over years taking the change in shape and size of roundabouts into consideration. The research resulted in the formation of several popular models and guidelines to estimate the capacity and performance parameters. George et al. (1998) produced NCHRP: Synthesis of Practice 264 dealt with the modern roundabout practice in USA. It covered the history and the basic definitions of roundabouts capacity, safety, and design aspects of the roundabouts. It stated the two primary capacity methods and the software used in USA i.e. the Australian SIDRA method and the UK-based RODEL or ARCADY method. It was further improvised by Rodegerdts et al. (2010) to NCHRP report 672 which included the recent trends in roundabouts around the world. These guidelines provide the description of HCM (2010) method for estimating entry capacity of the roundabouts. Regarding the calculation of capacity of the roundabout, two methods, namely the regression analysis and the gap acceptance model had been considered. It explains in detail the gap acceptance theory to develop the model based on driver behavior. A book on calculation of roundabouts (capacity, reliability, and waiting phenomenon) was written by Mauro (2010), which explains the method of developing the OD matrix for a roundabout.

Various empirical models developed across the world

The progress of being a modern roundabout from the ancient rotaries has seen considerable changes through ages. Timely researches had been carried out to change its shape and size. The modern roundabout was first introduced in UK and then in USA. For the adequate movement of traffic, to determine its performance many models were developed in different parts of world.

UK TRRL model

The first model for estimating the capacity of roundabout by Kimber (1980) for roundabouts is based on empirical analysis. UK had many roundabouts which operated at capacity flow at that time. The effect of various geometric parameters on the entry capacity was determined and six geometrics were selected to form a model. Linear relationship was found between the entry capacity and the circulating flow. Software based on this model were also developed and improvized. RODEL and ARCADY are the software packages based on this method.

French model

Three parallel modeling efforts was going on in France to develop the equation for capacity. The model developed by Louah (1992) is an exponential regression- based model that takes into account the influence of exiting flow and a number of geometric parameters. This model considers both entry and the exit flow and also considers two different conflicting flows. The model also considers driver behavior along with geometrics by taking the follow-up time.

Jordan model

Al-Masaeid and Faddah (1997) developed a capacity model by collecting the data collected from about 10 roundabouts and then analysis was carried out using different lanes of roundabout. To develop the model based on traffic flow and geometrics total of 27 lanes were considered to obtained the data. The relationship between the estimated entry capacity, circulating flow and roundabout geometric variables had a multiplicative form. The performance of the model was compared with capacity models in Europe and found that the same results were obtained under the conditions of low circulating flow.

Australian model

National Association of Australian State Road Authorities, NAASRA (1982) developed a model considering the headway for estimating the capacity. This model is based on assumption of headways at the roundabout and the major drawback is that the model gives the same value of capacities for large and small roundabouts having the same headway. Another drawback of this model is that it neglects the exit flow estimation for performance of roundabouts.

US Federal Highway Administration model

Robinson and Rodegerdts (2000) wrote a synopsis of Federal Highway Administration (FHWA) guide on capacity and performance of roundabouts which included single-lane roundabouts, double-lane roundabouts, and the capacity curves for urban compact roundabouts, as it has been used to estimate capacity in USA till HCM 2000 was formed.

Model for determination of capacity of roundabouts was formed by Robinson and Rodegerdts (2000) under FHWA. This model developed three equations for three conditions i.e. for the single-lane roundabout, for dual-lane roundabouts and for the urban compact roundabouts. For the case of urban compact roundabouts, the German model was used to form an equation. While in case of single- and dual-lane roundabouts, the UK model was taken as reference and an equation was developed assuming some fixed values for the geometry of the roundabout.

Effect of Geometry on Capacity and research in India

A study was conducted by Polus and Shmueli (2011) showing the capacity model depending only on the circular island diameter. They analyzed the traffic flow and geometric data from six roundabouts and the individual and cumulative entry capacity models were developed using the diameter and circulating flows as dependent variables. The model showed the relationship between entry and the circulating flow as exponential manner. Circulating flow was considered by taking only the conflicting flow for modeling rather than total circulating flow. From the model, it showed that with increase in diameter of roundabout by 30m about 21% increase capacity was found. The circulating flow model based on the weaving section was developed by Diah et al. (2011) in Malaysia, which explained the effect of geometry on traffic flow characteristics. The model so developed considered the capacity of the weaving section as depended variable and the size and shape of the weaving section as independent variable. Firstly, a model taking weaving section flow and the gap in circulating roadway was used and then it was cross checked with the model considering the weaving section geometrics like weaving length and weaving width. A relationship was derived for roadway design parameters and traffic flow characteristics (capacity and weaving section flow in this case). The lane width of the approach leg was studied by Hammond (2014) for the roundabouts in USA. The increase or decrease in capacity and delay of at the site per increase in lane width was the objective of the study. It was found that up to a certain limit the increase in lane width helped in reducing the delay. But later, it didn’t have much significance on the delay.

As Per the study conducted by Rajat Rastogi et.al (2014), the entry capacity of the roundabout with larger diameter Central Island is found to be more than that of roundabout with smaller diameter. The relationship between circulating flow and entry capacity is found to be negative exponential i.e. the entry capacity decreased exponentially with an increase in the circulating flow. The presence of 2-W about 40% in the traffic stream has led to higher value of entry flow as two wheelers show higher aggressive behavior while entering the circulating flow as compared to large size vehicles. Hence, the critical gap and follow-up time values as recommended by HCM 2010 are not applicable to traffic conditions in developing countries like India.

An Empirical capacity model for roundabouts under mixed traffic flow conditions was developed in India, by taking large data from about 10 roundabouts of 5 different states (Published in Transportation letters on 28th July, 2016). According to this model, the relationship between entry capacity and circulating flow is found to be negative exponential and five geometrics namely Weaving Width, Weaving Length, Entry Width, Entry Radius, and Central Island diameter played a vital role in deciding the capacity of roundabouts in India.

From the detailed study on literature, it could be summarized that the geometry of a roundabout plays a crucial role in determining its performance. Many researches have been carried out based on this aspect, which resulted in rigid models for different nations. When compared with other models, the models based on empiricism showed better results in some cases, while underestimated in other cases, especially, when used in different countries. Overall, it was found that the model based on geometry of roundabouts along with flow characteristics gives a better explanation of its performance under heterogeneous traffic flow conditions like India.

Methodology

Inferring the significance of the geometric variables, a model solely based on it had been developed to measure its impact on heterogeneous traffic of Hyderabad. The framework of the procedure followed to develop the model has been stated in Figure 1.

Study Area

To develop a model, it is being essential to have a proper and sufficient data-set. Some principles which lay down for selection of site for data collection for purpose of model development are stated below:

- Location of site in city- The location of site in the city determines the composition of traffic at the roundabout. Considering a roundabout situated at residential area, the proportion of independent mode of traffic would be predominant. Contradictorily, if the site lies at the outskirts of the city, the heavy vehicles connecting one place to another or on industrial purpose could be seen more in number.

- Geometry of roundabout- It is the prime factor which is considered for forming a model. The change in geometry leads to great change in its performance. Thus, dissimilarity in terms of size of Central Island, number of approach legs and width of legs is important point of consideration.
- Traffic composition- The nature of traffic changes with respect to area as the transportation facilities are significantly different. The frequency of public transport determines the composition of heavy vehicles and comparatively less usage of independent transportation techniques.

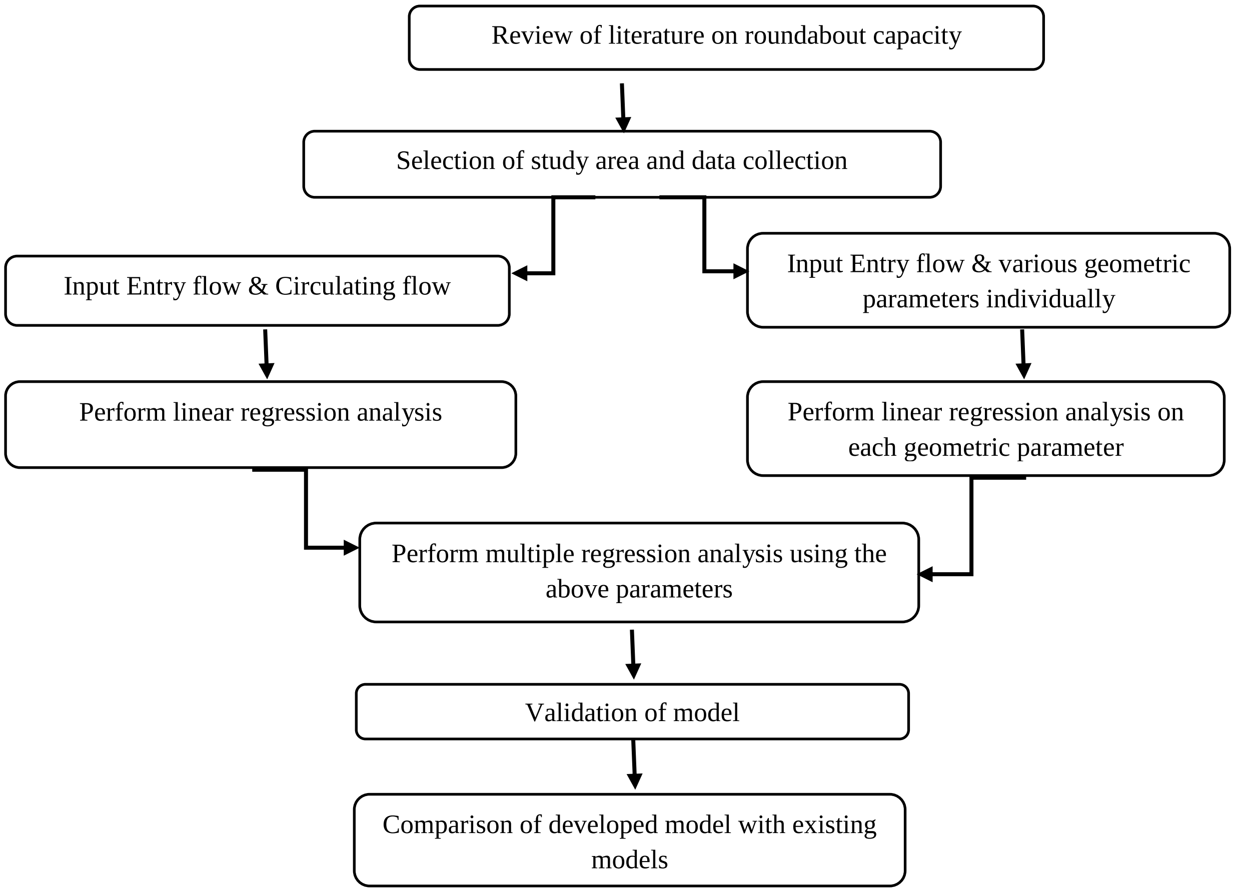

Figure 1 Frame work of procedure followed to develop the model

To satisfy the requirements of site selections, many roundabouts were studied and the following three roundabouts were selected:

1. Roundabout at Barkathpura
2. Roundabout at YMCA
3. Roundabout at Necklace Road

For the purpose of data collection, it is required that the data comprise peak hour traffic volume. The peak hour at the site can be known by its location in the city. For example, Barkatpura or YMCA roundabouts located at commercial/educational/office area would have peak hours twice a day during starting and finishing time of office hours or school hours, whereas Necklace road roundabout located at recreational area will have peak hours during weekends. Data collection comprised collecting the traffic data at the study area, which is required to analyze the roundabouts in that areas. The data were collected in the form of video recordings of the traffic flow for morning peak 2 hours at Barkatpura and YMCA roundabouts, whereas for Necklace road roundabout the available CCTV footages were taken from Hyderabad traffic police. 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. It also provides the data about the type of traffic and predominant mode of transport in that area.

Determination of Geometric Elements

The geometrics comprising central island diameter, entry width, weaving width, and weaving length were measured on field for every site during the off-peak hours of traffic to avoid hindrance. The details of Entry Radius (Which was used to compare with existing Indian model) was obtained by importing maps of the site into AutoCAD. To do so, initially, the latitude and longitude of two points placed at a certain distance from the site has been listed on map from Google Earth using marker. Later, these points were set as reference points aligned along the scale to actual dimensions. The map was then saved as an image and imported to AutoCAD using external referencing. This helps in reading the map and calculating various geometrics. The ER was found to have multiple curves, thus the radius was extracted through this process. The geometrics collected on-site had been again rechecked using these maps.

Table 1 Details of Entry Traffic volume at Barkatpura

Leg Direction	Vehicle Count				
	Left turning	**Straight**	**Right turning**	**Traffic Vol (PCU/h)**	**Circulating Volume (PCU/h)**
N-E	34	1412	1027	2473	**1000**
S-E	65	61	20	146*	**3381**
S-W	670	1789	33	2492	**1108**
N-W	1300	25	942	2267	**1842**

Table 2 Details of Circulating Traffic Volume at Barkatpura

Leg Direction	Heavy Vehicle	Light Motor Vehicle	Motor Cycle	Bicycle	Total Vehicles	Traffic Volume (PCU/h)
N-E	47	750	2028	14	2839	**2410**
E	24	765	2191	8	2988	**2479**
S-W	61	671	1511	6	2249	**1978**
N-W	6	675	1017	12	1710	**1461**

Table 3 Details of Entry Traffic Volume at YMCA

Leg Direction	Heavy Vehicle	Light Motor Vehicle	Motor Cycle	Bicycle	Total Vehicles	Traffic Volume (PCU/h)
N-E	44	888	1946	4	2882	**2473**
S-E	0	45	131	6	182	**146***
S-W	49	898	1939	6	2892	**2492**
N-W	15	903	1758	6	2682	**2267**

Table 4 Details of Circulating Traffic Volume at YMCA

Leg Direction	Vehicle Count				
	Left turning	**Straight**	**Right turning**	**Traffic Vol (PCU/h)**	**Circulating Volume (PCU/h)**
N-E	410	1330	670	2410	**1650**
E	487	1247	746	2479	**2354**
S-W	162	1194	622	1978	**2663**
N-W	433	674	354	1461	**2562**

Table 5 Details of Entry Traffic Volume at Necklace Road

Leg Direction	Heavy Vehicle	Light Motor Vehicle	Motor Cycle	Bicycle	Total Vehicles	Traffic Volume (PCU/h)
N	5	1692	1683	-	3380	**2968**
E	14	1705	1732	4	3455	**3045**
S	6	785	915	-	1706	**1488**
W	14	1429	1236	-	2679	**2395**

Table 6 Details of Circulating Traffic Volume at Necklace Road

Leg Direction	Vehicle Count				
	Left turning	Straight	Right turning	Traffic Vol (PCU/h)	Circulating Volume (PCU/h)
N	1784	307	877	2968	**1981**
E	157	587	2301	3045	**1330**
S	256	589	643	1488	**3765**
W	1057	1193	146	2395	**3533**

Table 7 Details of roundabout geometrics of various roundabouts

Site	Leg	ER (m)	EW (m)	WW (m)	WL (m)	D (m)
Barkatpura	N-E	36.73	4.1	7.2	58.42	48.8
	S-W	33.48	4.2	7.15	55.95	48.8
	N-W	23.29	4.2	7.36	34.14	48.8
YMCA	N-E	24.36	4.5	7.42	23.14	14.8
	E	23.93	4.6	7.41	32.96	14.8
	S-W	25.23	4.3	7.58	35.29	14.8
	N-W	27.86	4.3	7.62	25.47	14.8
Necklace Road	N	29.32	8.6	8.48	57.44	62.2
	E	39.67	8.5	8.46	56.93	62.2
	S	29.17	8.0	8.58	38.12	62.2
	W	17.67	8.1	8.52	46.46	62.2

Development of Model

The first step to develop a model is to determine the relationship between entry and the circulating flow. For this, trend lines are drawn for various entries and it was found that exponential relation between entry and circulating flow is giving the best fit with higher R-Squared value when compared to linear relationship. The relation obtained is resembling with that of Rajat Rastogi et.al (2014) (but with a lower R^2 value)**,** who had conducted wide range of studies on estimation of entry flows of roundabouts in India. Significance values for regression for Circulating flow (**Table 8**)

Parameter	R-Squared Value	ANOVA significance F	t stat	p-Value
Circulating flow	0.40	0.04	-2.32	0.04

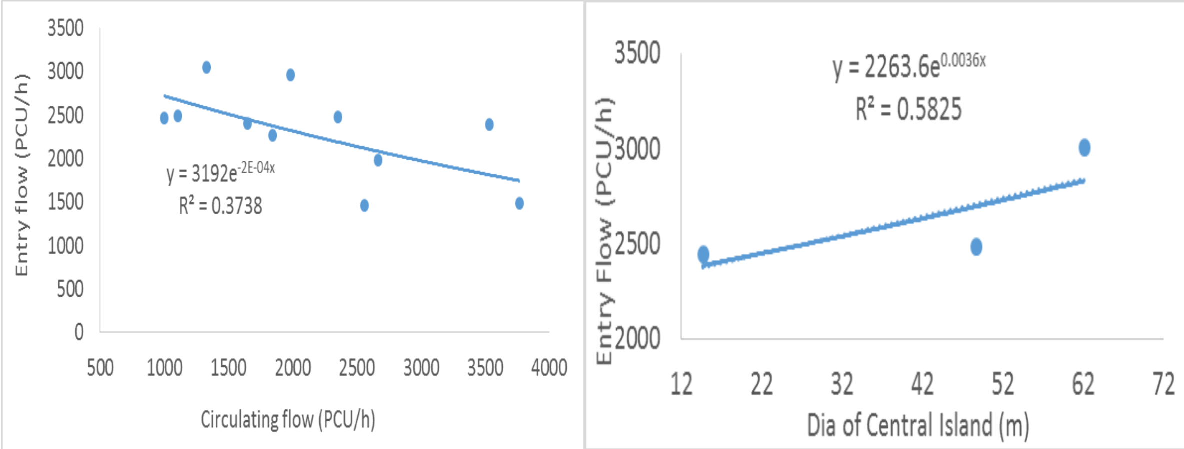

Figure 2&3 Relationship between Entry flow & Circulating flow & Central Island diameter

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. For the purpose of determining this relationship, it was essential to bring both the entry flow and the geometrics into linear form. To do this, the logarithms of the values of entry flow were calculated. This provided linearity between the two variables and it was easy to determine the relationship between them. The variation of each geometric with the logarithm value of entry flow was determined individually and the same was preferred for the development of complete model based on all geometrics along with circulating flow taken together. Every geometric showed a different type of variation for entry capacity. For example, the variation in entry capacity with variation in central diameter is as shown in figure 3. The central island diameter and weaving width varied exponentially with respect to entry capacity, whereas entry width and the weaving length showed linear variation with respect to entry capacity. The statistical significance of every geometric on entry capacity along with t-stat & p-value are shown in **Table 9** below.

Table 9 Statistical data

Parameter	R-Squared Value	ANOVA significance F	t stat	p-Value
Entry Width	0.41	0.033	2.52	0.033
Central Island Diameter	0.58	0.044	2.18	0.044
Weaving Width	0.92	0.018	3.36	0.018
Weaving Length	0.40	0.035	2.47	0.035

The entry and circulating flow data relationship as shown above had been obtained for 11 approaches (One approach of Barkatpura roundabout is not considered, as it was a minor street). The regression parameters obtained by these approaches were used for further analysis. The regression was carried out with geometric variables and entry flow as discussed earlier to know the variation of entry capacity with each variable. Finally taking into consideration the geometric variables and circulating flow, an equation was developed using multiple regression analysis. The regression value of 0.833 was obtained and the parameters were also found to be significant even when considered all together.
The equation obtained for capacity by this method is as follows:

$$Qe = 4837.92 * e^{(-7.22*10^{-5}*Qc)} * EW^{0.762} * e^{(-0.279*WW+0.00129*D)} * WL^{0.072}$$

Where, Qe = Entry Capacity (PCU/h)
D = Diameter of Central island (m)
WL = Weaving Length (m)
EW = Entry Width (m)
WW = Weaving Width (m),
Qc = Circulating flow (PCU/h)

Table 10 Significance test of entry capacity model

No.of observations - **11** R^2 – **0.833** Adjusted R^2– **0.666**

*(i) **Analysis of variance test results***

	DOF	**Sum of squares**	**Mean square**	***F***	**Significance *F***
Regression	5	0.4827	0.0965	4.987	0.05
Residual	5	0.0968	0.0194	…….	…..
Total	10	0.5796	………	…….	…..

*(ii) **Estimated parameters***

	Coefficients	**Standard error**	***t* Stat**	***p*-value**
Intercept	8.48424	1.63211	5.1983	0.00347
Ln (EW)	0.76167	0.29617	2.5717	0.04993
D	0.001295	0.00445	2.29085	0.07828
WW	-0.278885	0.23069	2.20891	0.02807
Ln (WL)	0.071961	0.25849	2.27839	0.07918
*Q*c	-0.000072	0.000089	-2.8153	0.045198

Results and discussion

It was the prime requirement for the model so developed, to prove its validity for the Indian traffic scenario. For this cause, the method discussed by Wei et al. (2011) has been used. According to this method, a model satisfies the traffic condition if it neither overestimates nor underestimates the capacity of roundabout for varying circulating flow conditions. If a model underestimates the capacity, it is on the safer side in terms of safety. But these models laid to overdesign of roundabouts to improve capacity. On the other hand, it is on a more risky side to overestimate the capacity, as the safety is at stake in those cases. Thus, a model which neither underestimates nor overestimates the capacity is to be developed for proper results. The model seemed to underestimate the Entry capacities for high Circulating flows and overestimate for low circulating flow at YMCA roundabout, whereas for the other roundabouts the variations are almost insignificant i.e., the developed satisfied the site traffic. A bar diagram is shown below in **Figure 4** for reference.

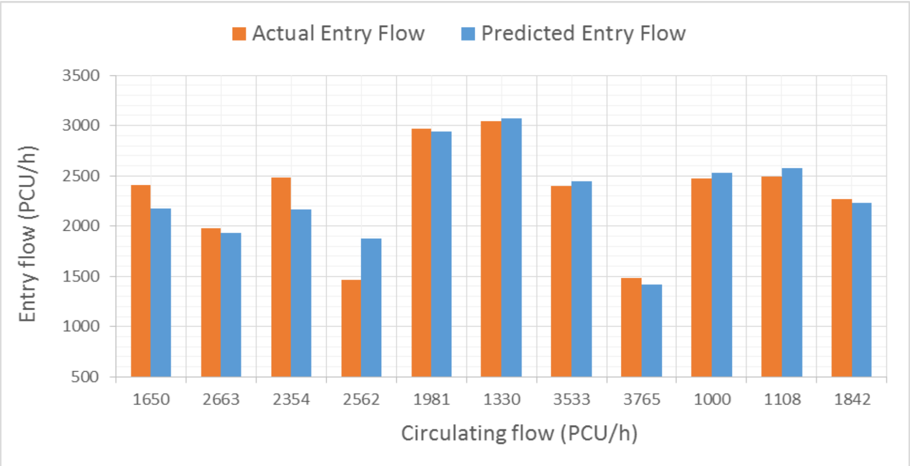

Figure 4 Graph showing Actual and Predicted Entry flow

The results obtained from the developed empirical equation have been compared with the existing empirical models. For this purpose, IRC method, UK TRRL method, French model, Jordan capacity model and Indian model has been initially considered. But, the French model and UK TRRL method laid special emphasis on the width of Splitter Island. But from the data collected, very few sites had considerable splitter island width. Hence, these models were discarded for comparison and the developed model was finally compared with three models. The bar graphs showing the comparison of models for respective sites are as shown below. It can be observed from the graphs that the Jordan model gave the lowest entry capacity of a roundabout as compared to Indian models for all values of circulating flow. This is supported by the work of Rajat Rastogi et.al (2014) on “Selection of Roundabout Entry capacity model for Indian condition”. This may be due the heterogeneity factor which changes the value of traffic flow considerably. IRC method which gives the capacity of weaving section, overestimated the capacity at Necklace road roundabout, whereas underestimated the capacity for the other two roundabouts. It can be attributed to the higher values of geometrics at Necklace road roundabout. Indian model (2016) provided to be a good fit for most of the entries, excluding YMCA. The variation can be attributed to the higher entry flows even for small central island diameter at YMCA.

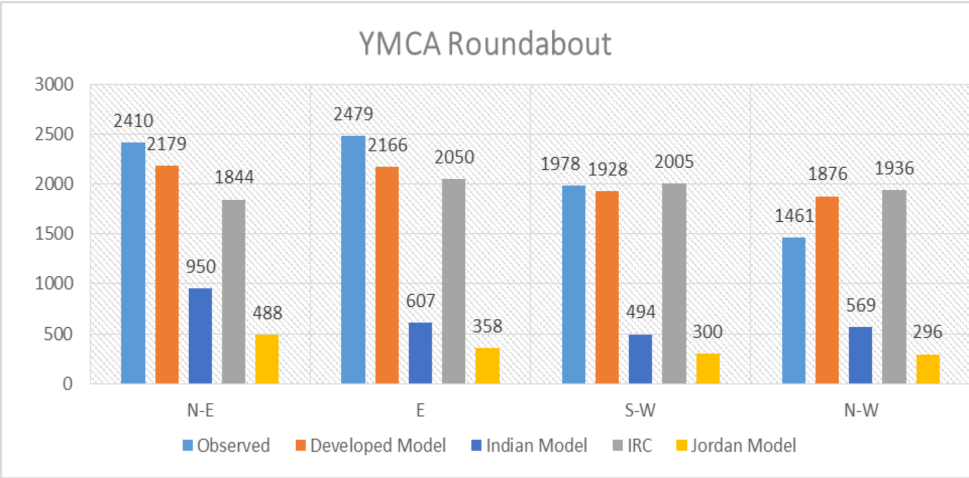

Figure 5 Comparison of capacities by various models for YMCA Roundabout

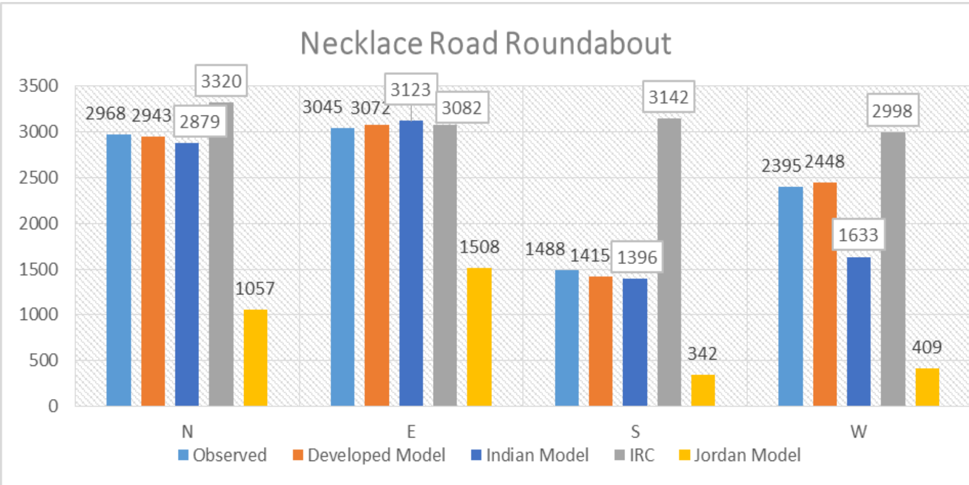

Figure 6 Comparison of capacities by various models for Necklace Road Roundabout

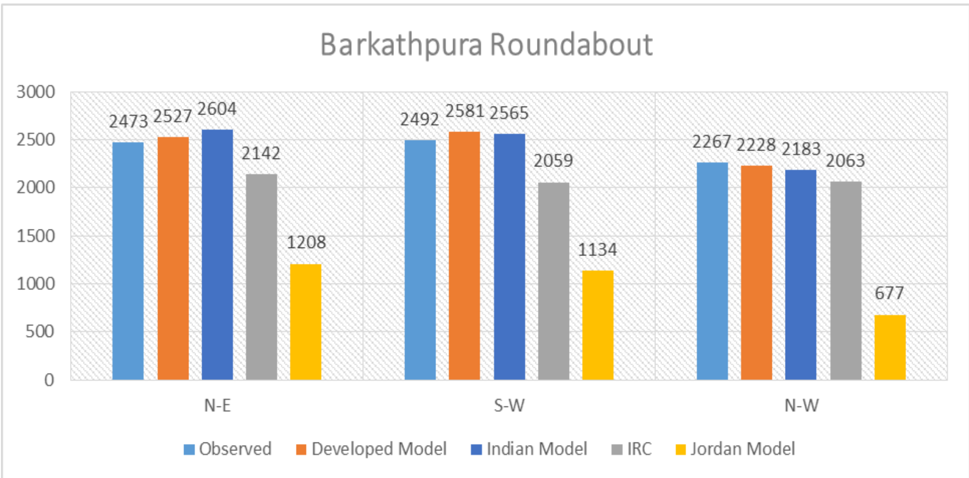

Figure 7 Comparison of capacities by various models for Barkathpura Roundabout

The entry capacity as stated earlier depends on four geometric components of roundabout, i.e. central island diameter, entry width, weaving width, and weaving length. Every geometric element had a significant effect on the entry capacity. Hence, a study has been conducted to study the variation in entry capacity per increase or decrease in individual geometrics. For this comparative study, the circulating flow for an entry of a site was used along with variation in geometry from the data collected.

Variation in central island diameter

The central island diameter (D) varied exponentially with the entry capacity. Hence, even a small variation in Central island diameter changes the entry capacity of the roundabout. So, the change in entry capacity for 15m increase in central island diameter was calculated for variation in diameter from 15m to 60m. The observation stated the 15m increase in diameter increased the entry capacity by 2% to 3%. The variation in entry capacity per increase in central island diameter is shown below in Figure 8.

Variation in weaving length

Weaving length (WL) varied in power form with the entry capacity as discussed in the developed equation. The study was conducted varying the weaving length from 20 to 50 m with a difference of 10 m each. The entry capacity was found to vary between 3 and 4% for every 10 m increase in weaving length and the overall variation for increase in weaving length from 20m to 50m is about 7%. This variation is represented pictorially in Figure 9 below.

Variation in entry width

Entry width (EW) varied in power form with the entry capacity. Hence, even a small variation in entry width changes the entry capacity of the roundabout drastically. EW was varied from 4 to 20 m with difference of 4 m. The entry capacity found to increase by almost 40% for first 4m to 8m and from there on for every 4m increase in EW there is an increase of 25% to 35% in Entry capacity. The plot showing the variation in entry capacity with increase in entry width is given below in Figure 10.

Variation in weaving width

Weaving width (WW) varied exponentially with the entry capacity. The weaving width was varied from 8 to 16 m with each 4 m rise. The entry capacity was found to drastically decrease by 60% for first 4 m rise in WW and for the next 4m rise in WW there is a decrease of about 50% in Entry capacity. The figure showing variation in entry capacity with weaving width is given below in Figure 11.

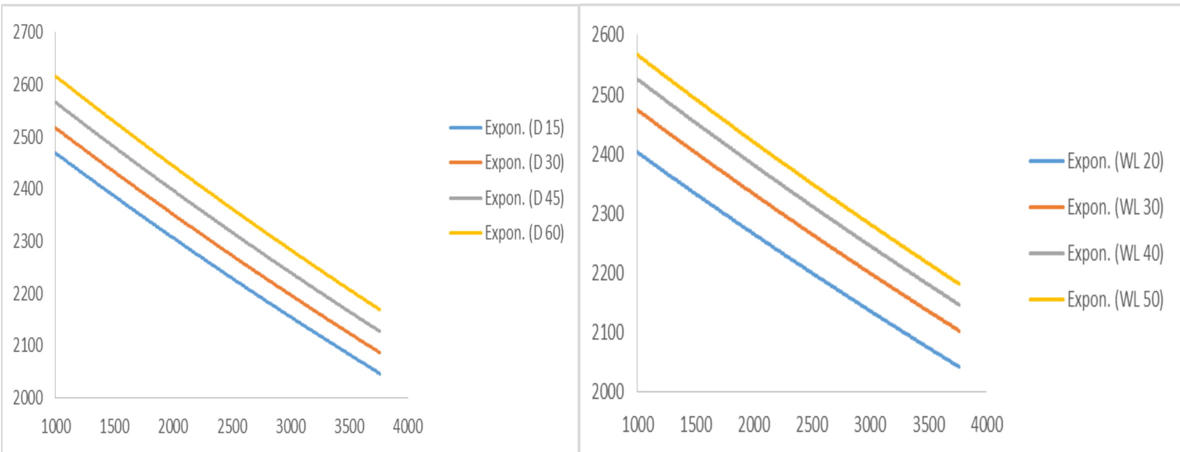

Figure 6&7 Effect of Entry capacity per change in Central island diameter and Weaving Length

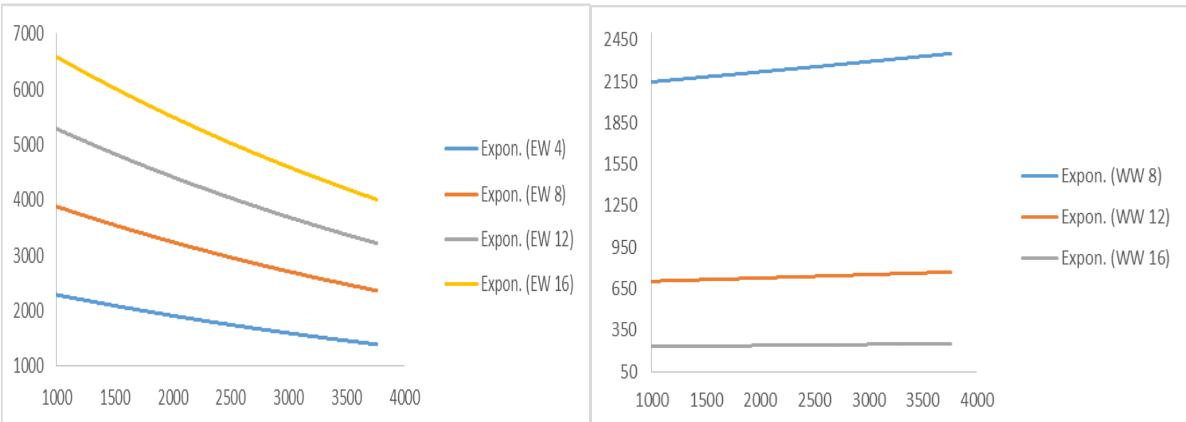

Figure 8&9 Effect of Entry capacity per change in Entry Width and Weaving Width

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 method used to estimate the capacity of roundabouts was very primitive, thus a new model defining the capacity of roundabouts was to be developed. The literature on various models developed around the world indicated that the geometry of the roundabout is a prime deciding factor of capacity and performance of roundabout. Thus, this concept has been taken as base for developing the model in Indian context as wide variation in terms of geometry was observed. Giving importance to geometry and traffic composition, 3 sites were finalized.

The data have been collected during the respective peak hours of the site. The data comprised entry and circulating flow and the geometric variables. The required values of entry and circulating flow for one-minute interval were extracted. The plot between entry and circulating flow depicted exponential relationship for the data so extracted. Regarding the various geometric variables, diameter of Central Island, entry width, weaving width, and the weaving length were found to have significant impact on capacity. These geometrics when plotted against the logarithm value of entry flow showed linear relationship in case of Central island diameter and weaving width both; whereas, the rest of the geometrics showed logarithmic variations. The model for entry capacity was then developed using these geometric parameters and circulating flow.

An empirical model was finally developed for capacity of roundabouts with the geometric parameters and circulating flow as explanatory variables. The facts that could be concluded from the study are:

(1) The relationship between the entry and the circulating flow was found to be exponential for the best fit.
(2) The geometric variables, central island diameter, entry width, weaving width, and weaving length showed significant impact on capacity. It was observed that Entry width showed an increase in capacity of up to 30%, whereas weaving width showed a decrease in capacity of up to 50% respectively, for 4 m rise in their dimensions. Comparatively, Central island diameter and weaving length was found to have less impact on capacity as 3-4% increment in capacity was observed with increase of 10 m length.
(3) Validation of the model proved that the proposed model provided a good fit for the saturated flow conditions for maximum in all the sites. For YMCA roundabout, overestimation of capacity was found, when the circulating flow was too low and a bit underestimated, in case of very high circulating flow values. The latter case may be due to involvement of large number of heavy vehicles in the major stream, hence reducing the entry flow. Overall, the model provided satisfactory results for Indian conditions.
(4) The Jordan model was found to underestimate the capacity of roundabout in mostly all the sites used for validation.
(5) From the detailed study, it can be concluded that the capacities of Barkatpura and YMCA roundabouts can be increased by slightly increasing the Entry width from 4m to 6m.

The data collected for the empirical analysis was from three different sites of Hyderabad. When compared with other existing empirical models, the size of the data used for model development was smaller, hence more data can be used to obtain more accurate relationship. On the other hand, the model only takes into consideration the geometry 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 Indian scenario.

The study was conducted only for the unsignalized roundabout intersections, thus a study could be done for the capacity evaluation for the signalized roundabouts for various cities in India. Along with it, the parameters like pedestrian behaviour and sidewalks could be studied along with it.

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