Proceedings of 10th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2021 Month: October Volume: 10

Model development for entry capacity estimation of selected roundabouts of Nepal

Bipin Gyawali [a], Anil Marsani [b]

[a, b] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
Corresponding Email: [a] bpngwl@gmail.com, [b] anilmarsani.ioe.edu.np

Abstract
This paper comprises development of entry capacity model to estimate entering vehicles from an approach of roundabouts for mix traffic conditions in Nepal. Entry flow, circulating flow and other geometrical data were taken from the roundabouts of cities like Chitwan and Itahari. The flow of the vehicles in these roundabouts, were video recorded from a suitable vantage point, while the geometrical data of the roundabouts were measured in the field. The data was analyzed through regression to formulate the entry capacity model from relevant parameters. From the analysis, it was observed that entry capacity of roundabouts was dependent upon the circulating flow in front of the corresponding entry flow, central island diameter, approach width and exit width.

Keywords
Roundabouts, Entry capacity, Regression analysis, Nepal

1. Introduction

A roundabout can be defined as the form of an uncontrolled intersection in which approaching vehicles move around an island along with circulating vehicles in a fixed direction and then leave out in the direction of their desired destination. Roundabouts offer efficient traffic operation and safe riding conditions by reducing conflict points due to improved geometry for a range of traffic flow traversing through it. Therefore, roundabouts must be carefully studied for its capacity and level of service. However, due to few number of roundabouts in Nepal, very limited studies regarding its capacity has been carried out. Hence, the evaluation of the roundabouts for its capacity has become very important. Different studies and methods have evolved with time for examining the capacity of roundabouts across the world. All the developed methods can be studied by grouping under three classes.

1. Weaving maneuver based analytical model
2. Gap acceptance model
3. Regression models

2. Literature Review

Wardrop (1957) [1] gave the equation for the estimation of the capacity of the rotary for the first time. This model was based on the weaving capacity of the rotary and hence can be categorized as weaving based model. The model considered various parameters like entry width, weaving length, width of weaving section, ratio of the weaving traffic over total traffic in rotary etc. IRC-65 (1976) [2] outlines the method for the design of a rotary based on Wardrop's method. Hence, both these models estimates the capacity of the weaving section to provide the capacity of the roundabout.

Among critical gap based models the US based, HCM 2010 model [3], German models and Australian models all use observations from the roundabout site i.e. gaps in the roundabout between the two circulating vehicles for the entering vehicles. The HCM 2010 method proposes an exponential function based on gap acceptance theory for evaluating the entry capacity of single-lane and two-lane roundabouts given in equation 1. The HCM-2010 suggests the critical gap and follow-up time values as 4.1-4.6 s and 2.6-3.1 s respectively in equations 2 and 3. For different set of entry and circulating lanes other than standard roundabout the modifications for roundabouts is also provided.

$$C = A \times e^{(-B \times V_c)} \quad (1)$$

where,

$C = Entry\ Capacity$

$V_c = circulating\ traffic$

$$A = \frac{3600}{t_f} \qquad HCM\ 2010 \quad (2)$$

$$B = \frac{t_c - \frac{t_f}{2}}{3600} \qquad HCM\ 2010 \quad (3)$$

$t_c = critical\ headway$

$t_f = follow-up\ headway$

While, Highway capacity manual-2010 gives the critical gap and follow up time for US conditions, these may be different for other traffic conditions. Indo - HCM 2017 [4] provides the capacity estimation formulas based upon the equation provided in the HCM-2010 using critical gaps and follow up times for different diameter roundabouts which are presented in the Table 1

Table 1: Critical gap and Follow up time Indo-HCM 2017

Diameter D (m)	Critical Gap t_c (s)	Follow up time t_f	$C = A \cdot e^{(-B \times Q_c)}$
20 - 30	2.01	1.51	$C = 2384 \cdot e^{\left(\frac{-35 \times Q_c}{100000}\right)}$
30 - 40	1.87	1.40	$C = 2571 \cdot e^{\left(\frac{-32 \times Q_c}{100000}\right)}$
40 - 50	1.65	1.24	$C = 2903 \cdot e^{\left(\frac{-29 \times Q_c}{100000}\right)}$
50 - 70	1.61	1.21	$C = 2975 \cdot e^{\left(\frac{-28 \times Q_c}{100000}\right)}$

Similar studies to work out the entry capacity of roundabout was carried out in Jordan, but with an empirical approach by Al- Masaeid and Faddah(1997) [5]. The model is presented in equation 4. The study reached to an interesting conclusion that the geometric variables like entry width of an approach and the central island's diameter had the greatest effect on the entry capacity while other variables like circulating lane width had the limited effect on the entry capacity.

$$Q_e = 168.2 D^{\frac{31.2}{100}} S^{\frac{21.9}{100}} e^{\frac{7.1}{100}EW + \frac{1.9}{100}CW} e^{\frac{-5.602 Q_c}{1000}} \quad (4)$$

Q_e = entry capacity, pcu/h;

Q_c = circulating traffic flow, pcu/h;

D = central island diameter m;

S = distance between the entry and near-side exit, m;

EW = entry width, m;

CW = circulating roadway width, m

In India, Rastogi et. al. (2017) [6] carried out similar research and recommended the model as in equation 5 .

$$Q_e = 1.014(589.9 \times e^{\frac{-0.3}{1000}Qc} \times D^{0.391} \times CW^{0.099}) \quad (5)$$

Q_e = entry capacity, pcu/h;

Q_c = circulating traffic flow, pcu/h;

D = central island diameter, m;

CW = circulating roadway width, m

2.1 Research-objective

The objective of the research is to determine the mathematical model to estimate entry capacity of roundabout for Nepalese conditions.

2.2 Limitations

The entry flow in roundabout is affected by pedestrian flow in the crosswalks near the roundabout. The pedestrian flow has been discarded in the analysis as the pedestrian flow in these selected roundabout did not offer much hindrance to entry of the vehicles.

3. Methodology

3.1 Study area

The study area included roundabouts of Itahari, Chaubiskoti- Chitwan, Paras buspark- Chitwan. The analysis provided in this study consist of hourly volume data of these sites between 9:00 A.M to 12 P.M during working days of the week between 20th January to 10th February of the year 2021 by the means of video graphic recording and the data has been extracted by counting manually from the recording.

The roundabout having following criteria were selected for study

- Having four approach legs.
- Vehicular flow in the roundabout is free i.e. uncontrolled traffic flow.
- Roundabout having a level gradient.
- Roundabout is free from the hindrance by unwanted parking, bus stops.

3.2 Data collection and Processing

The volumetric flow of the vehicles entering the roundabout has been collected for every minute of these roundabout and also the circulating flow entering the vehicles has been collected manually from the recording.The recorded film was played on the computer screen to extract the desired information.

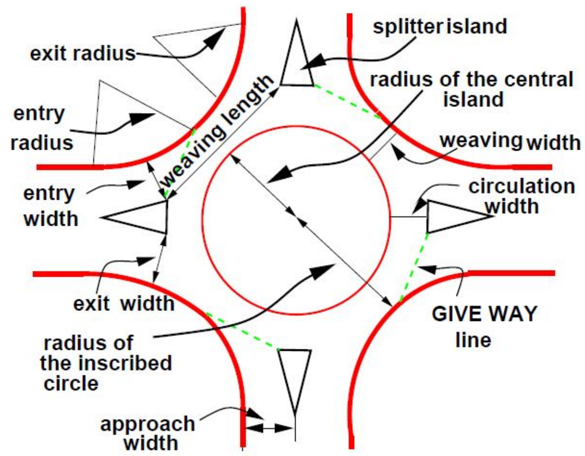
Since the traffic in Nepal is mixed, to make the analysis significant, the vehicles were divided into four different categories as motorized two-wheeler (2W), motorized three-wheeler (3W), small car (SC) or standard car, and heavy vehicle (HV). So, the analyis is done in terms of Passanger car unit per hour (PCU/hr) rather than vehicle per hour(V/hr).

The volumetric data so obtained in a minute is then summed for a 60 min period to calculate (V60) i.e. hourly volume for comparison purposes. The PCU values for converting the heterogeneous traffic into a homogeneous one are taken from Nepal Urban Road Standard 2076 and research regarding Passanger Car Unit(PCU) for Nepalese conditions done in Institute of Engineering. For conversion into PCU, the equivalence factors for two wheelers 0.25 PCU, autos are 1.0 PCU and buses and Heavy Vehicles (HV) are assessed as 3 PCU. The datasets consist of twenty seven hour video recording of each four approaches of Itahari Chowk, Chaubiskoti Chowk and Paras Buspark Chowk roundabout of Chitwan for research purpose. Of the twenty seven hour video , two-third of the data is used for the formulation of the model and while remaining datasets has been set aside for the data validation purpose.

The following geometrical data of the roundabouts was collected manually from the field.

- Central Island Diameter (D)
- Entry width (EW)
- Exit Width (Exit)
- Circulating Width(C.W.)
- Approach width (A.W.)

Figure 1: Geometrical parameters in a Roundabout



The Figure 1 shows the geometrical parameters of the roundabout.

The geometrical data of the Itahari Chowk roundabout is given in Table 2. Dimensions are provided in metre.

Table 2: Geometrical parameters for Itahari Chowk Roundabout

	Biratnagar	Dharan	Mechi	Koshi
D	19.85	19.85	19.85	19.85
EW	5.8	8.3	15.65	17.6
Exit	14.4	9.2	15.1	9.4
A.W.	5	7.6	14.8	16.2
C.W.	11.2	11.4	11.2	11.2

The geometrical data of the Chaubiskoti chowk roundabout is given in Table 3. Dimensions are provided in metre.

Table 3: Geometrical parameters for Chaubiskoti Roundabout

	Narayan ghat	Buspark	Rampur	Hospital Road
D	13.2	13.2	13.2	13.2
EW	11.78	12.4	8.2	6.2
Exit	11.6	13.15	11.65	11.8
A.W.	9.65	7.87	5.1	5.57
C.W.	11.8	12.3	12.5	12.5

The geometrical data of the Paras Buspark Chowk is given in Table 4 respectively. Dimensions are provided in metre.

Table 4: Geometrical parameters for Paras Buspark Chowk Roundabout

	Chaubis koti	Hetauda	Bypass Road	Bharatpur Buspark
D	9.85	9.85	9.85	9.85
EW	10.98	9.65	8.4	6.16
Exit	10.94	7.74	8.7	6.2
A.W.	10.52	9.1	8.15	5.85
C.W.	13.7	13.76	14.1	12.85

4. Analysis of Data

To identify relation between the variables co-relation between the parameters has been checked and the result can be seen below in the table 5. However, for analysis all the data will be considered the choice of the variables for the regression modelling is done by considering the co-relation between the statistical parameters.

Table 5: Correlation Matrix of Entry Capacity, Circulating flow and geometric parameters

	Qe	Qc	D	C.W	A.W	Ew	Exit
Qe	1.0						
Qc	0.7	1.0					
D	0.9	0.9	1.0				
C.W	-0.8	-0.8	-0.9	1.0			
A.W	0.6	0.6	0.6	-0.5	1.0		
Ew	0.3	0.4	0.4	-0.3	0.7	1.0	
Exit	0.4	0.5	0.5	-0.5	0.4	0.2	1.0

4.1 Entry Capacity model

From the correlation matrix shown in the Table 5, it can be seen that entry flow has a co-relation with the central island diameter (D), circulating width (C.W.), circulating flow (Qc), approach width (A.W) ,the entry width (Ew) and exit width(Exit). Both, linear and non linear regression was performed and the variables that are non-significant in regression was discarded later from the general model.

From the table 5 the general equation in linear form can be written in the form of equation 6

$$Q_e = a + a1 * Qc + a2 * D + a3 * CW + a4 * A.W + a5 * Ew + a6 * Exit \quad (6)$$

The general equation in exponential form can be expressed as equation 7

$$Q_e = b \cdot e^{-b1*Qc} \cdot D^{b2} \cdot e^{b3*CW+b4*AW+b5*Ew} \cdot Exit^{b6} \quad (7)$$

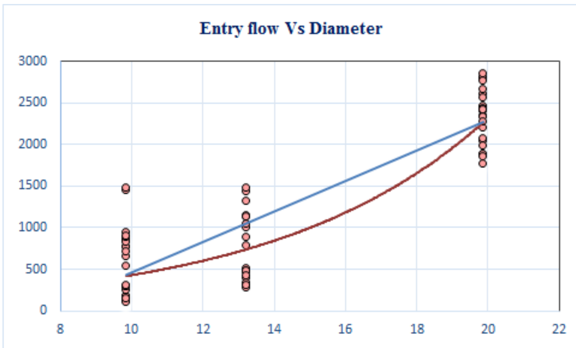
5. Analysis and Discussion of the Result

Firstly, the nature of variation between the entry flow with respect to various parameters considered in the equation 6 and equation 7 like circulating flow, approach width, circulating width, central island diameter etc. has been examined through plots and linear and exponential trend-line show the individual affect of the variables on the entry flow.

5.1 Variation of Entry flow with respect to Various Parameters

The variation of entry flow with respect to Diameters is shown in the Figure 2. As the diameter of the central island increase, the entry flow also increases.

Figure 2: Entry flow Vs Diameter of Central Island



The variation of entry flow with respect to Circulating width is shown in the Figure 3. As the circulating width increase, the entry flow values decreases.

The variation of entry flow with respect to Circulating flow is shown in the Figure 4.

The variation of entry flow with respect to approach width is shown in the Figure 5. As the approach width increase, entry flow increases accordingly.

The variation of entry flow with respect to entry width is shown in the Figure 6.As the entry width increase, it is seen that entry flow also increases.

The variation of entry flow with respect to exit width is shown in the Figure 7.As the exit width increase, it is seen that entry flow decreases.

Figure 3: Entry flow Vs Circulating width

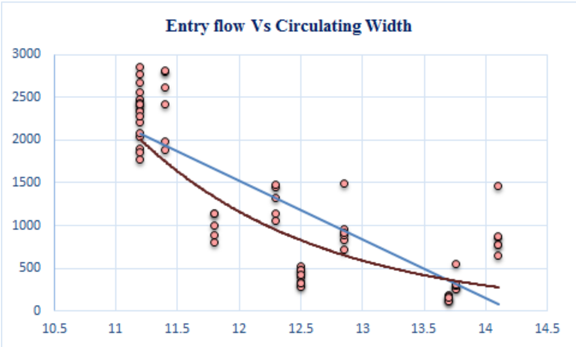
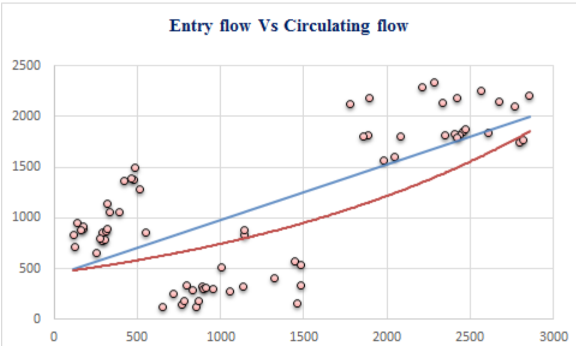


Figure 4: Entry flow Vs Circulating flow



5.2 Linear Regression Analysis

5.2.1 Calibration of Linear Model

Linear regression analysis was performed using 18 hrs. of hourly volume data of entry flow, circulating flow and other geometrical parameters of the approaches. From the analysis, it was found that entry width and circulating width did not have much affect in the model. Hence, regression was performed excluding these variables. The results of the linear regression analysis is shown below:

Table 6: Regression Model

	Coeff.	*Standard Error*	*t Stat*	*P-value*
Intercept	-2081.63	113.52	-18.34	4.69E-49
Qc	-0.59	0.06	-9.95	4.97E-20
D	306.07	9.94	30.80	1.49E-89
A.W	35.75	6.13	5.83	1.62E-08
Exit	-58.80	8.41	-6.99	2.22E-11

The R squared-value obtained is 0.90 and the adjusted R-squared value is 0.90. It can be said that 90 % of the data can be explained by the model. From the analysis of variance the F-value obtained is 605.15 which gives the significance F-value as in Table 7 indicating that the model is good.

Figure 5: Entry flow Vs Approach Width

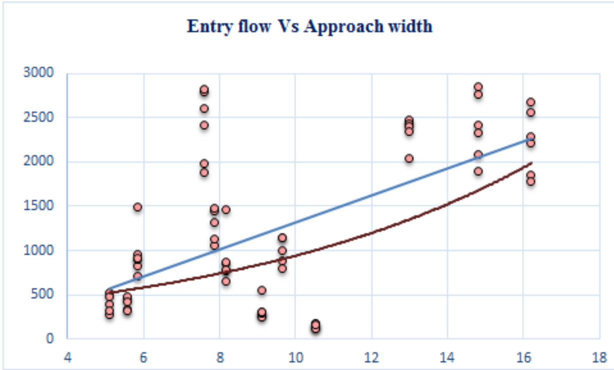
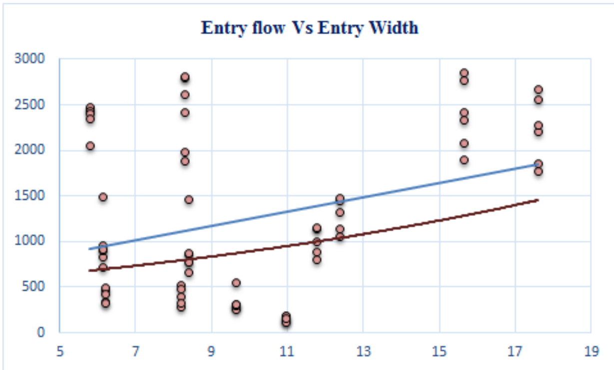


Figure 6: Entry flow Vs Entry Width



The P- value of the selected independent variables is well below confidence limit of 5 % indicating that the selected coefficients are significant to the model. Hence the linear model for the entry capacity is given by the equation 8

$$Q_e = -2081.63 - 0.59 * Qc + 306.07 * D + 35.75 * A.W - 58.8 * Exit \quad (8)$$

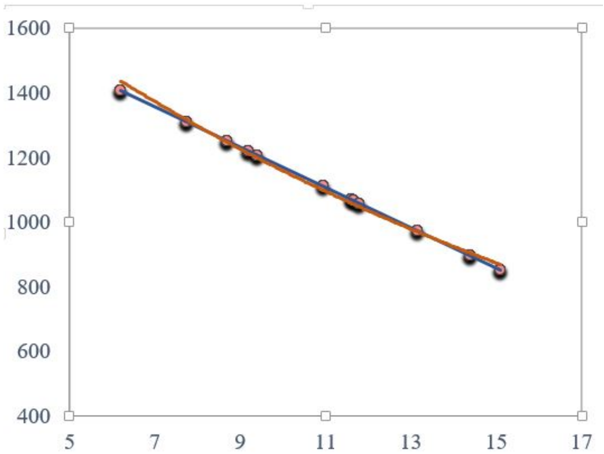
5.2.2 Validation of Linear Model

The remaining data were used to compare the output from the models. The observed independent variable were fed into the model to see the output of the model

Table 7: Linear Regression Statistics of the Model

Regression Statistics	
Multiple R	0.95
R Square	0.90
Adjusted R Square	0.90
Standard Error	308.41
Observations	270
F	605.15
Signficance-F	6.50E-132

Figure 7: Entry flow Vs Exit Width



with respect to observed field values. Z-test was performed to compare the datasets. Z-test analysis is presented in the Table 8.

Table 8: Data Validation by Z-test Analysis

	Qe(model)	*Qe(output)*
Mean	1445.84	1411.24
Known Variance	707901.2	1058525
Observations	146	146
Hypothesized Mean Difference	0	
z	0.31	
$P(Z \leq z)$ one-tail	0.33	
z Critical one-tail	1.64	
$P(Z \leq z)$ two-tail	0.75	
z Critical two-tail	1.96	

Since Z- value is 0.31 which is less than 1.96, the null hypothesis that the difference of mean is zero is not rejected indicating the datasets are not significantly different within 5 % confidence limits.

5.3 Non-linear Regression Analysis

5.3.1 Calibration of Non-linear model

Non-linear regression analysis was performed using 18 hrs. of hourly volume data of entry flow, circulating flow and other geometrical parameters of each approaches. From the analysis considering all the variables, it was seen that circulating width and entry width were non-significant.So, the regression analysis was performed excluding these variables. The results of the non-linear regression analysis is shown in the Table 9

The R squared-value obtained is 0.91 and the adjusted

Table 9: Non Linear Regression Model

	Coeff.	*Standard Error*	*t Stat*	*P-value*
Intercept	-3.00	0.41	-7.29	3.57E-12
Qc	-9.8E-04	0.00	-13.17	8.19E-31
ln(D)	5.10	0.18	27.70	3.17E-80
A.W	0.04	0.01	4.52	9.46E-06
ln(Exit)	-1.17	0.12	-10.12	1.48E-20

Table 10: Non Linear Regression Statistics

Regression Statistics	
Multiple R	0.91
R Square	0.82
Adjusted R Square	0.82
Standard Error	0.40
Observations	270
F	304.52
Signficance-F	8.73E-98

R-squared value is 0.82. It can be said that 82 % of the data can be explained by the model. From the analysis of variance the F-value obtained is 304.52 which gives the significance F-value as indicated in Table 10 indicating that the model is good. The P-value of the selected independent variables is well below confidence limit of 5 % indicating that the selected coefficients are significant to the model. Hence the non linear model for the entry capacity is given by the equation 9.

$$Q_e = 0.0499 \times e^{-0.00098 \times Q_c + 0.04 \times A.W.} \times D^{5.1} \times Exit^{-1.17} \tag{9}$$

5.3.2 Validation of Non Linear Model

The remaining data were used to compare the output from the models. The observed independent variable were fed into the model to see the output of the model with respect to observed field values. Z-test was performed to compare the datasets. Z-test analysis is presented in the Table 11.

Since Z- value is -0.02 which is less than 1.96, the null hypothesis that the difference of mean is zero is not rejected indicating the datasets are not significantly different within 5 % confidence limits.

Table 11: Data Validation by Z-test Analysis

	Qe(model)	*Qe(output)*
Mean	1408.25	1411.24
Known Variance	1309308	1058525
Observations	146	146
Hypothesized Mean Difference	0	
z	-0.02	
$P(Z \leq z)$ one-tail	0.31	
z Critical one-tail	1.64	
$P(Z \leq z)$ two-tail	0.98	
z Critical two-tail	1.96	

6. Conclusion and Recommendations

The volumetric count of the entry flows and the circulating flow along with the geometrical features of the roundabout was used to formulate an empirical approach to estimate the entry capacity of the roundabouts. Linear and non-linear regression was performed among the parameters and from the analysis following conclusions were drawn:

1. The model developed showed that both circulating traffic flow and geometrical parameters have significant effect on the entry capacity . Hence, models considering both factors are appropriate for traffic conditions like that of Nepal.The model developed for the entry capacity was seen to be significantly affected by the parameters like circulating traffic, central island diameter, approach width and exit width.

2. Linear model outputs were seen more closer to the field observations than non-linear models.

In this study the PCU used is based on the Nepal Urban Road Standard 2076 which is constant rather than Dynamic PCU as suggested in the Indo-HCM. The developed model hence can be used to predict entry capacity of approach of four-legged roundabout based on circulating flow and geometrical features for mix traffic conditions with less hindrance to traffic flow in roundabouts from external factors like pedestrians, unwanted stops near roundabout etc.

Acknowledgments

The authors express gratitude towards the faculty of Trasnportation Engineering, Department of Civil Engineering of Institute of Engineering, Pulchowk campus for their valuable guidance. The authors also appreciates the assistance from Ashim Gautam, Anusha Sharma and Chetan Gyawali for their contribution at various stages.

References

[1] J.G. Wardrop and Road Research Laboratory. *The Traffic Capacity of Weaving Sections in Roundabouts*. 1957.

[2] IRC-65. *Recommended Practices for Traffic Rotaries*, 65 edition, 1976.

[3] *Highway Capacity Manual*, 5th edition, 2010.

[4] *Indo- HCM 2017*, 2017.

[5] Hashem R. Al-Masaeid and Mohammad Z. Faddah. Capacity of roundabouts in jordan. *Transportation Research Record*, 1572(1):76–85, 1997.

[6] Abdullah Ahmad and Rajat Rastogi. Regression model for entry capacity of a roundabout under mixed traffic condition – an indian case study. *Transportation Letters*, 9(5):243–257, 2017.