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Modelling Entry Capacity Reduction Factor of Roundabouts under the Influence of Pedestrians in Developing Countries

Ashish Kumar Patnaik,
Ph. D Research Scholar,
Department of Civil Engineering, NIT Rourkela, India,
Tel: +91-661-246 2313; Email: ashishkumar.patnaik@yahoo.in

Rima Sahani
Ph. D Research Scholar,
Department of Civil Engineering, NIT Rourkela, India,
Tel: +91-661-246 2313; Email: luckyrima44@gmail.com

Kalpana Sahoo
Former M. Tech Student,
Department of Civil Engineering, NIT Rourkela, India,
Tel: +91-661-246 2313; Email: kalpana.s494@gmail.com

Prasanta Kumar Bhuyan, Corresponding Author
Assistant Professor,
Department of Civil Engineering, NIT Rourkela, India,
Tel: +91-661-246 2313; Email: pkbtrans@gmail.com

Abstract

Objective of this study is to develop an entry capacity reduction factor model of roundabout under the influence of circulating flow, pedestrian flow and diameter of Central Island. Multivariate regression analysis is carried out with R-Square value observed to be 0.946 and 0.965 in the development and validation of this model. Capacity reduction factor increased by (15%, 30% & 35%), (10%, 15% & 20%) and (25%, 35% & 45%) respectively with increase in circulating flow, pedestrian flow and diameter of Central Island by (50, 100 & 150) PCU/h, (50, 100 & 150) Ped/h and (10, 20 & 30) m respectively.

Keywords

Roundabout, Circulating Flow, Pedestrian Flow, Multivariate Regression, Entry Capacity Reduction Factor

1. Introduction

Due to rapid urbanization in developing countries, mobility of both motorized and non-motorized mode of transport is also increasing on city road networks. Roundabouts are very popular transportation infrastructure facility at which motorized vehicles get full spatial advantage to carry out stream lined movements. However, stream lined movements often get interrupted because of pedestrian activities along and across the premises of roundabouts. Thus roundabouts are not being able to accommodate number of vehicles as it is designed to do so. In India, under heterogeneous traffic condition, the modes of traffic consist of varying static and dynamic characteristics and also heterogeneity depends upon the land use pattern of the city. The short width vehicles always tried to find the lateral and longitudinal gaps in between wide width of vehicles. Therefore efficient space is utilized for motorized traffic movements in heterogeneous traffic flow condition than homogeneous traffic flow condition. But at the same time lane markings, zebra crossings, refuse islands and grade separated sidewalks are not consistent provisions at roundabouts in India. Hence pedestrians hardly get any wishful space to carry a smooth movement under such constrained conditions.

The evaluation of capacity at roundabout based on two methods such as gap acceptance and empirical analysis have not given due considerations on effect of pedestrian activities on capacity reduction. These two existing methods are developed by researchers by assuming the influence factor such as traffic flow and geometric variables taken together without considering pedestrian activity. The reduction in capacity of roundabouts due to frequent interruption of pedestrians need a thorough investigation. From available literatures it has been observed that limited research has been carried out in this regards in a developing country like India. This study primarily focus with an objective to develop a methodology that can be used to estimate the reduction in entry capacity of roundabouts because of pedestrian interruptions to the normal flow of traffic. To what extent does the strength of pedestrian stream influence the roundabout capacity is described in this Study.

This study has been carried out by employing multivariate regression analysis for modelling the capacity reduction factor by integrating two factors like circulating flow and Diameter of Central Island with additional pedestrian factors that influences the roundabout capacity. Data splitting method is employed in the model validation process to observe the prediction performance of new model that could be applied to new data set. To examine the effect of influencing variable with capacity reduction factor for which the variables named as circulating flow, pedestrian flow and diameter of Central Island increased up to certain value to observe how much capacity reduction factor varying under heterogeneous traffic flow condition. Data collection has been carried out in four roundabouts located in four cities (Bhubaneswar, Ranchi, Nagpur & Rourkela) of India by employing two high resolution camera mounted on tripod stand from high rise buildings to capture the entire roundabout conveniently. Recorded videos are processed through AVIDEMUX software to extract the data appropriately.

The entire paper is organized into six sections in which the brief idea about the study is reported in section 1. Section 2 describes detail literature review regarding various aspects relating to effect of pedestrian at roundabout. Location of the study area and data collection process is addressed in section 3. The methodology adopted for modelling the capacity reduction factor considering pedestrian impact is explained in section 4. Results and discussion part is described in section 5. The last part that is section 6 includes the summary & conclusion of this study.

2. Review of Literatures

Limited research has been carried out regarding the effect of pedestrian entry on roundabout capacity reduction. Marlow and maycock (1982) developed a capacity reduction factor model for crosswalk and entry flow at roundabouts under the influence of pedestrian using queuing theory. Assuming flow of pedestrian have priority over motorized vehicles at roundabouts, capacity of the crosswalk was developed by Griffiths (1981). Louah (1992) developed an analytical method for the determination of capacity reduction factor by utilizing queuing theory in the absence of pedestrians. Brilon, stuwe, and Drews (1993); modelled the capacity reduction factor as a function of circulating flow and pedestrian flow while crossing, in which data collection was carried out by taking the roundabout sites in Germany and observed that pedestrian crossing did not have any significant impact while the circulating flow exceeds about 900 PCU/h and 1600 PCU/h for single and double lane roundabouts respectively. Duran (2010) investigated the effect of pedestrian volume and the distance between crosswalk & yield line for the determination of roundabout capacity. Sindi (2011) estimated the vehicular delay as operational performance variables in the account of pedestrian crossing.

De Leeuw, Botma, and Bovy (1999); studied the effect of cyclist on determination of roundabout entry capacity and delay. The matter concerning to the impact of upstream roundabout entry capacity while there was exit blocking happened by pedestrian crossing which was observed by Rodegerdts and Blackwelder (2005) and Bergman, Olstam, and Allstrom (2011). A simulation study was carried out to quantifying the interaction between vehicles and pedestrian at roundabout (Schroeder, Rouphail, &Hughes, (2007&2008)). Marisamynathan and Perumal (2014); developed a logistic regression model for signalized intersection by analysing crossing behaviour of pedestrian named as crossing speed, acquainted with signal and pedestrian-vehicle interaction in which 775 numbers of pedestrian samples were collected from three signalized intersections of Mumbai.

Rouphail, Hughes and Chae (2005); applied the microscopic simulation model at roundabout to observe the impact of pedestrian on vehicular traffic by using gap acceptance theory and found that there was an increase in pedestrian delay with an increase in volume of the vehicles. Schroeder, Rouphail, Salamati and Bugg (2012); explained the effect of pedestrian impedance of vehicular capacity at multilane roundabout with consideration of crossing treatment and found that the model depend upon the conflict area, speed of vehicles, pedestrian walking speed, pedestrian behaviour, pedestrian route choice decision and turning movement of the vehicles. Cohen, Bar-Gera, parmet, and Ronen (2013); studied about the pedestrian crossing behaviour at roundabouts by observing the effect of guardrails at roundabout in which data collection was carried out at 20 arms of 10 roundabouts at Israel. Petritsch, Landis, Huang, Mc leod, Lamb and Farah (2007); developed a level of service (LOS) model that represents pedestrian perception of how well urban arterials with sidewalks meet their needs.

This model based on the Pearson correlation analysis and regression model for which the variables included were pedestrian age, gender, walking experiences and location of residency.

Ashmead, Guth, Wall, Long and Ponchillia (2005); examined the street crossing by sighted and blind pedestrians at a modern roundabout and judged that blind pedestrians have taken three times more for crossing as comparison to sighted pedestrians and found that 6% of the pedestrian crossing seems to be dangerous. Perdomo, Razaei, Patterson, Saunier and Mirando-moreno (2014); investigated the pedestrian preferences at roundabouts by using stated preference (SP) survey and reported that pedestrian preference are influenced by pedestrian crossing, pedestrian island, markings and also the speed and volume of traffic. HCM 2010 suggest that pedestrian-vehicle interaction model is the alternative tools for deterministic roundabout analysis. From the literature review, it is concluded that pedestrian as well as traffic flows and geometric variables have significant effect on roundabout entry capacity.

3. Study Area and Data Collection

Modelling entry capacity reduction factor of roundabouts under the influence of heterogeneous traffic flow conditions in developing countries was carried out by using traffic flow and road geometric details of four roundabouts located in different parts of India. Therefore multivariate regression analysis was carried out for developing the roundabout entry capacity reduction factor by taking circulating flow, Pedestrian flow and diameter of Central Island as explanatory variables. Data collection was carried out in four roundabouts which are Albert Ekka Square (Ranchi, Jharkhand), Master Canteen Square (Bhubaneswar, Odisha), Bisra Square (Rourkela, Odisha) and Medical Square (Nagpur, Maharashtra) shown in figure 1 below. These roundabouts carry strategic importance and are influenced by activities due to commercial, industrial, residential and government offices but free from the impact of heavy vehicles during peak hours. These four roundabouts are 3, 4, 4, 6 legged with varying in geometry such as diameter of central island varies as 10.76, 46.87, 44.21 & 41.22 meters respectively along with two lanes in the circulating and entry stream approaches respectively.

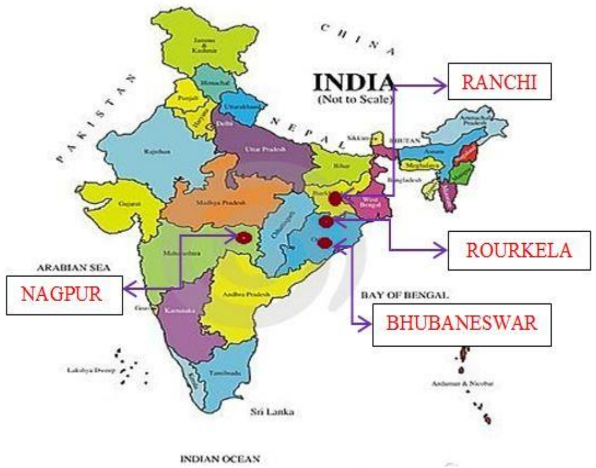

Figure 1: Location of the Study Area

Video graphic technique is adopted by using two high resolution camera mounted on a tripod stand to record the video data very clearway for the convenient data collection process shown in figure 2 below. Data collection was carried out during peak hours of morning (9-11) AM or evening (5-7) PM traffic flow for acquiring an extensive and legitimate data set. Geometric variables are measured by using measuring tape in the early morning to avoid obstruction of traffic flow for details given in figure 3 below.

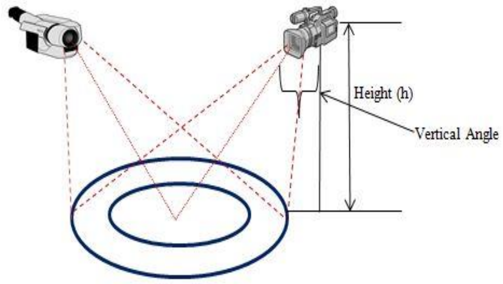

Figure 2: Camera Configuration adopted during the Data collection Process

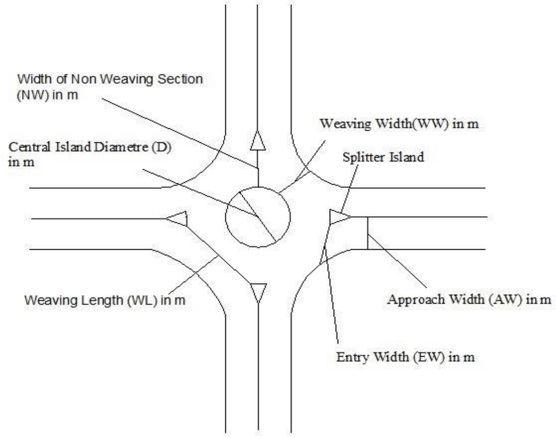

Figure 3: Geometric Variables measured during Data Collection Process

After collection of data, these recorded videos are displayed in the office computer to extract the traffic flow data like circulating flow and pedestrian volume for modeling the entry capacity reduction factor. These flow data were converted to PCU along with measured geometric variables are utilized for model development which are shown in table 1 below.

Table 1: Traffic Flow and Geometric Variables measured at Roundabouts

Roundabout	Approach Leg	Circulating Vehicle (PCU/h)	Pedestrian Volume (Ped/h)	Diameter of Central Island (m)
Albert Ekka Square, Ranchi	Leg1	436	974	10.76
	Leg2	290	870	
	Leg3	257	772	
Master Canteen Square, Bhubaneswar	Leg1	882	1140	46.87
	Leg2	789	1070	
	Leg3	760	1139	
	Leg 4	533	965	
Bisra Square, Rourkela	Leg1	394	1057	44.21
	Leg2	773	1030	
	Leg3	711	1011	
	Leg4	411	1048	
Medical Square, Nagpur	Leg1	686	1170	41.22
	Leg2	483	1156	
	Leg3	993	1223	
	Leg4	554	1071	
	Leg5	432	1118	
	Leg6	508	918	

4. Results & Discussion

4.1 Model Development

In a heterogeneous traffic flow condition, there is a mixture of all kinds of vehicles with different manoeuvring as well as pedestrian impact is highly influencing at roundabouts. Due to strong stream of pedestrians, it occupies vehicles space at roundabout; hence it affects the capacity of roundabout. Up to what extent, the pedestrian impact affect the capacity, then the assumption regarding entry capacity of roundabout with considering pedestrian is

$$Q_{\max} = q_{\max} * F \tag{1}$$

Here in this equation $Q_{\max} =$ Reduction of entry capacity of roundabout with considering pedestrian.

$q_{\max} =$ Maximum entry capacity at roundabout without considering pedestrian.

$F =$ Capacity reduction factor.

The entry capacity reduction factor based on pedestrian occupancy in which percentage of space occupied for pedestrian is

$$P_{occ} = 0.0052 v_p^{\,0.699} \tag{2}$$

Where $v_p =$ Pedestrian volume (Ped/h)

The percentage of occupancy of pedestrian is determined from recorded video under stable queued condition. Finally the entry capacity reduction factor $M = \sqrt{(1 - P_{occ})}$ (3)

The study focused about the pedestrian occupancy while modelling the entry capacity reduction factor. But the entry capacity reduction factor depends upon the other variables such as traffic flow, pedestrian flow and geometric variables as examined in the study. Hence the study has been carried out by applying empirical approach regarding regression analysis to develop the entry capacity reduction factor model as a function of circulating flow, pedestrian volume and geometric variables named as diameter of Central Island at roundabout.

An empirical modelling adopted by employing regression analysis to study the roundabout entry capacity reduction factor. A preliminary assessment regarding model development is to determine the dependency of independent variables with the dependent variables means up to what extent the variables are correlated. Hence it is examined from all the entries of roundabouts that reduction factor varies power wise with circulating flow in which the measured R square is 0.875 shown in figure 4(a) below. The relationship between reduction factor and entry pedestrian varies as power form with R square measured as 0.685 shown in figure 4(b) below. It is also found that the capacity reduction factor varies exponentially with diameter of Central Island in which R square is 0.649, which indicates that it is best fitted with the capacity reduction factor as shown in the figure 4(c) below.

Henceforth considering the above three variables like circulating flow, entry pedestrian flow and diameter of central island, multivariate regression analysis is utilized to develop a new capacity reduction factor model. The geometric variables such as approach width, entry width, weaving length, weaving width, width of non-weaving section did not show any significant relationship with the reduction factor. Hence these variables are neglected for the study.

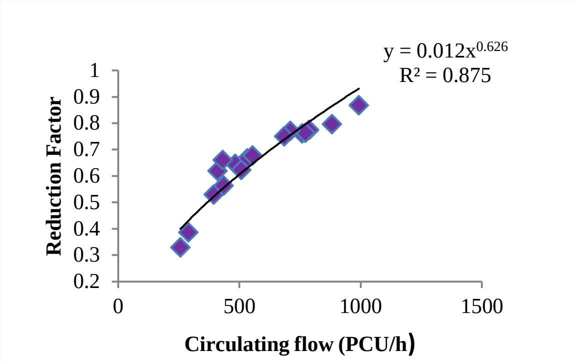

Figure 4(a): Variation of Reduction Factor with Circulating flow

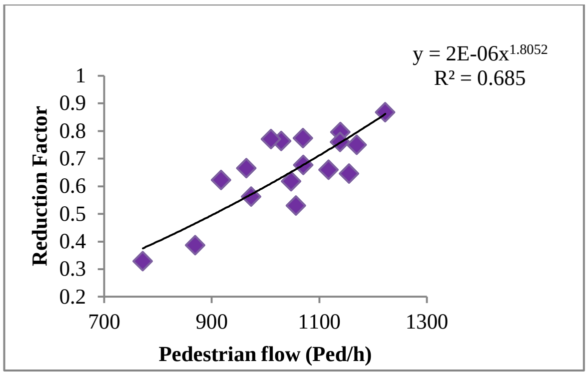

Figure 4(b): Variation of Reduction Factor with Pedestrian flow

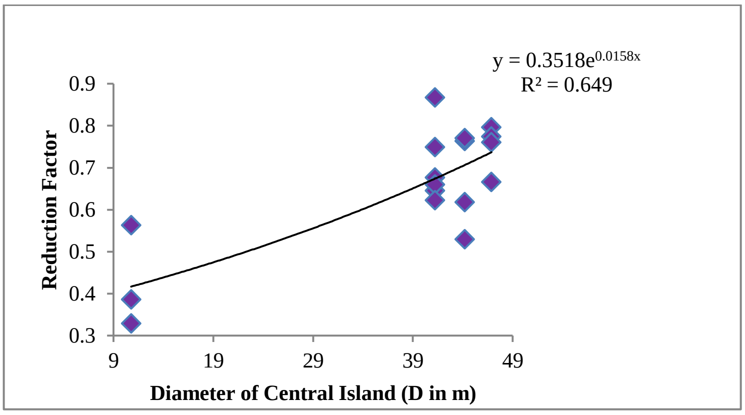

Figure 4(c): Variation of Reduction Factor with Diameter of Central Island

For modelling the entry capacity reduction factor, independent variables such as circulating flow and pedestrian flow are measured by logarithmic scale and diameter of Central Island is measured by linear scale; the dependent variable (reduction factor) is measured by logarithmic scale. After regression analysis the following equation (4) is found to be best fitted by considering all the variables together.

$$F = 0.00130 * (C_f)^{0.413} * (P_f)^{0.439} * e^{(0.004D)} \tag{4}$$

Where

F = Entry Capacity Reduction Factor

C_f = Circulating flow per hour (PCU/h)

P_f = Pedestrian flow per hour (Ped/h)

D = Diameter of Central Island (m)

A descriptive statistics of variables used in the model development showing number of data samples (N), their mean & standard deviation is represented in table 2 below.

Table 2: Descriptive Statistics of Variables used in the Model Development

Variables	Mean	Standard deviation	Number of samples (N)
$\ln F$	.4472	.256	17
$\ln C_f$	6.30	.383	17
$\ln P_f$	6.94	.117	17
D	37.87	13.12	17

Pearson correlation defines the sample correlation means it measure the degree of linear dependence between two variables. The ranges of Pearson correlation should be “-1”to “+1”in which “-1” and “+1” signifies negative and positive correlation between two variables respectively and value close to “-1” and “+1” indicates the strong association between two variables. It is retrieved from the analysis that correlation between variables ranges in between 68% to 93% which holds good for model development, in details shown in table 3 below.

The Pearson correlation is calculated as

$$r = \frac{N\sum xy - (\sum x)\cdot(\sum y)}{[N\sum x^2 - (\sum x)^2][N\sum y^2 - (\sum y)^2]} \tag{5}$$

Where $N =$Number of pair variables.
$\sum xy =$Sum of products of pair variables.
$\sum x =$Sum of x variables.
$\sum y =$ Sum of y variables.
$\sum x^2 =$Sum of squared of x variables.
$\sum y^2 =$ Sum of squared of y variables.

The significance of correlation is defined as the probability of observed correlation occurred by chance. The significance level suggest that the correlation of chance of occurrence is no more than 5 out of 100, means the value is less than .05, hence from the model analysis, the significance values of different variables also less than 5% as shown in table 3 below.

Table 3: Correlation among Variables after Regression

		$\ln F$	$\ln C_f$	$\ln P_f$	D
Pearson Correlation	$\ln F$	1.000	.936	.828	.806
	$\ln C_f$	.936	1.000	.724	.688
	$\ln P_f$	.828	.724	1.000	.689
	D	.806	.688	.689	1.000
Significant value	$\ln F$	-	.000	.000	.000
	$\ln C_f$	.001	-	.001	.001
	$\ln P_f$	000	.001		.001.
	D	000	.001	.001	-

The statistical characteristics of capacity reduction factor model are shown in table 4 below in which the model is significant at 95% confidence level by implementing all variables constituting together. The R square of the capacity reduction factor model is 0.946. The R square represents the linear relationship between dependent and independent variable. The larger the R square value, better will be the fitness of the model.

The analysis of variance (ANOVA) shows that whether the model is statistically significant or not. The significance level of the model is 0.000, which is below 0.05. Hence the model is significant by considering all the variables together in details given in table 4 below.

After regression analysis, different statistical tests such as standard error, *t*-statistics and measure of significance are applied to assess contribution of each variable in the developed model.

The standard error represents the average distance that the input value falls on the regression line and it give the idea about how wrong the regression model which is developed by considering the response variable. Smaller value gives the better result because it indicates that input which has been taken for developing model is closer to the regression line. From the table 4, it is cleared that the standard error coming for different variables nearly equal to zero. Hence the three variables which have been taken in the model development contributed with a fair degree of accuracy in the prediction process. The t-statistics value represents the coefficient divided by the standardised error of regression variables which has been taken for model development and its value varies across cases. Since the standard error is significant for model development, hence the t-statistics value also significant for developing the model for which values are tabulated in table 4. The other that was carried out, significant value means how much the input variables are fitted with the regression model and its value should be less than 5%. That means the variable which has been taken for regression, about 95% of the value is significantly contributing for model development. From the table 4, it is observed that all significant values for different variables are coming less than 5%. Hence the new model is significantly holds good.

Table 4: Statistical Characteristics of Entry Capacity Reduction Factor Model

Analysis of variance (ANOVA)					
Model	Sum of squares	Degree of freedom	Mean square	F	Significant value
Regression	0.999	3	0.333	76.379	0.000
Residual	0.057	13	0.004		
Total	1.056	16	0.337		
R Square = 0.946 Adjusted R Square=0.934					
Variable Estimation by Multivariate Regression Analysis					
Model variables	Variable's Co-Efficient	Standardized Error	t-statistic Value	Significant Value	
Constant	-6.638	1.339	-4.959	0	
$\ln C_f$	0.413	0.067	6.135	0	
$\ln P_f$	0.493	0.22	2.243	0.043	
D	0.004	0.002	2.354	0.035	

The significant value of three influencing variables like circulating flow (C_f), Pedestrian flow (P_f) and diameter of central island (D) measured as 0, 0.043 and 0.035 by employing multivariate regression analysis for which the measured value to satisfy the significance criteria is less than 0.05, hence the model is proved to be statistically significant and from the analysis it is also found that circulating flow (C_f) influencing most in the developed model than that other two existing variables.

4.2 Model Validation

Model Validation is the process of deciding whether the numerical results quantifying the developed relationships between variables, acquired from regression analysis, are acceptable as descriptions of the data. Validation of model is used to assess the performance of model on account of observing new data set. The process can also involve by analysing the goodness of fit for the regression and examining whether the regression residuals are random. If the model's predictive performance deteriorates substantially when applied to new data set, then the model estimation is not valid for the study.

Data splitting method is applied for model validation in this study in which data set is spliced into two parts. First part is used for development of model and rest part is used to validate the model means to measure the prediction accuracy. Hence for this study, 70% & 30% of total data are used for model development and validation of model in the first and rest part respectively. So for the validation purpose 30% of data means 7 approach legs of four roundabouts are randomly selected out of total 17 numbers of approach legs. Then the scatter plot is developed in between observed capacity reduction factor obtained using equation (3) and predicted capacity reduction factor obtained using equation (4) to observe the validity of the model as shown in figure 5 below. The R Square acquired from this validation is 0.965. Hence the model is validated and proved to be significant in heterogeneous traffic flow condition in developing countries.

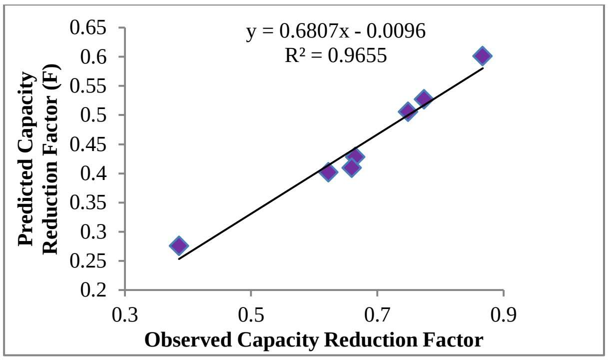

Figure 5: Validation of the Model

4.3 Effect of Change in Capacity Reduction Factor with Influencing Variable

Three influencing variable such as circulating flow, pedestrian flow and diameter of central Island plays as major contributing variables for determination of roundabout capacity reduction factor. Every variable has significant effect on capacity reduction factor. Hence the study has been conducted to observe the variation of capacity reduction factor per increase in individual variable.

Variation of Capacity Reduction Factor w.r.t circulating flow

The reduction factor is found to be varying power wise with the circulating flow. By considering the capacity reduction factor with due consideration of circulating flow as base condition in x co-ordinates, It is observed that for an increase in circulating flow by 50, 100 &150 PCU/h, shown in figure 6(a) below, there is also an increase in predicted capacity reduction factor by 15%, 30% & 35% respectively.

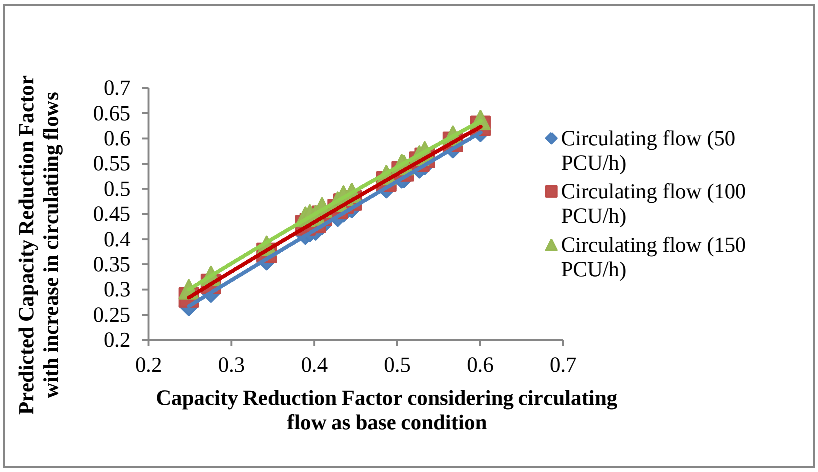

Figure 6(a): Variation of Capacity Reduction Factor with increase in circulating flows

Variation of Capacity Reduction Factor w.r.t Pedestrian flow

The capacity reduction factor exhibits power wise relationship with Pedestrian flow. For an increase in pedestrian flow by 50,100 & 150 PCU/h, there is also an increase in capacity reduction factor by 10%, 15% & 20% respectively shown in figure 6(b) below.

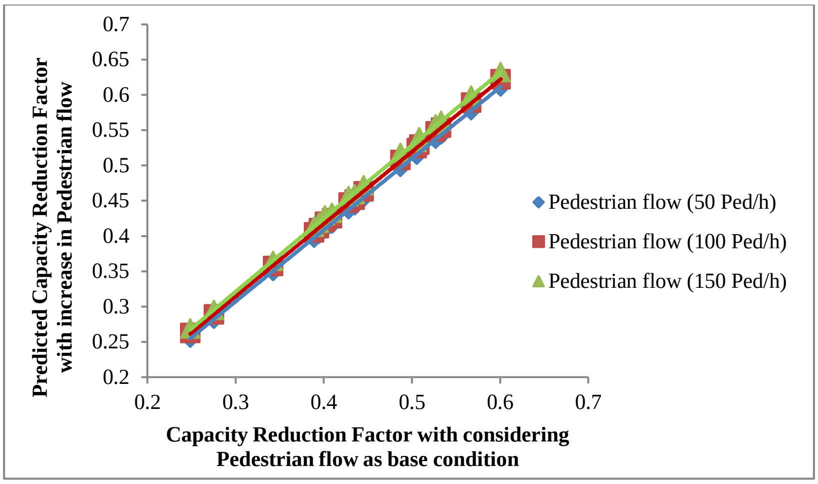

Figure 6(b): Variation of Capacity Reduction Factor with increase in Pedestrian flows

Variation of Capacity Reduction Factor w.r.t Diameter of Central Island

There is an exponential relationship between the capacity reduction factor and diameter of Central Island. It is examined that an increase in the diameter of central island (10, 20, 30) meter, there is an increase in capacity reduction factor by (25, 35, 45) % respectively shown in figure 6(c) below.

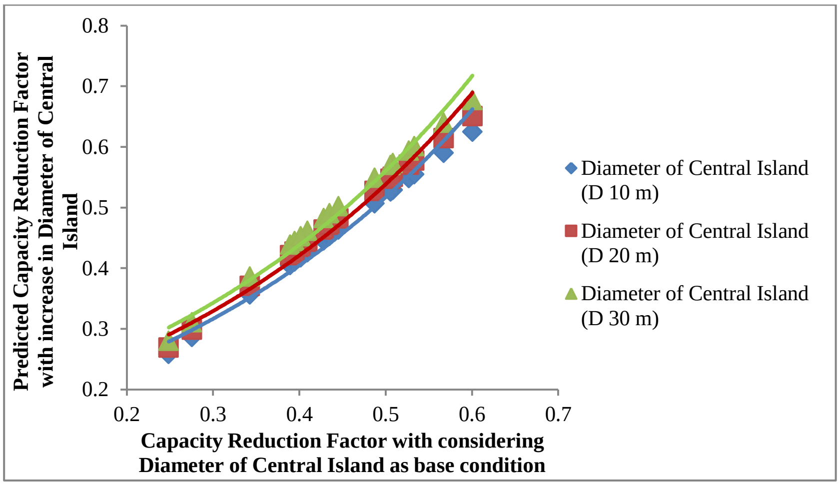

Figure 6 (c): Variation of Capacity Reduction Factor with increase in Diameter of Central Islands

5. Summary & Conclusion

The prime objective of the study is to develop an empirical roundabout capacity reduction factor model assuming circulating flow, pedestrian flow and geometric variable named as diameter of Central Island as explanatory variables for which data has been collected from four cities such as Ranchi, Bhubaneswar, Rourkela and Nagpur in India. Video graphic technique is adopted for collecting the data in which two high resolution video cameras mounted on tripod stands to record the traffic flow very clearly.

In a developing country like India it is observed that flow of traffic is highly influenced by presence of excess number of two wheelers, auto-rickshaws and various sizes of light motor vehicles at roundabouts. For developing a model, an assessment is carried out to determine the dependency of the capacity reduction factor on various influencing variables. It is examined that the influencing variables established significant relationship with the capacity reduction factor for which the capacity reduction factor varies power wise with circulating flow& pedestrian flow in which R Square measured as 0.875, 0.685 respectively and also varies exponentially with diameter of central island for which the R Square measured as 0.649 respectively. Hence by assuming these above variables, multivariate regression model is employed to develop the capacity reduction factor model under heterogeneous traffic flow condition.

In regression analysis, Pearson-correlation indicates that the correlation among influencing variables varying from 68% to 93% respectively. The statistical characteristics of capacity reduction factor model examined that the model is significant at 95% confidence level by constituting all the variables described earlier. The R-Square of the model is found to be 0.946, which indicates the better fitness of the model under heterogeneous traffic flow condition. The analysis of variance (ANOVA) test also signifies that the model is significant because of the significance level is below 0.05 by considering all the variables together. Data splitting method is applied in the model validation in which (70% & 30%) of total data is used for model development and model validation respectively. The R-Square measured from the model validation is 0.965 which indicates that the model is validated and proved to be efficient. To observe the effect in capacity reduction factor with the increase in circulating flow & pedestrian flow by [(50, 100 & 150) PCU/h] and [(50, 100 & 150) Ped/h], there is an increase in capacity reduction factor by (15%, 30% & 35%) and (10%, 15% & 20%) respectively. It is also examined that, for increase in the diameter of Central Island by (10, 20 & 30) m, the entry capacity reduction factor increased by (25%, 35% & 45%) respectively.

The model provides valuable information regarding entry capacity reduction factor that could be helpful for the researchers, engineers and designers to improve the operational efficiency of roundabout. The limitation of the study is that the model is developed with due consideration of geometric variable, circulating flow & pedestrian flow without considering the bicyclist impact at roundabout. Hence revised model could be developed by implementing bicyclist impact along with the three existing variables under prevalent heterogeneous traffic flow condition in developing countries.

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