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Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Entry Capacity Quantifying Model through Drivers' Behavior Analysis at Roundabouts

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Abstract

The prime objective of this study is to develop the entry capacity model for roundabouts by employing Multiple Linear Regression (MLR) analysis under heterogeneous traffic flow conditions. Required data were collected from 27 selected roundabouts spanning across 8 states of India by using high-defination video (HD) cameras. To reflect the driver behaviour, critical gap and follow up time are estimated by using INAGA method. To develop the robust model, data such as speed of vehicles and lateral clearance to Central Island are collected in microscopically way. To ascertain the lateral clearance of vehicles w.r.t. Central Island of roundabouts, path analysis is carried out by employing Cam Shift algorithm in trajectory analysis. The coefficient of determination (R^2) and Nash-Sutcliffe model efficiency coefficient (E) are found to be (0.83, 0.84) and (0.9, 0.91) respectively. The p-value in the test of Analysis of variance (ANOVA) is found to be 0.00 (p-value<0.05) that indicates the proposed model is statistically fit at 95% confidence level. The percentage contribution of each independent variable is observed through sensitivity analysis in this study. It is observed that the variables like lateral distance and speed contributes the most and least variable and sharing about 32% and 11% in the proposed model respectively. These findings will be useful for traffic planners and designers in the capacity estimation of roundabouts under heterogeneous traffic conditions in developing countries with similar traffic characteristics as India.

Keywords: Roundabout; Capacity; Critical gap; Follow up time; INAGA method; Trajectory analysis; Sensitivity analysis; Heterogeneous

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1. Introduction

A roundabout is a modified form of an un-signalized intersection, where traffic movement is forced to move around a central circular island almost in one direction only. The circular traffic movement can follow either left hand rule or right hand rule depending on the rules governed by their respective countries. Roundabouts have several advantages as compared to other intersections in terms of safety and operational efficiency. In terms of conflict points (safety), roundabouts have less number of conflict points as compared to signalized intersections. Roundabouts have 8 and 16 number of conflict points for one and two lane-based path respectively. Where signalized roundabouts have 32 number of conflict points. Apart from the reduction number of conflict points, other positive aspects of introducing roundabouts are speed reduction of vehicles, reduction of seriousness of fatal accidents, reduction in delay time, increasing the safety of the pedestrians and controlling the environmental pollution etc. With an increase in the traffic rate and road infrastructure day by day, it is essential to assess the performance of road infrastructure like roundabout under heterogeneous traffic conditions. Capacity is the important parameter under operational performance that describes about the present traffic condition. Capacity is the maximum entry flow that can be accommodated in the approach stream under prevailing traffic and geometric conditions (HCM, 2010).

Capacity of a roundabout rely on the three major factors that include the dynamics of the vehicles, geometrical features and driver behaviour at roundabouts (Al-Madani 2013). Generally, in a roundabout, the circulating flows refer to the priority movement, at that time the approaching traffic is waiting for a headway to move into the circulating stream of traffic. However, under heterogenous traffic flow conditions in a developing country, the situation is rather different. The approaching traffic forced to move in the circulating stream of traffic as well as reluctant to give the priority to the circulating traffic. This leads to hamper the traffic performance of roundabout.

Quantifying and investing the driver behaviour of individual drivers is the challenging task for observers to determine the interaction between consecutive vehicles. Drivers behave more aggressively in a congested network and also small size vehicles always tried to find a headway in between large vehicles to move into the circulating stream of roundabout. This is not possible in homogeneous traffic condition, but it is somewhat possible under heterogeneous traffic condition because the dimension of the vehicle is different from one to another. Geometric variables of roundabouts play as crucial role to determine the capacity of roundabouts. These said variables reflect the local site conditions (Al-Masaeid and Faddah 1997; Patnaik et al. 2018). Therefore, attempts have been made to develop the roundabout entry capacity model through measuring the driver behavioural parameters, geometrical features and dynamics of vehicles under heterogeneous traffic flow conditions. These parameters could helpful for the researchers, planners and designers to short out the operational efficiency and to improvise the design criteria.

2. Background literature

Broadly, two types such as empirical and gap acceptance based modeling approaches have been given by the previous studies for the capacity estimation of roundabouts. In empirical regression based models, entry capacity is taken as the dependent variable, whereas the circulating flow and other geometric variables are taken as independent variables (Al-Masaeid and Faddah 1997; Patnaik et al. 2017a, 2017b, 2018a, 2018b). The gap acceptance capacity model considers the driver's decision to move from the minor stream of traffic flow to the major stream of traffic flow. Critical gap and follow up gap are two important variables used for the development of this model. The HCM (2000) method of capacity estimation is one of the most popular method that follows the concept of gap acceptance. Further enhancements have given in the HCM (2010) in which detailed procedures for the determination of capacity and LOS are described. This model is a combination of gap acceptance and exponential regression concepts and calibrated by estimating critical gap and follow up gap.

Limited number of studies have been carried out to estimate capacity of roundabouts under the influence of heterogeneous traffic flow in Indian context. Ahmad and Rastogi (2016) developed roundabout capacity model and observed that the entry capacity varies negative exponentially with an increase in circulating flow. Arroju et al. (2015) developed a micro simulation model by using VISSIM software for roundabouts in which vehicles were classified and their critical gaps were evaluated by using Raff and Equilibrium of Probabilities method. Mathew et al. (2016) estimated the passenger car unit (PCU) for various categories of vehicles based on the concept of time occupancy at four-legged roundabouts. The critical gap and follow up time values are estimated to calibrate the HCM 2010 model equation and a multiplicative adjustment factor is recommended for the direct use of HCM 2010 model. Ahmad et al. (2015) proposed an iterative procedure based on the minimization of sum of absolute difference in critical gap for the determination of capacity at roundabouts. NCHRP 572 reported the comprehensive evaluation of roundabouts in United States to determine critical and follow up headway. Ericsson et al. (2006) examined that driving behaviour is the integration of group of parameters that are accomplish with driving speed, acceleration, lane changing behaviour and the headway formation during the period of driving. Mudgal et al. (2014) simulated the circulating speed and maximum accelerations from speed profiles model by implementing Bayesian inference methodology and compared along with the field study. The roundabouts having multiple circulating lanes provide greater capacity as well as their driver behaviour and speed is not efficiently controlled as compared to single lane roundabouts. (Bastos 2004*,* St-Aubin et al. 2013*,* Lindenmann 2006).

Tanyel and Yala studied the distribution of gaps in the circulating flow is based on poissons random arrival process of cowan M3 distribution but their parameter should be locally calibrated based on condition of driver behaviour (2003). Hardwood et al. (1999) reported that the speed of circulating traffic is reduced consequently while giving gap to minor stream of traffic to enter into the roundabout and also suggested that speed is reduced up to 85 percent for the circulating traffic. Xu et al. (2008) studied that speed and circulating flow is greatly influence the critical gap at roundabouts. A study is carried out in the state of winconsin's roundabout, regarding critical gap reported that truck and motor cycle was higher and lower critical gap values as comparison to critical gap of car (2011). Kilpelainen and Summala (1977) studied the effects of adverse weather on driver behaviour at finland in which driver behaviour at roundabouts principally affected under observable condition. Ashworth and bottom (*13*) studied the driver behaviour in uncontrolled intersections for which thirty exponential drivers were employed to determine human factors that influence the gap acceptance behavior. Hyden and Varhely (2013) studied about 21 intersections on arterial roads that are converted to mini roundabouts later to improve safety and reported that the operating speed increases of about 30 km/h after installation of roundabout which as before 20 km/h at intersection and also found that the changing in speed imparts negative influence on travel time. Vasconcelos et al. (*15*) observed the critical and follow up headway in six portugese roundabouts by employing Raff, Siegloch, Wu, Maximum likelihood and logit model and compared these with other countries conclude that the differences in headways is due to driving style and country specific.

A thorough literature review has been explored concerning driver behaviour at roundabouts that gap acceptance theory assuming the behaviour of driver is consistent and homogeneous in homogeneous traffic flow condition. Driver behaves uniformly in this situation but as comparison to the heterogeneous traffic condition in developing countries the behaviour of driver vary depending upon the dimension of the vehicle, inadequate geometric design and road markings at roundabouts. Despite the gap acceptance theory, the study has been carried out towards the driver behaviour by implementing speed analysis of driver in the most conflicting part of roundabout and the trajectory that are followed during interaction between the vehicles under prevailing heterogeneous traffic flow condition in developing countries. The next section discussed about study area and data collection procedures.

3. Study Objectives and Organization of the Study

The prime objective of this study is to develop the entry capacity model for roundabouts by employing semi-analytical approach. With an overview of heterogeneous traffic conditions, the following study objectives are provided below.

- To assess the performance of roundabouts through driver behavior by executing three methodologies in terms of microscopic analysis which include gap acceptance, speed, circulating flow and path analysis.
- To determine the critical and follow up headway by the application of Influence Area for Gap Acceptance (INAGA) method in the most critical part of roundabout to observe the aggressiveness of the driver under heterogeneous traffic conditions.

- To observe the variation of speed of car, motor cycle and truck in the conflicting zone at roundabouts by using speed analysis.
- To ascertain the lateral clearance of vehicles w.r.t. Central Island of roundabouts, path analysis is carried out by employing Cam Shift algorithm in trajectory analysis to improve the safety and operational efficiency of roundabout.

The content of the paper is categorized as follows. The section "Methodology" describes about the critical gap and follow up time estimation by using newly developed INAGA method. A brief introduction about modelling technique such as multiple linear regression (MLR), study area and data collection procedure, analysis of speed and path are also given in methodology part. Variable selection for the development of model, development of model by using MLR technique and validation of model by using statistical techniques are included in the "Results and Analysis" section. The last section addressed about "conclusion" of the study in which limitation and direction for further research are also discussed.

4. Methodology

The detail discussion about study area and data collection procedure is given in this section. Estimation of gap acceptance variables by using newly developed INAGA method is included in this section. Details regarding speed and path analysis and modelling technique like MLR are also added in that section.

4.1 Study Area and Data Collection

To quantify driver behaviour analysis and to develop roundabout capacity prediction model, 27 roundabout sites data were collected. The selected roundabouts are situated in different parts of India in different states like Andhra Pradesh, Chhattisgarh, Jharkhand, Kerala, Madhya Pradesh, Odisha, Punjab, and West Bengal. Details of study site situated cities were shown in below Fig.1. Following criteria have considered for selecting roundabouts to carryout current study. All selected roundabouts were at grade intersection with two to four lanes of entry and circulating paths. Selected sites exclusively free from on street parking, bus stops, side friction and curvature effects.

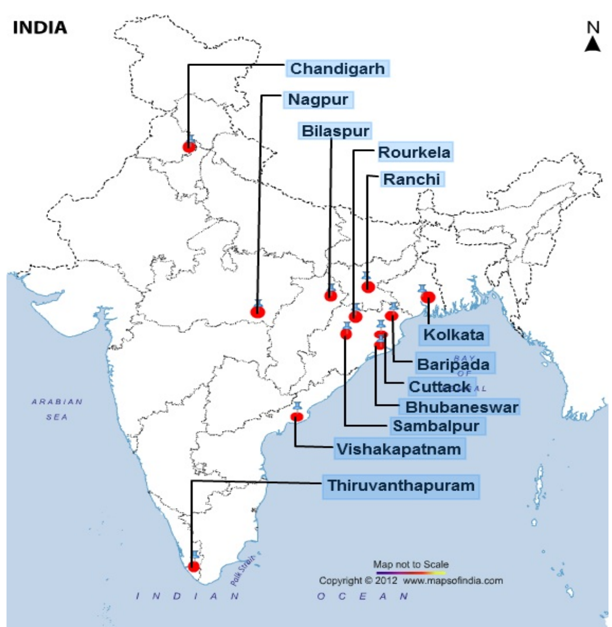

Fig.1. Location of study sites on India map

The Traffic data was collected using high definition video cameras. Two high resolution cameras were employed and fitted at high raised buildings with help of tripod stand. The cameras are adjusted in such a way that the traffic related parameters such as gap acceptance parameters are clearly quantifiable. Video shooting was done in peak hour periods at least of two hours for each approach legs of roundabout. Data were collected in the months of October to February for which traffic flow is least affected by atmospheric circumstances. Video shoot was held either in morning 9 to 11 am or evening 5 to 7 pm on weekdays. All 27 roundabouts data were collected and analyzed in laboratory to extract desired data. Required variables were taken based on incorporated techniques (MLR) for capacity finding of roundabouts. Variable details were shown in Table 1 below. Vehicular speed is another variable which observed illustratively with the help of stationary speed gun (Works on the Radar Principle). So absolute speed of the vehicle can be measured by keeping gun at angle of 45 degrees to moving vehicles. After obtaining precise and quality data, all required variables are used in regression based techniques like multiple linear regression (MLR) to generate roundabout entry capacity model.

Due to Heterogeneity scenario in traffic flow, vehicles are classified into five groups. These included vehicles are Bicycles (BC), Motorcycles/Scooters (MC), Light motor vehicles (LMV), Heavy vehicles (HV) and Human/Animal drawn vehicles (HDV). All the vehicle values are converted into static PCU (Based on Size and speed) according to IRC: 65-1976 for calculating circulating and entry flow uniformly. These PCU factors are depends on vehicle geometrics and dynamics, which differ from country to another (Mauro 2010).

Table 1. Investigation of explanatory variables in this Study

Variables	Units	Minimum	Maximum	Mean	SD
Entry Capacity (Q_e)	PCU/h	250	3415	1819	774.85
Critical gap (T_c)	sec	1.45	3.08	2.098	0.317
Follow-up time (T_f)	sec	0.67	2.03	1.35	0.207
Lateral distance ($Ld_{\max}$)	m	2.12	5.98	4.12	0.640
Speed (Spd)	m/s	2.481	6.640	5.152	0.795
Circulating flow (q_c)	PCU/h	219	3688	1071.291	721.52

Note: SD=Standard deviation of the sample size

Due to heterogeneous traffic flow conditions, Heavy vehicles such as trucks, buses and commercial vehicles are merged in traffic streams, all road geometrics like kerb height, speed breaker width etc., parameter are designed by considering the HVs also. In HVs also huge range of vehicle dimensions are there like 7m to 12.5m depends on its carriage capacity and efficiency. On the other hand, traffic flow consists of three-wheeled cycle rickshaw of two passengers carrying capacity over to short distance. Rickshaws and Human Drawn vehicles does not have any specific and special markings so they bound to follow motorized traffic controls. Average dimensions of LMV are (4-4.5) meters length and (1.6-1.7) meters width. It is obtained that entry flow varies from 250 PCU/hr to 5683 PCU/hr, which are like free flow and capacity flow conditions. Traffic flow ranges, its composition and variation with respect to vehicle compositions is given in Table 2 below illustratively. Traffic share of any category vehicles are not occupying more than 80%, hence it is found to be widely heterogeneous in nature. (Arasan and Krishnamurthy 2008)

Table 2. Ranges of traffic volume and their composition at Roundabouts

	Volume (veh/hr)	%HV	%LMV	%(MC/S)	%BICYCLE	%HDV
Mean	1847	10.60	37.08	47.31	4.65	0.69
SD	1006	13.18	19.95	18.03	7.21	1.34
Minimum	240	0.26	10	14.55	0.05	0.1
Maximum	5683	61	79.5	79	33.1	7

Note: SD=Standard deviation of the sample size

4.2 Estimation of gap acceptance variables

Critical Gap is the minimum time gap of the vehicle in the minor stream to enter into major stream at intersections. It is depending upon the traffic composition, traffic flow and geometrics. Especially under heterogeneous traffic conditions calculation of critical gap is hectic task. Follow up time the time gap between consecutive vehicles of approaching lane. It can easily measure from the video graphs and these two generally measured in seconds. In heterogeneous traffic condition determination of gap acceptance parameters is quite different process because of drivers' behaviour assessment is a bit difficult phenomenon. As of now many researchers have proposed many type of analysis to find out critical gap and follow up time. In HCM 2000, it stated that minimum gap in the circulating path in which the vehicle can safely enter to the roundabout is taken as critical gap is the. Average time difference between two consecutive vehicles is known as follow-up time. According to Raff's method critical is time gap in which number of accepted gap are shorter or lesser than number of rejected gaps. In Equilibrium probabilities to find the critical gap based on accepted and rejected gaps cumulative distribution and it is sophisticated iterative process which is finally goes complex than raff method. As far as widely accepted methods are assumed that drivers' behaviour is consistent in all times and homogeneous conditions so which leads inaccurate estimates of critical and follow-up times. To justify these kind of issues, this study is used Influence Area for Gap Acceptance (INAGA) method.

4.3 Analysis of Speed

As the heterogeneous traffic flow condition manifested in a developing countries, the speed of the vehicles while interacting with other vehicles considered as a group of interaction at roundabout renders essential information that can be taken into account as vehicle-vehicle interaction that helps to determine the driver behavior. The vehicles (motor cycle, cars and truck) considered for the study is converted to PCU as recommended in IRC: 65-1976 code for the analysis. For obtaining the speed data, two RADAR guns are operated by two personnel's at a time in the most conflicting part of roundabout, where the influence between entry flow and circulating flow is maximum. The data is collected case wise keeping the car as a base parameter, when the car is interacting w.r.t other vehicles, one observer has observed only speed of car while the other observer observed the speed of remaining vehicles simultaneously as efficient data collection process for further analysis.

4.4 Analysis of Path

Drivers' behaviour can be analysed through identifying the path followed by vehicles in the roundabout. It has been microscopically observed from the field analysis that different types of vehicles follow different paths when interacting with other vehicles. To quantify drivers' path tracing of roundabout at entry leg w.r.t central island was taken as one of the parameter (i.e. maximum perpendicular distance of path trace w.r.t central island) shown in Fig. 2. For a specified influence, area of each leg has taken into account to calculate lateral clearance of vehicles for each entry leg. Vehicle path quantified in such a way that maximum number of vehicles followed (mode value). The maximum value of it by weighted average method has considered. Path followed by vehicles, which can be, resemble as some kind of weaving traffic parameter in rotaries and it is calculated using Cam Shift algorithm integrated in MATLAB.

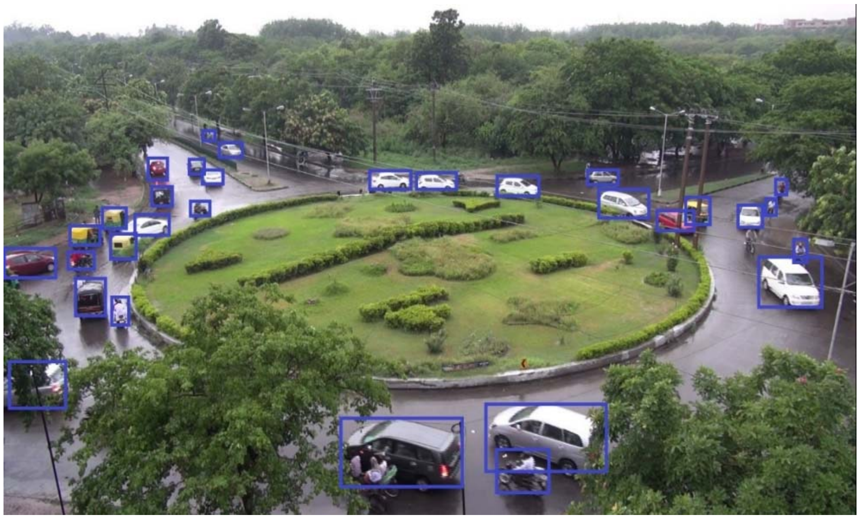

Fig. 2. Tracking of vehicles at Sector 43& 44 Junction, Chandigarh

Hence, the analysis of the path followed by car that being interacted with other vehicles like motorcycle, car and truck by using cam-shift algorithm, in details given in Fig. 3, Fig.4 and Fig. 5 respectively.

Fig. 3. Trajectories followed by motorcycles at Sector 43-44 Junction, Chandigarh

Fig. 4. Trajectories followed by cars at Sector 43-44 Junction, Chandigarh

Fig. 5. Trajectories followed by trucks at Sector 43-44 Junction, Chandigarh

4.5 Multiple Linear Regression (MLR)

The model establishes the relationship between independent variables (two or more) to express the output variable (dependent variable) by fitting into a linear equation. The collected data is used in the process to produce the output response. Each single of explanatory variable has assigned with dependent variable in some linear form. The regression line for explanatory variables are form a linear equation with some coefficient constants that have generated in order to get the desired output. Some of the following assumptions has considered for generating output.

All residuals in regression model should be normally distributed and the relationship between dependent variable and independent variable should be in linear form. The homoscedasticity in residuals and data should be in rectangular. Independent variables should not follow the multi-collinearity (Independent variables are prominently correlated).

5. Results and Analysis

Variable selection by using Pearson co-relation analysis is given in this section. Development of roundabout entry capacity model by using MLR analysis is incorporated in this section. In addition to these, percentage contribution of each individual variable by using sensitivity analysis is also added in that section.

5.1 Selection of variables

To assess the contributing variables in the model development, selection of variables is an important aspect; it gives an idea about dependency of dependent variable (output) on the independent variables (inputs) in the model development process. Before development of semi analytical model, flow variable such as circulating flow (q_c), traffic variables such as speed (Spd) and lateral clearance w.r.to central Island ($Ld_{\max}$) and Drivers' behaviour variables like critical gap (T_c), and follow up time (T_f) are tested through Pearson correlation analysis and output details are given in Table 3 below. 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.

Table 3: Pearson correlations of independent variables

Sl.NO	Variables	Correlation	Significance
1	Critical gap	0.715	0.000
2	Follow up time	0.698	0.000
3	speed	-0.736	0.001
4	Circulating flow	-0.845	0.000
5	Lateral clearance w.r.t to Central Island	0.684	0.001

The significance criteria also have shown in the above Tables 3 and found that all the selected variables are significant at 95% level of confidence because all the variable significance values are less than 0.05.

5.2 Model development

To develop the roundabout entry capacity model under heterogeneous traffic conditions, MLR is employed in this study. In this study, total 110 numbers of data points (observations from each approach leg of roundabouts) are used. Out of 110 data points, 70% of data (77 data points) are used for model development and the remaining 30% (33 data points) are used for model validation purpose. The entry capacity model is developed by using capacity as dependent variable and rest of independent variables like circulating flow (q_c), traffic variables like speed (Spd), lateral clearance w.r.t to central Island ($Ld_{\max}$) and drivers' behavior variables like critical gap (T_c) and follow up time (T_f) are taken as independent variables.

Hence empirical model is obtained by using above explanatory variables and entry capacity (Q_e) as dependent variable is represented in equation 1.

$$Q_e = -1027.215 + (513.89 \times Ld_{\max}) + (759.89 \times t_f) - 2.85 \times \left(\frac{q_c}{t_c \times spd} \right) \quad (1)$$

[R^2 = 0.83, Adjusted R^2 = 0.82, Standard error of estimate = 138.29]

Where (Q_e) = Observed entry capacity (PCU/h)

(q_c) = Circulating flow (PCU/h)

(Spd) = Speed (m/s)

($Ld_{\max}$) = lateral clearance w.r.to central Island (m)

(T_c) = critical gap (s)

(T_f) = follow up time(s)

All the selected variables are proven significant in developing the capacity model of roundabout. The details of the significance test conducted for the above equation is shown in Table 4. The co-efficient of determination (R^2) of the model is found to be 0.83. The p-value in the test of Analysis of variance (ANOVA) is found to be 0.00 (p-value<0.05) and the standard error of estimate is 138.29, which signifies that the model is statistically fit at 95% confidence level. After development of the model, different statistical tests have conducted to determine the significance of each explanatory variable in the model development. In this model, the significant value of different variables are found to be ranges in between (0.00 to 0.001), which is close to zero. At 95% confidence level (p value <0.05), t-statistic value should be greater than ($\pm$ 1.960). In this study, the t-statistic value of all five variables is found to be greater than $\pm$1.960, which indicates that these variables are statistical significant.

Table 4: Statistical characteristics of MLR Model of Roundabout

Analysis of variance (ANOVA)					
Model	Sum of squares	Degree of freedom	Mean square	F	Significant value
Regression	39618966.946	3	13206322.315	115.398	0.000
Residual	8010873.014	70	114441.043		
Total	47629839.959	73			
R Square = 0.83 Adjusted R Square=0.82					

Estimation of variables in MLR model				
Model variables	Variable's Co-efficient	Standardized error	t-statistic value	Significant value (p<0.05)
$Ld_{\max}$	513.89	67.647	7.597	.000
T_f	759.89	218.694	3.475	.001
$\frac{q_c}{t_c \times spd}$	-2.85	0.299	-9.522	.000

5.3 Model validation

Validation is the process of deciding whether the numerical results quantifying the developing relationships between variables, obtained from regression analysis, are acceptable as descriptions of the data. Validations of the model is used to assess honestly the likely performance of the model on a new data set. To assess the performance of the developed model, several statistical parameters are employed in this study. The included parameters such as Co-efficient of determination (R^2), Nash-Sutcliffe co-efficient (E), Average absolute error (AAE), Maximum absolute error (MAE), Root mean square error (RMSE), mean 'μ' and standard deviation 'σ' are applied to evaluate the prediction performance of the developed model. The parameter values are given in Table 5 below.

Table 5: Statistical tests of developed model

Data set	R^2	E	AAE	MAE	RMSE	μ	σ
Training	0.83	0.84	290.01	1067.24	402.84	0.96	0.16
Testing	0.9	0.91	180.0	609.0	286.0	1.02	0.12

Note:
R^2= Co-efficient of determination
E = Nash-Sutcliffe co-efficient
AAE = Average absolute error
MAE = Maximum absolute error
RMSE = Root mean square error
μ = Mean
σ = Standard deviation

It is observed from Table 5 that, the values of R^2 and E is found to be (0.83, 0.84) and (0.9,0.91) in both training and testing stage of the model respectively. The values of mean 'μ' and standard deviation 'σ' are found to be close to one and zero respectively, that indicates that the developed model is statistically fit under heterogeneous traffic conditions.

5.4 Sensitivity analysis

In order to assess the percentage contribution of each input variable in MLR model, Garson's algorithm (Gandomi et al. 2013) is applied in this study. The ranking of each input variable is based upon percentage of contribution in the model development, which is given in Table 6 below.

Table 6: Sensitivity analysis of MLR Model

Sl. No.	Variables	Sensitivity of WLSR (%)	Rank
1.	Critical gap (T_c)	21.10	2
2.	Follow-up time (T_f)	18.56	3
3.	Lateral distance (Ld_{max})	31.73	1
4.	Speed (Spd)	10.76	5
5.	Circulating flow (q_c)	17.83	4

Inference can be drawn from the sensitivity analysis of MLR model that critical gap, follow up time and lateral distance parameters are prominent variable in the model development. The percentage (%) contributing of these three said variables are 21.10%, 18.56% and 31.73% in the developed model respectively. These variables altogether contributing around 70 % in the model development process. This indicate that the model variables actually reflect the driver behaviour under heterogeneous traffic conditions.

6. Conclusion

- At selected roundabouts, traffic flow is observed to be highly heterogeneous, in which percentage share of Bicycles, Two Wheelers, Light Motor Vehicles (Car, Three Wheelers), Animal Drawn Vehicles and Heavy Vehicles varies from 0.06% to 36.51%, (6.84-77.9)%, (10.52 to 78.9) %, (0.04-7.49) % and (0.14-15.07) % respectively.
- To reflect the actual driver behavioural habits under heterogeneous traffic conditions, gap acceptance variables such as critical gap and follow up time are determined by using the INAGA method developed in this study. The critical gap values are varying from 0.54 seconds to 2.87 seconds, which are nearly half the values of (4-4.6) seconds as mentioned for developed nations like USA and European countries. These differences in critical gap values are due to the large percentage share of two-wheelers in the prevailing conditions. Actually, two wheelers require small gap as compared to other vehicles to merge into the major stream of traffic flow.
- The speed analysis reported the speed variation of vehicle while interacting with the other vehicles. After observing different sites around the country, it is found that the interaction speed gradually decreases when the vehicle, which is being followed, becomes larger.
- The path analysis demonstrated that there should be given a clear clearance of 2.5-3.5 meters with the curve of Central Island which not only reduces the risk of hitting with other vehicles but also helps in improvising the operational efficiency of the roundabout.
- The Co-efficient of determination (R^2) and Nash-Sutcliffe co-efficient (E) of the proposed model is found to be 0.83 and 0.84 respectively. The p-value in the test of Analysis of variance (ANOVA) is found to be 0.00 (p-value<0.05) and the significant value of each independent variables are found to be ranges in between (0.00 to 0.001). These indicate that the proposed model is statistically fit at 95% confidence level.
- Sensitivity analysis reports that the variables like lateral distance is the prominent variable in the study and almost contributing 32% in the model development. In addition, it is observed that the variable like speed is acted as least contributing variable in the proposed model.

The study explored regarding development of entry capacity model for roundabouts under heterogeneous traffic conditions. Driver behaviour at roundabouts is primarily influenced by composition of various types' of vehicles and geometric variables at roundabouts. The circulating path around Central Island should be broaden including the diameter of central island should be increased so as to hold more traffic in heterogeneous traffic conditions. The model will be workable on low to medium traffic volumes having similar kind of traffic flow observed in other countries. The proposed model is very simple and manageable quite easily. The model will be useful for traffic engineers and researchers by providing ample information. Future scope of the study can be categorized into two areas. Impact of cross traffic and application of dynamic PCU values can be incorporated for the development of entry capacity model for roundabouts under heterogeneous traffic flow conditions.

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