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Effect of two-wheeler proportion on passenger car units at roundabout in Indian urban scenario

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ABSTRACT
The present study focuses on modeling roundabout in heterogeneous condition and understanding the effect of change in two-wheeler composition on the entry capacity using microscopic simulation technique. A four-legged roundabout of 25m diameter, located in the city of Chandigarh, India was considered as the study area. As Indian traffic flow is highly heterogeneous due to the presence of vehicles with varying physical and operational characteristics, each vehicle modelled separately in PTV VISSIM. Model calibrations were performed using speed distributions, conflict areas, priority rules, and driving behavior parameters. Comparison with the field data obtained from the study roundabout (indicates the applicability of the developed simulation model in assessing the hypothetical scenarios. Study results indicate that the PCU values remain steady under varying compositions of two-wheelers in the traffic stream. In addition, the effect of two-wheeler proportion on roundabout capacity is insignificant in the study area.

KEYWORDS
Roundabout; Passenger Car Unit; Two Wheeler; Critical Gap; Capacity

Introduction

Traffic in developing countries like India is composed of the vehicle with varying physical and operational characteristics. In addition, vehicles occupy any convenient lateral position on the road without considering any lane discipline. Conditions are very unsafe at intersections where vehicles moving in two or more directions are bound to use common space. This generates conflicts points at the intersection, making it critical by either reducing safety or increasing the travel time. Hence, for planning and designing safer and efficient traffic flow it is essential to understand various flow characteristics and operation of the roundabout before planning and designing of an intersection. At intersections, during moderate traffic flows, a roundabout is found to be safer with lower delay when compared with un-signalized intersection. Since the vehicles are bound for a single direction movement at the roundabout, vehicles are rarely subjected to complete stop, instead steady movements are observed, which further enhances the efficiency of the traffic system. Further, roundabouts are known to shift the crossing conflict into merging and diverging at smaller angles reducing the risk of accidents and its severity.

The capacity of the roundabout is based on the maximum entry flow of vehicles from each approach to the circulatory lane in a unit time. The vast majority of the studies on the roundabout are carried out in developed countries having homogenous traffic flow with lane discipline. Studies on the roundabout are found to be limited to developing countries where rules of priority and lane discipline are rarely followed. This is basically due to the unavailability of standard roundabouts with varying geometry, flow, and composition. This generates the need for simulation tools which can easily depict heterogeneous traffic condition for possible analysis of roundabout under different conditions. Out of various options available for simulation, VISSIM is observed to be more suitable for depicting heterogeneous traffic conditions. This is possible since VISSIM gives the flexibility to create links without any lane discipline. Also, driver behavior can be adjusted easily by modifying the clearance (front and lateral) gap values in the model. Hence, the present study uses VISSIM for understanding the effect of change in two-wheeler proportion on the PCU values and performance of roundabout.

The base scenario simulation is at first calibrated and followed by the simulation for varying percentages of two-wheelers in the traffic stream. Observed field data for conflict areas, priority rules and speed distributions are fitted to the model for calibration. Parameters related to the driver's behavior are changed to fine-tune the model. Accuracy of the calibrated model is examined through validation, by comparing the field data with respective simulation outputs. Entry capacity and critical gap values were used in the present study to validate the model. It is observed through validation that the model generated performs satisfactorily. Hence, the model is further utilized for wide-ranging analysis on the roundabout by modifying two-wheeler composition. Entry capacity in the roundabout approach fairly reveals the effectiveness of roundabout. It is to be noted that entry capacity is highly influenced by the gap acceptance behavior in the conflict zone. At roundabouts with a lack of priority rules being observed, the drivers of entering vehicle try to merge in circulatory flow even at the smaller available gap by forcing the circulatory vehicles to yield. Such incidents of forced gaps are observed frequently in traffic conditions prevailing in India. The present study also analyzes the effect of forced gap on critical gap values. An effort is also made to understand the effect of change in the proportion of two-wheelers on PCU values. The results of the present study are expected to highlight the effect of change in the composition of two-wheeler on PCU values and entry capacity of approach at a typical four-legged roundabout in a mixed traffic scenario.

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Literature review

As discussed earlier, the performance of roundabout is dependent on the number of vehicles entering the circulatory roadway. In developing countries where lane discipline and priority rules are not followed, entry flow depends on the driver's skill and behavior. Drivers based on their behavior can be classified as cautious and risk-taking drivers. Cautious drivers shall enter in the circulatory flow only when they find a suitable gap. For which, they may reject certain gaps and wait for comparatively larger gaps to merge in the circulatory flow which shall increase the delay time for the entering vehicles resulting in reduced entry capacity. Risk-loving drivers, on the other hand, shall accept a smaller gap and sometimes create a forced gap before entering the major stream (circulating stream) which may certainly, increase the entering capacity of the leg. This driver's behavior, as a whole, is quantified through a critical gap. Troutbeck and Brilon (2001) defined a critical gap as the minimum time gap in the circulating stream, that is acceptable by the driver of entering a vehicle for crossing or entering the circulatory flow. They also defined the follow-up time as the time gap between two successive vehicles entering the roundabout in the same gap from the circulatory flow. Greenshields, Schapiro, and Ericksen (1947) defined a critical gap as an acceptable average minimum time gap. The authors also concluded that variations in driver behavior along with heterogeneity in the vehicle category make it difficult to estimate the critical gap. Brilon, Koenig, and Troutbeck (1999) discussed about the various methods to estimate the critical gap and concluded that, the maximum likelihood method and the Hewitt method are best suited for practical application. However, the selection of the methodology for determining the critical gap is based on suitability and data availability. In the present study, Raff's method is used to determine the critical gap. It is to be noted that the estimation of the critical gap should be carried holistically since various studies in the recent past suggest a critical gap as an important factor for estimation of entry capacity.

Study carried out by Chandra and Rastogi (2012) reported that majority of the research on entry capacity of roundabout have been carried out on data collected in developed countries like United States, Australia, United Kingdom, Germany, and France. Kimber (1980) has defined the methods for estimating the entry capacity of a roundabout and classified as empirical or on the basis of gap acceptance process. The former method develops an empirical relation between the number of entering vehicles and geometric elements and the gap acceptance process, as discussed earlier, considers drivers' behavior quantified through critical gap values. The UK method is based on the formula proposed by Transport and Road Research Laboratory (TRRL) that mainly considers geometric parameters. Bovy, Dietrich, and Harmann (1991) analyzed roundabouts in Switzerland and suggested a model which considers the effect of existing traffic in the direction opposite to the entering traffic. The model proposed in HCM (2000) is on the basis of the assumption that entry capacity of the roundabout (Qe) has a negative exponential relation with circulating flow (Qc), while the HCM (2000) model uses an analytical approach based on the critical gap and follow-up time to determine the entry capacity of a roundabout.

Akçelik (2011) used SIDRA simulation software for assessing the entry capacity model suggested by (HCM 2000). Yap, Gibson, and Waterson (2013) carried out the empirical analysis for the entry capacity of roundabouts located in the UK and suggested that exponential relation predicts entry capacity values better than the linear model. Mahesh, Ahmad, and Rastogi (2016) used heterogeneous traffic flow data at the entry leg during queue formation to evaluate (HCM 2000) suggested model and concluded that negative exponential relation exists between entry and circulatory flow. They concluded that the (HCM 2000) model predicted higher values for heterogeneous traffic flow since critical gap values and follow-up time in heterogeneous traffic condition are comparatively lower due to the absence of priority rules.

From the above works in literature related to the roundabout capacity model, it is observed that the majority of the studies on entry capacity are based on data from developed countries. It is also evident that entry capacity values for non-lane-based traffic where priority rules are not observed, using the above-suggested models may not provide reliable results and hence, reliability of those models in heterogeneous traffic conditions like India is still unknown. This warrants the need for such studies using data observed from heterogeneous traffic conditions.

Heterogeneous traffic flow deals with vehicle categories differing in their static and dynamic characteristics. Hence, it is logical to express flow as well as entry capacity in terms of Passenger Car Unit per hour (PCU/hr) by converting all vehicle types into an equivalent passenger car. PCU values depend on various parameters related to traffic such as geometrics, speed, composition and volume and hence considered to be dynamic in nature. This originates a need for a proper methodology for estimation of PCU values from the field data. It is evident from the literature that various researchers have considered different approaches for estimating passenger car equivalency factor. Craus, Polus, and Grinberg (1980) considered delay as a factor for estimating PCU values. Krammes and Crowley (1986) used headway maintained by each vehicle category to estimate the PCU values. Elefteriadou, Torbic, and Webster (1997) compared speed of different vehicles with the speed of passenger car in the given stream for suggesting PCE values. Later, Webster and Elefteriadou (1999) considered density for obtaining PCU values. Al-Kaisy et al. (2002) used queue discharge as a parameter for estimating PCU values.

It is to be noted that the above methods were adopted for suggesting PCU values are fairly homogeneous conditions. However, Chandra and Kumar (2003) suggested a dynamic PCU value concept and defined PCU of the subject vehicle as a ratio of the speed of passenger car with the subject vehicle to the ratio of area consumed by subject vehicle category to the area consumed by the subject car. This concept considers static and dynamic characteristics for estimating PCU and hence seems reliable in Indian traffic conditions. The present study modifies the equation suggested by Chandra and Kumar (2003) to determine PCU values through field observations.

Drivers behavior is likely to vary with variation in composition, geometry and flow values. In order to capture the effect of each parameter, analysis of data with varying conditions is necessary. Obtaining varied data is a concern in developing countries like India due to the inexistence of properly designed intersections. Simulation model proves to be an important tool in such conditions. Once calibrated and validated, data analysis for the varied field, geometry and flow conditions can be easily carried out. Simulation model depicts the actual behavior of vehicles on the road utilizing various driving behavior parameters, speed and clearance between the vehicles in longitudinal as well as in transverse direction observed in the field, being sustained as input in the simulation model. Some of the highly accepted and utilized examples are SIDRA, VISSIM, RODEL, and SYNCRO. Sisiopiku and Heung-Un (2001) analyzed delay at roundabout using SIDRA. They modified the control methods at the intersection and analyzed their effect on an increase in delay time. Further, sensitivity analysis for different turning movements was studied. They concluded that two-lane roundabout is more efficient in case of heavy left-turning movement. Gallelli and Rosolino (2008) used the VISSIM model to analyze the change in traffic flow under different traffic conditions for various traffic behaviors.

The VISSIM micro-simulation software is used in the present study for its suitability in depicting Indian traffic conditions. The first step for using the VISSIM model is calibration where the parameters in the base model are adjusted from field observed data. To create a precise model, it is necessary to identify and analyze important parameters based on field observations. Various researchers for calibration suggest different methodologies. Manjunatha, Peter, and Tom (2013) used sensitivity analysis on various parameters by adjusting the error between field observed and simulation-based delay through genetic algorithm. Li et al. (2013) calibrated model based on the critical gap and follow-up time observed in a homogeneous traffic scenario. Based on sensitivity analysis, the authors suggested calibrated additive and multiplicative values in Wiedemann 74 model. The present study uses their suggestions with few modifications for its suitability in heterogeneous traffic conditions.

In summary, literature shows that studies on roundabouts are majorly based on data observed in homogeneous traffic conditions. It is inappropriate to apply the conclusions and findings of these studies to heterogeneous traffic conditions, which exist in developing countries like India. The present study concentrates on understanding the effect of change in proportion of two-wheelers on PCU values and entry capacity. Due to the lack of availability in standard roundabouts with expected variation in flow and composition, VISSIM simulation model is used. The model is calibrated and validated through microscopic and macroscopic parameters and found to depict the field condition satisfactorily.

Study area

Field studies are carried to assess the present condition of traffic and its behavior for future traffic management-related decisions. Four-legged roundabout of 25 m diameter, present in the city of Chandigarh, located in the northern part of India is considered. Intersection selected is free from any curves and gradients on all four-approach roads.

Videography was used to collect the data since video can help extract all microscopic as well as macroscopic parameters by repeatedly running the videos. The recording was carried out on a typical weekday to capture peak hour behavior under subsequent queue formation. Inventory survey for the study area is presented in Table 1.

Roundabout considered in the present study is located in an urban area. Roundabout consists of two entry lanes and three circulatory lanes from each direction. The composition observed is dominated by two-wheelers and cars which is a typical condition for roundabouts in India. Figure 1 shows the image of roundabout R1 and corresponding geometric details considered in the present study.

Observation of composition suggests a mixed traffic condition in the study area. All the vehicles are free to use every lane. Observed composition in the study area is shown in Figure 2.

It is evident from Figure 2 that traffic consists of different categories of vehicle, and two-wheeler and car have the major share in composition, which is a typical scenario in urban roundabout situated in developing countries like India.

Gap analysis

As discussed earlier, the driver's behavior can be quantified through critical gap values. Various methodologies have been suggested for the determination of critical gap values through accepted and rejected gaps. The selection of methodology to be implemented depends on the suitability of the method and nature of accepted and rejected gap data extracted. In the present study, Raff's method was utilized for determining the critical gap through accepted and rejected gaps observed. Due to the presence of risk-loving drivers, which tends to enter into a smaller gap value resulting in yielding of vehicles in circulating flow, the forced gap was frequently observed. Since accepted gaps are gaps through which entering vehicles merge in circulatory flow without disturbing the major vehicle, the forced gap was not considered as accepted gap in the present analysis. However, due to the frequent generation of the forced gap, it was essential to understand its effect on the critical gap. The paired t-test was carried out at 95% confidence interval to check the statistical significance of the difference between the accepted gaps and forced gaps. Table 2 shows the descriptive statistics for the rejected, accepted and forced Gap from the study roundabout.

It is observed that the means of accepted and forced gap by the vehicle categories are quite similar. It is apparent that the major vehicles at a forced gap tend to slow down or stop before crossing the conflict point. In the case of three-wheelers, the mean of an accepted gap is slightly lower than the mean of the forced gap, which may be due to the acceleration rate, and the speed of three-wheeler while maneuvering the roundabout area. The result of the paired t-test is as obtained for two wheelers is 0.732 and 0.133 for three wheelers whereas for small car and big car the t-statistics is obtained as 0.070 and 0.298 respectively.

It is clearly observed that the t-value for samples of each vehicle category for accepted gap and the forced gap is less than the t-critical value at 95% confidence interval, and hence it can be concluded there is no significant difference between an accepted gap and forced gap in the study roundabout. To check the statistical difference in means of accepted gap values and forced gap values, ANOVA test was carried out for each vehicle category. The results are tabulated in Table 3.

The F-values for all the vehicle category samples of the accepted gap and a forced gap can be observed to be lower than the f-critical signifying that the samples are similar. The similarity of samples proves that there would not be much difference in critical gap values due to non-consideration of forced gap values.

Estimation of PCU values using occupancy method

Heterogeneous traffic flow consists of vehicle categories differing in their static and dynamic characteristics. Hence, it is logical to express flow as well as entry capacity in terms of Passenger Car Unit per hour (PCU/hr) by converting all vehicle types into an equivalent passenger car. Chandra and Kumar (2003) suggested dynamic PCU values at mid-block sections and proposed a model considering speed ratio and area ratio as shown in Equation 1:

$$PCUi = (Vc/Vi)/(Ac/Ai) \quad (1)$$

Where, PCU_i is the PCU of the subject vehicle i and V_c/V_i is the ratio of the average speed of passenger car to the average speed of

Table 1. Inventory details for the study area (R1).

Location	Diameter (m)	Circulating roadway width (m)	Entry width (m)	Exit width (m)	Approach width (m)	Departure width (m)	Weaving Length (m)
Chandigarh	25	9	7	7	6.7	6.7	28

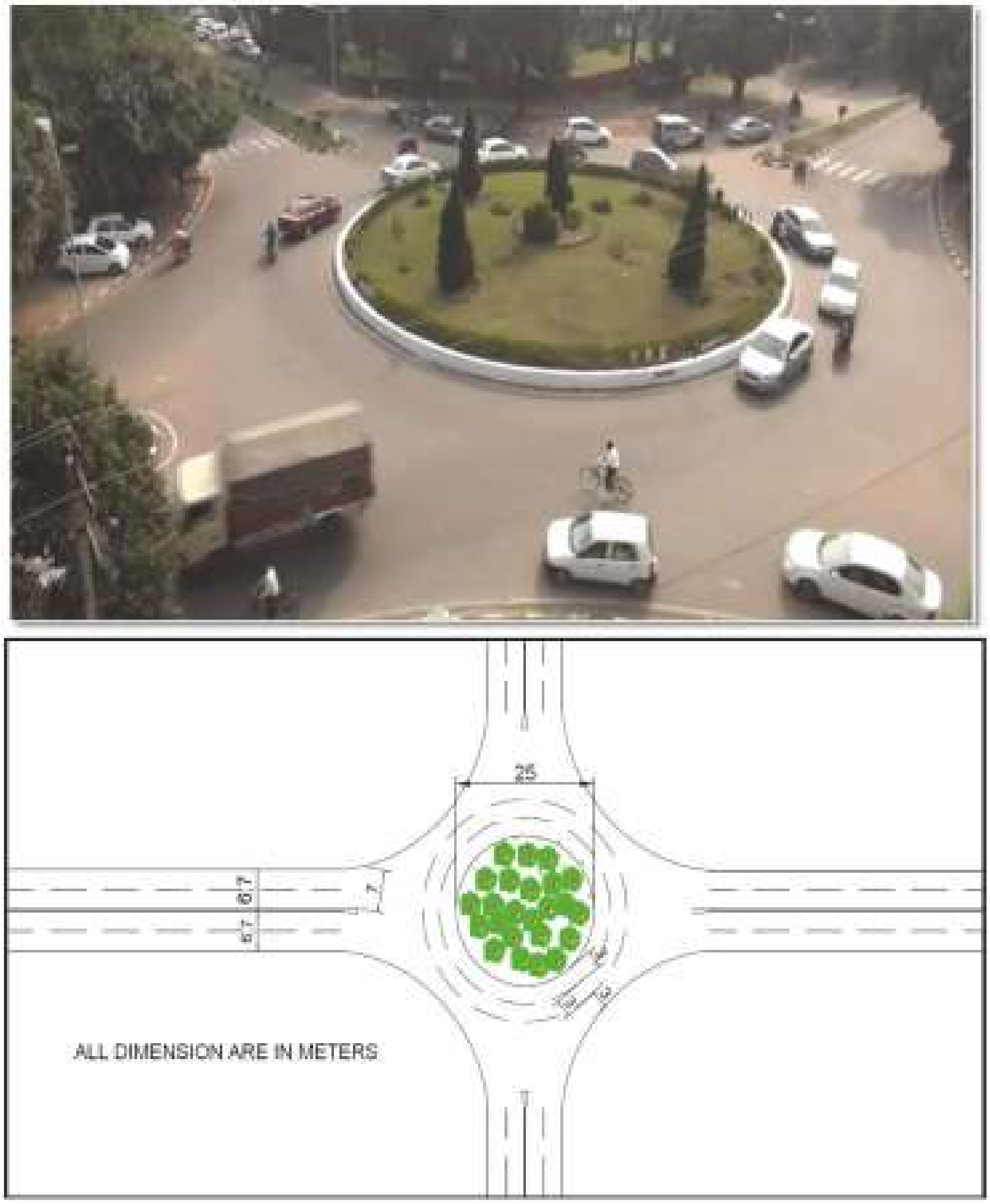

Figure 1. Image of roundabout R1 and corresponding geometric details.

subject vehicle i. A_c/A_i is the ratio of the projected area of a passenger car to the projected area of subject vehicle i in consideration. It is to be noted that the above model is suggested to be used in midblock sections.

The movement of vehicles in a roundabout is different from that at mid-block since the vehicles entering have to merge and diverge into different streams. In addition, the movement is not straight with the presence of inevitable lane changes. As a solution to this variation in flow characteristics at the roundabout, Dhamaniya, Arkatkar, and Joshi (2016) have modified the equation for dynamic PCU suggested by Chandra and Kumar (2003) by replacing speed ratio with occupancy time ratio. Dhamaniya, Arkatkar, and Joshi (2016) defined occupancy time as the time taken by the subject vehicle to clear the roundabout area. The authors also mentioned that the occupancy time should be observed separately for left turning, straight and right turning movements. The equation modified by the authors is used in the present study for the determination of dynamic PCU values at the roundabout. The proposed equation for the estimation PCU at roundabouts is shown in Equation 2.

$$\text{PCU}i = (Ti/Tc)/(Ac/Ai) \quad (2)$$

In Equation 2, T_i/T_c is occupancy time ratio of i^{th} vehicle to the passenger car. Importantly, the occupancy time also includes the delay to the subject vehicle while traversing the roundabout area. The rectangular projected area for the different vehicle classes is taken from the study of Chandra and Kumar (2003) and Dhamaniya and Chandra (2013) carried out on Indian roads under mixed traffic conditions and shown in Table 4.

The PCU values for different categories of vehicles were computed for all three possible movements considering an entry from all four legs and the values are given in Table 5. Further, the occupancy time considers the delay time occurred during the period when vehicle is in the roundabout area and therefore it is noteworthy that the delay caused incorporates the effect of neighboring vehicle as well. Hence, the PCUs given in Table 5 as

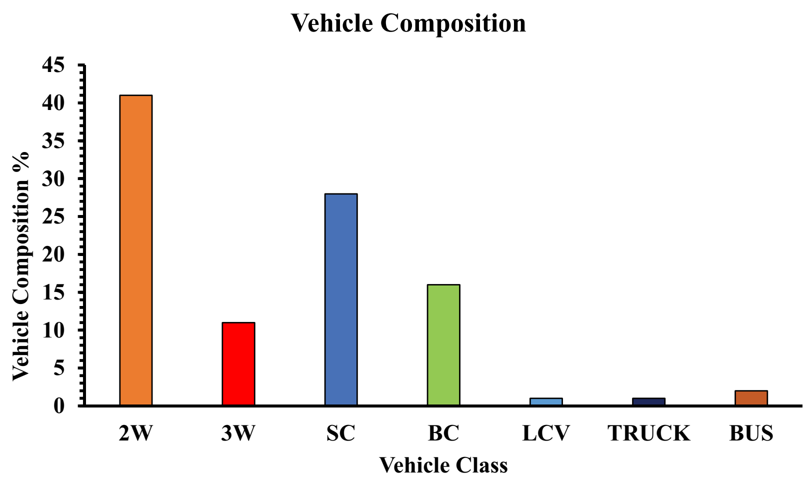

Figure 2. Vehicle composition at roundabout R1.

Table 2. Mean and standard deviation for gap values of various vehicle categories.

		Rejected gap	Accepted gap	Forced gap
Two-wheeler	Mean	1.082	2.050	2.071
	Std. Dev	0.389	0.786	0.823
Small Car	Mean	0.270	2.688	2.839
	Std. Dev	0.494	0.581	0.505
Big Car	Mean	0.202	3.026	3.105
	Std. Dev	0.440	0.932	0.761
Three-Wheeler	Mean	0.201	2.734	2.415
	Std. Dev	0.379	1.010	1.019

Table 3. Results of ANOVA test between an accepted and forced gap.

Vehicle Category	F-value	p-value	F-critical
2-Wheler	0.118	0.731	3.884
Small Car	2.193	0.141	3.918
Big Car	0.246	0.621	3.914
3-Wheeler	0.696	0.406	3.946

Table 4. Vehicular dimensions [Chandra and Kumar (2003) **and** Dhamaniya and Chandra (2013)**].**

Sr. No.	Vehicle category	Average dimensions of vehicle (m)		Projected Area (m2)
1	Two- wheeler	1.87	0.64	1.2
2	Three- wheeler	2.6	1.4	3.64
3	Small car	3.72	1.44	5.36
4	Big car	4.58	1.77	8.11
5	LCV	5.00	1.90	9.5
6	Bus	10.3	2.5	25.75
7	Truck	7.2	2.5	18.0

Table 5. Observed PCU values for various vehicle categories.

Vehicle type	Left	Straight	Right	Average
Two-wheeler	0.20	0.20	0.20	0.20
Three-wheeler	0.73	0.70	0.63	0.69
Small Car	1.00	1.00	1.00	1.00
Big Car	1.60	1.74	1.76	1.70
LCV	2.20	1.90	2.59	2.23
Bus	6.10	5.98	5.79	5.96

calculated by using Equation 2 give full consideration of actual field conditions and incorporate all delay times.

From Table 5, it is observed that PCU values for each vehicle category for different movements do not differ from each other. For understanding, if there is any significant difference, a paired t-test was carried out for PCU values reported for left-turn, right-turn and straight movement. Results indicate that there is no significant difference in PCU values estimated for different turning movements of each vehicle category. Hence, the average of PCU for all three movements is used for further determining the entry capacity values.

Determination of entry capacity

Entry capacity can be defined as the maximum flow of vehicles from entry lane merging into circulatory flow in the available field condition. The entry of vehicles in the circulatory flow is majorly affected by the type of vehicle in entry and circulating lane and conflicts caused by the turning movement, which increases delay to the vehicles entering the roundabout area. This delay results in queue formation in the entry lane. For estimating entry capacity, queue thus generated, is observed and the relation between entry capacity and circulating flow is developed by considering entry capacity as the dependent variable. Data for circulatory flow and entry flow for the congested period were extracted for R1. The negative exponential relationship observed between the entry flow and circulating flow is shown in Figure 3.

It is understood that the entering vehicle accepts a gap which is either equal to, or larger than the critical gap. Hence, in low flow conditions, the number of vehicles in circulatory flow is less and which results in an increased gap for entering vehicles. However, in case of higher circulatory flow, the gap available between two successive vehicles circulating may not be found suitable by the entering vehicle due to which the driver may restrain from entering. Hence, it is acceptable that, with an increase in circulatory flow, entry capacity decreases exponentially.

Development of simulation model

In developing countries like India, the availability of varied field data concerning geometry, composition and driver's behavior is a challenge. However, for reliable analysis, there is a need for varied data for firm conclusions. In such cases, a simulation model is found to be a suitable tool for different analysis at microscopic and macroscopic levels. Inputs from the field observations are feed-in simulation model for calibration. The model is thus calibrated and depicts the behavior of vehicles in field conditions. Parameters in the consideration are thus modified in the model and their effect

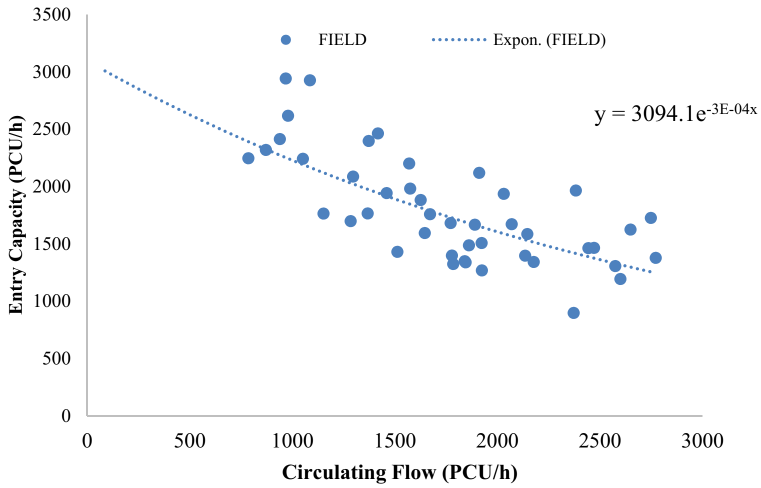

Figure 3. Plot for field observed entry capacity.

is analyzed. Hence, the accuracy of the results depends on the calibration process. The parameters in the basic model are modified to represent real field behavior. Inadequate calibration may result in faulty conclusions. Therefore, the validation of the model is required. For validation, field observations are compared with values obtained from simulation output. In case of any discrepancy, the fine-tuning of the model is done by modifying the parameters until the desired accuracy is achieved. Hence, utmost care is needed while calibrating the model. It is also to be noted that the flexibility for modifying vital parameters plays an important role, especially in the case of heterogeneous traffic conditions with absence of lane discipline and priority rules. In such cases, vehicles occupy the minimum possible space in the lateral as well as the longitudinal direction.

Initially, the base network with proper links and connectors is generated by overlapping over the aerial map, which appears as the background image. Network prepared for study area R1 is shown in Figure 4.

VISSIM software provides a base model consisting of default values which are calibrated and validated to depict the field flow characteristics up to a satisfactory level. It is evident that flow behavior is significantly affected by the static and dynamic characteristics of vehicles. Hence, it is required to modify vehicular dimensions and speed distribution for each vehicle. To replicate the stream characteristics, the types of vehicles observed in the study area were added as a 3D model in VISSIM.

For any vehicle type, the speed distribution is an important parameter that has a significant influence on roadway capacity and achievable travel speeds. Specifically, in the case of low-volume conditions when the vehicles can move with the desired speed. However, vehicles are required to yield before entering the roundabout. In Indian traffic conditions, the drivers behave randomly, making it difficult to identify the speed reduction areas.

If not hindered by other vehicles, a driver will travel at his desired speed (with a small stochastic variation called oscillation). The more vehicles differ in their desired speed; the more platoons are created. If overtaking is possible, any vehicle with a higher desired speed than its current travel speed is checking for the opportunity to pass – without endangering other vehicles. Stochastic distributions of desired speeds are defined for

Figure 4. VISSIM model of R1.

each vehicle type within each vehicle composition. To give speed as stochastic form, S curves were plotted for each category irrespective of the composition. Speed of vehicle traversing the roundabout is estimated by observing the time taken by the vehicle to traverse in the roundabout area. The distance traveled is calculated using Google Maps. Thus, speed distributions are plotted for each category of vehicles and are inputted in VISSIM. The speed values for R1 are shown in Figure 5. The obtained desired speed distributions are fed in the base model without giving reduced speed areas.

Beyond static and dynamic characteristics of the vehicle, VISSIM also provides flexibility for marking the conflict areas and defining the priority rules which facilitates to calibrate the model to best suit for traffic condition present in developing countries. Conflict areas are the location on intersections that are shared by the vehicles of different directions. Conflicts are classified as crossing, merging or diverging conflicts. Crossing conflicts are most critical since the angle is higher as compared to merging and diverging. Roundabouts are well known for converting possible crossing conflicts into merging and diverging. Hence, at a roundabout, conflict points are the locations where entering and circulating vehicles merge and later the exiting vehicles diverge. Circulating flow is to be given priority during merging and hence the entering vehicles are required to wait for a suitable gap for merging. The conflict areas for the study roundabout are shown in Figure 6.

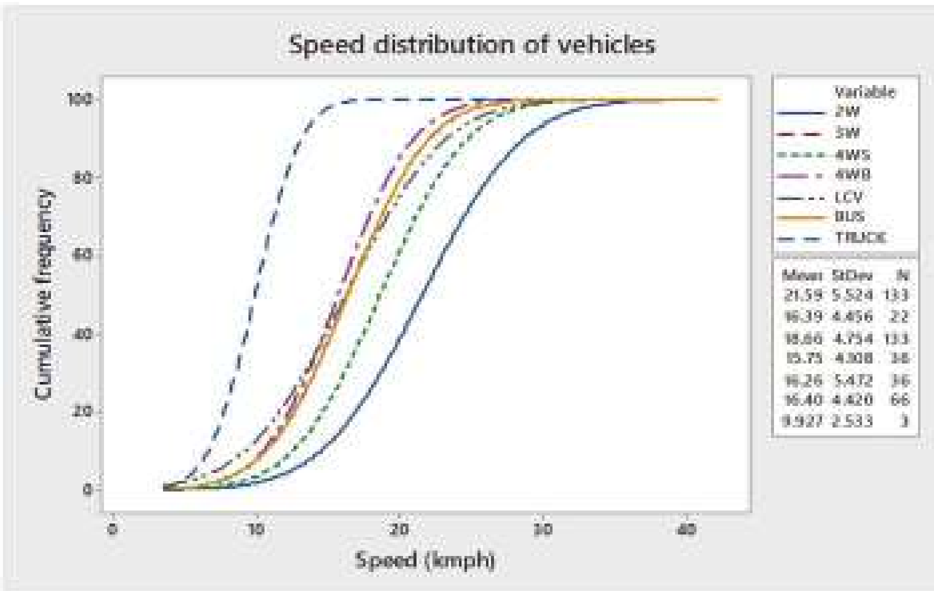

Figure 5. Speed distribution of vehicles in R1.

Figure 6. Conflict areas for intersection R1.

Red marked zone indicates a priority zone where entering vehicles are required to stop and wait for a suitable gap before entering. Green marked zone shows the area considered for merging, and yellow-colored area indicates diverging. It is also required to enter the gap values for vehicles traversing conflict areas. Gap values were observed and the same was modified in the VISSIM model by using trial and error method to predict the actual field behavior in the conflict zone. The calibrated values are shown in Table 6.

Indian drivers do not follow lane discipline and occupy smaller lateral space available, and overtake if possible. This behavior affects the flow characteristics and hence car following behavior and lateral gap clearance by vehicles in approach and circulatory lane are calibrated through Wiedemann 74 parameters and lateral clearance in the model. The present study uses the values suggested by Arasan and Arkatkar (2010) for Indian traffic conditions. The values are shown in Table 7.

After modifying the values in the model, it is important to validate it by comparing field values with those obtained as a simulation output. Validation of the model generated in the present study is based on Macro (Entry capacity & Occupancy time) and Micro (critical gap) parameters. The entry capacity was similarly observed through simulation as discussed earlier for field data. If the desired accuracy is not achieved, the fine-tuning of the model is carried out until both field and simulated values match. Entry capacity curves thus obtained are shown in Figure 7.

Table 6. Conflict area settings.

Parameter	Default	Calibrated
Front gap	0.5	0.1
Rear gap	0.5	0.1
Meso critical gap	3.0	2.5
Safety distance factor	1.5	0.6
Additional stop distance	0	0

Table 7. Lateral clearance share and calibrated Wiedemann 74 parameters adopted.

		Lateral clearance share (m)		Wiedemann 74 parameters for		
Sl. No.	Vehicle category	@standstill condition	Moving @50 kmph	AX	bx_add	bx_mult
1	**Two-wheeler**	0.25	0.3	0.5	0.3	0.35
2	**Three-wheeler**	0.25	0.3	0.5	0.4	0.45
3	**Car**	0.3	0.5	0.5	0.6	0.7
4	**LCV**	0.3	0.5	0.5	1.2	2
5	**Bus**	0.4	0.7	0.5	1.5	2

From Figure 7, it can be seen that error between field and simulated entry capacity increases with an increased inflow. This may be explained by the driver's behavior during merging in the circulatory lane even when the flow is high and the gap is insufficient. The drivers tend to create a forced gap for entering the roundabout area.

Present study uses occupancy time (travel time) for estimation of PCU values. Hence, it is substantial to validation the model using occupancy time. Occupancy time considers the time between entries of the front bumper and the exit of the rear bumper in the roundabout area. The time occupancy data are observed for each direction separately since the travel time in each direction is expected to vary with travel distance. The occupancy time observed for all the three directions observed in the field are compared with occupancy time from simulation for any significant difference, hence, statistical analysis using paired t-test between field and simulated values, for all vehicle categories in the left, straight and right direction is carried out and the results are tabulated in Table 8. The results of the paired t-test suggest that there is no significant difference between field observed and values predicted by the simulation model for occupancy time at 95% confidence level.

Driver behavior is one of basic difference observed between Indian traffic and traffic in developed countries. Driver's behavior is best-quantified using gap acceptance behavior. Hence, for microscopic validation of the generated model, critical gap values were obtained from field and simulated data using Raff's method. Critical gap values for the field and simulated data are observed to be 1.5 s and 1.7 s, respectively as shown in Figure 8. Presence of risk-taking drivers on two-wheelers, which occupy all the possible gaps, can be the reason for the difference in observed and predicted values of the critical gap. Based on plots for entry capacity and statistical evidence on travel time for field observed and simulation data, it can be concluded that the model is performing reasonably well. Hence, the calibrated model is validated using Macro (Entry capacity & Occupancy time) and Micro (critical gap) parameters.

Estimation of PCU values

The validated model was employed for analyzing the effect of two-wheeler composition on PCU values. Traffic count suggests that

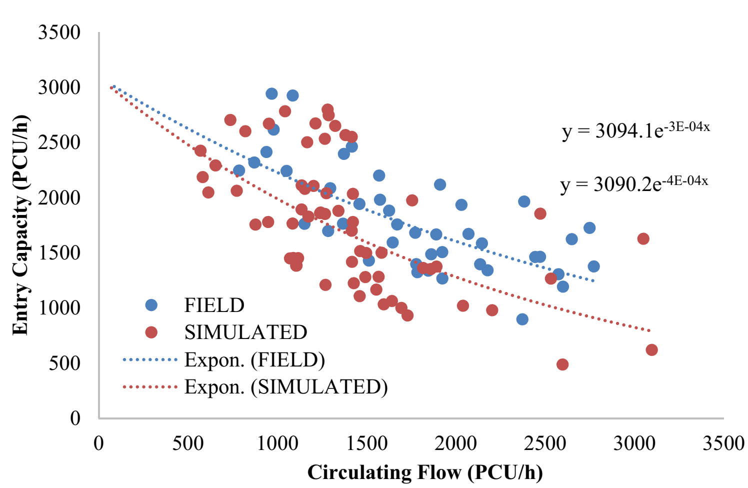

Figure 7. Comparison between field and simulated entry capacity.

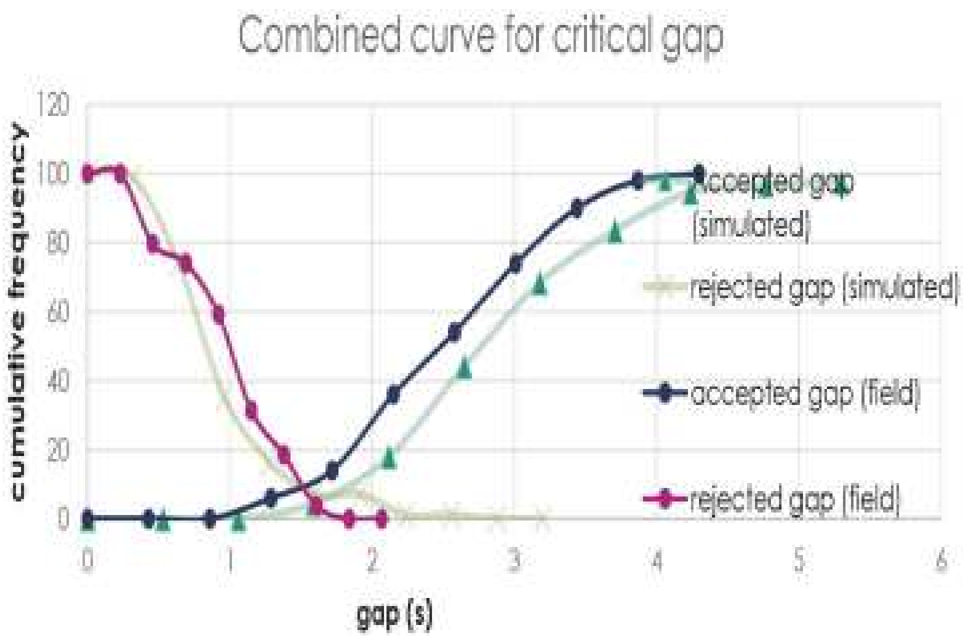

Figure 8. Raff's method for field and simulated values.

Table 8. Paired t-test results for occupancy time in R1.

Vehicle category		t-value	t-critical	p-value
Left Movement	2 w	0.60	1.96	0.551
	3 w	0.30	1.96	0.768
	Small car	0.37	1.96	0.717
	Big car	0.38	1.96	0.705
	LCV	−0.35	1.96	0.733
	Bus	-	-	-
Straight Movement	2 w	0.16	1.96	0.879
	3 w	0.42	1.96	0.674
	Small car	0.63	1.96	0.533
	Big car	0.51	1.96	0.612
	LCV	1.57	1.96	0.134
	Bus	0.15	1.96	0.884
Right Movement	2 w	1.15	1.96	0.258
	3 w	0.98	1.96	0.344
	Small car	0.99	1.96	0.328
	Big car	1.62	1.96	0.114
	LCV	-	1.96	-
	Bus	−1.9	1.96	0.1

two-wheelers are dominating vehicles in urban roundabouts. Due to smaller size and better maneuverability, two-wheelers tend to frequently change the lane, which creates impedance for the movement of other vehicles in the roundabout area. Further, lane changing and movement behavior of the drivers tend to change with an increase in flow, since unoccupied space is comparatively less during high flow values. This may result in a change in PCU values of other vehicle categories. To understand the same effect, the proportion of two-wheelers was modified and its effect on PCU value is analyzed at three different flow levels (volume-to-capacity ratio of 0.5, 0.7 and 0.9) at four different diameters (25 m, 30 m, 40 m, and 45 m). It seems logical to modify the proportion of two-wheeler based on field observed variation. Composition at the one-minute interval for the study duration shows that two-wheelers varied between 28% and 52% whereas the average proportion for the whole duration is found as 41%. Therefore, the proportion of two-wheelers was modified 35% to 55% at an interval of 5%. The PCU values were determined using occupancy method in a similar way. Values obtained for PCU at a different flow level, for a different proportion of two-wheeler in the stream at different diameters is tabulated in Table 9.

From Table 9, it is observed that the change in PCU values for different proportions at different flow levels does not follow any pattern. It also suggests that there is no considerable difference in PCU values for different diameters. However, it may be noted here that the developed calibrated parameters of VISSIM is actually replicating the field conditions in the given range of traffic composition and volume observed in the field. Simulating 100% two wheelers or any other category of vehicles may not replicate the actual field conditions and will not give the reliable results.

Study is further extended to estimate the variation in PCU values of other vehicle categories due to variation in two-wheeler proportion in the study area. As discussed earlier, the roundabout considered in the present study is located in the urban area. Bus and truck combined comprise less than 2% of the total composition. Observations drawn with such small proportion may lead to an erroneous conclusion and hence Bus and Truck are not considered during the analysis of PCU values. PCU values estimated for Three – wheelers, Big cars and LCV at different diameter roundabouts, are tabulated in Table 10.

It can be concluded from Table 9 that there is negligible effect of varying proportion and V/C ratio on PCU values of different vehicle categories. To enhance the confidence in the conclusion, 2-way ANOVA test was carried for 95% confidence. The statistical results suggest no significant difference in PCU values obtained at varying compositions, flow and diameters. One of the factors for similarity can be the methodology used for estimating PCU. The occupancy time was used for calculating PCU. The travel time for each vehicle category is compared with a passenger car. The negligible difference in PCU value suggests that the change in two-wheeler composition creates a similar effect on all vehicle categories as on passenger car. Hence, it is concluded that change in two-wheeler does not cause any change in PCU values of all vehicle categories under different flow levels. Therefore, static PCU values can be suggested for all vehicle categories. The comparison between the estimated PCU values and the PCU values suggested by Indo-HCM (2017) and Indian Roads Congress (2017) are summarized in Table 11.

Table 9. PCU values for two-wheelers at different flow, proportion and diameters.

V/C ratio		0.5				0.7				0.9			
Diameter (m)		25	30	40	45	25	30	40	45	25	30	40	45
Two – Wheeler Proportion	**35%**	0.21	0.20	0.21	0.20	0.20	0.20	0.20	0.21	0.21	0.20	0.21	0.21
	40%	0.20	0.20	0.21	0.21	0.20	0.20	0.21	0.21	0.20	0.20	0.20	0.21
	45%	0.20	0.20	0.20	0.21	0.20	0.20	0.20	0.21	0.19	0.20	0.20	0.21
	50%	0.20	0.20	0.20	0.21	0.20	0.24	0.20	0.21	0.19	0.20	0.20	0.21
	55%	0.20	0.20	0.20	0.21	0.19	0.20	0.20	0.21	0.20	0.20	0.20	0.21

Table 10. PCU values for different vehicle categories at different flow, proportion and diameter.

Diameter		25 m			30 m			40 m			45 m	
	Two- wheeler Proportion	3 W BC	LCV	3 W	BC	LCV	3 W	BC	LCV	3 W	BC	LCV
V/C = 0.5	**35%**	0.851.37	2.37	0.66	1.58	2.50	0.69	1.61	2.02	0.71	1.60	1.87
	40%	0.671.64	1.91	0.63	1.56	1.94	0.70	1.67	2.60	0.70	1.58	1.72
	45%	0.691.70	2.23	0.65	1.56	2.18	0.70	1.65	1.89	0.71	1.61	1.75
	50%	0.651.57	2.20	0.65	1.60	2.11	0.70	1.61	1.17	0.72	1.60	1.80
	55%	0.671.63	2.09	0.67	1.58	1.91	0.76	1.61	0.70	0.75	1.60	1.27
V/C = 0.7	**35%**	0.621.62	2.02	0.62	1.60	1.97	0.69	1.62	2.04	0.70	1.58	1.72
	40%	0.641.56	1.88	0.64	1.58	2.13	0.68	1.62	1.61	0.69	1.61	1.74
	45%	0.641.60	1.94	0.67	1.58	2.45	0.69	1.60	1.61	0.70	1.62	1.65
	50%	0.611.64	1.90	0.81	1.60	2.27	0.73	1.65	1.16	0.71	1.60	1.77
	55%	0.661.60	2.00	0.66	1.57	1.91	0.76	1.60	1.78	0.78	1.60	1.20
V/C = 0.9	**35%**	0.651.60	1.97	0.64	1.59	2.46	0.67	1.62	1.85	0.70	1.62	1.65
	40%	0.621.59	1.87	0.64	1.58	1.98	0.69	1.69	1.77	0.69	1.61	1.74
	45%	0.621.50	2.08	0.64	1.65	2.08	0.69	1.69	1.67	0.70	1.58	1.72
	50%	0.611.55	1.85	0.63	1.58	2.13	0.70	1.65	1.22	0.71	1.60	1.77
	55%	0.631.61	2.08	0.66	1.57	1.82	0.71	1.57	1.84	0.78	1.60	1.20

Table 11. Suggested PCU values for urban roundabout in heterogeneous traffic condition.

Vehicle Class	Present Study	Indo-HCM & IRC 65 2017
Two-wheeler	0.2	0.32
Three-wheeler	0.68	0.83
Small Car	1	1
Big Car	1.68	1.4
Light Commercial vehicle	1.86	1.88

It is clear that Indo-HCM and (Indian Roads Congress 2017) suggested PCU values for two-wheeler and three-wheeler are higher than the values obtained in the present study. This difference can be justified by the method implemented for determining PCU values. The values suggested by Indo-HCM (2017) and Indian Roads Congress (2017) are derived using the headway method which considers headway of particular vehicle category. Biswas, I Ghosh, and Chandra (2015) concluded that PCU values obtained from the headway method for mixed traffic conditions are often misleading due to the absence of lane discipline. Dhamaniya, Arkatkar, and Joshi (2016) reported that occupancy method incorporates an

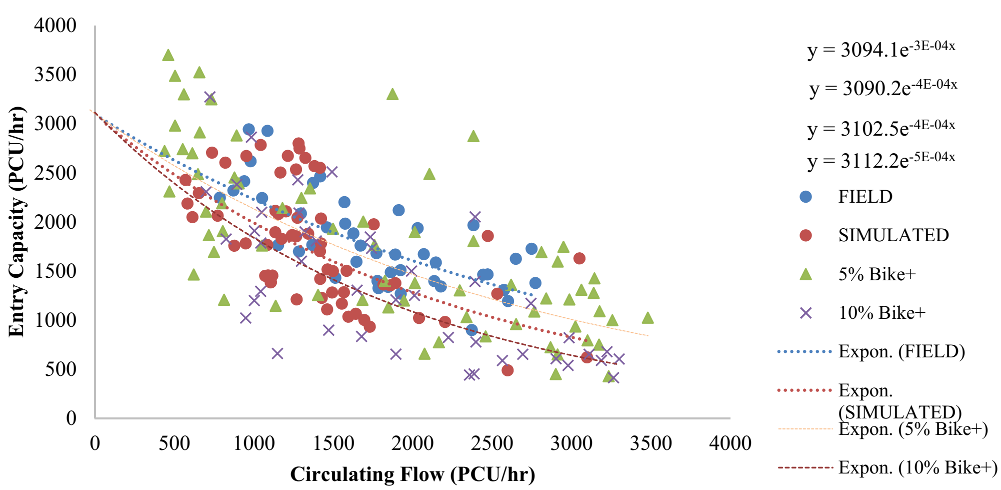

Figure 9. Plots for field and simulated values with 5% and 10% increase in two-wheeler.

Table 12. Entry capacity values.

Observation	Entry Capacity (PCU/h)	R^2 Values
Field data	3094.1	0.489
Simulated data	3090.2	0.397
5% increase in two-wheeler	3102.5	0.519
10% Increase in two-wheeler	3112.2	0.556

important parameter for performance, delay, which is faced by the vehicles while traversing roundabout. Hence, it is logical to consider occupancy time method for estimation of PCU.

Determination of entry capacity

PCU values suggested above were further utilized for analyzing the effect of two-wheeler proportion on entry capacity by converting the entry flow and circulatory flow in terms of PCU per hour. The graphs plotted for the entry capacity from the field and simulated samples along with the modified composition are shown in Figure 9.

Simulation runs were performed with three random seeds. It is evident from the plots that entry capacity microscopically increases with an increase in the proportion of two-wheelers. However, the percentage increase is not significant. Entry capacity values obtained through field observation, simulation, and after modifying two-wheeler proportion are shown in Table 12. The minor increase observed in entry capacity can be related to the hindrance created by the larger vehicles near the entry point. Two-wheelers being smaller in size utilize less space hence making space available for more vehicles to enter. Therefore, it can be concluded that there is no significant change in entry capacity due to the change in the proportion of two-wheeler.

Conclusion

The present study investigated the effect of change in two-wheeler composition on PCU values and entry capacity of a roundabout. In addition, the effect of a forced gap on gap acceptance behavior is studied. It is concluded that the occurrence of the forced gap does not create any effect on critical gap values. Due to insufficient field data, VISSIM simulation model is used. The model is calibrated to depict the field behavior using field observations. Accuracy of model prediction is examined through validation using macroscopic and microscopic parameters such as occupancy time, entry capacity and critical gap. The model thus generated and calibrated is further used to analyze the effect of two-wheelers proportion on PCU values. It is observed that there is no significant change in PCU value by varying the proportion of two-wheeler between 35% and 55%. Similar variation in the proportion of two-wheeler does not affect the entry capacity significantly. The results of the present study will be helpful for researchers and planners for effective analysis and planning of roundabouts.

The present study is limited to the heterogeneous traffic conditions as observed in the field. The developed calibrated parameters of VISSIM are actually replicating the field conditions in the given range of traffic composition and volume observed in the field. Developing a scenario where only one category of vehicle is present in 100% may not replicate the actual field conditions and will not give the reliable results. Therefore, as a part of future scope the readers may develop more robust calibrated model that can simulate 100% of two-wheelers and defines the priority and conflicts zone accordingly.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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