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Enhancing Passenger Car Unit Estimation at Roundabouts: A Comparative Analysis of Occupancy Time and Lagging Headway Techniques

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Abstract

The Passenger Car Unit (PCU) is a vital parameter in traffic engineering, essential for assessing road network capacity. Although the concept of PCUs has been fairly well-researched on urban and metropolitan mid-block roadways, PCU factors for various vehicle classes at unsignalized intersections have not been thoroughly studied. Due to inefficient lane management at the intersection, traffic in situations with varying densities moves abreast. This calls for a re-evaluation of the indifferent prior work on the examination of PCU factors at roundabouts in emerging nations. The purpose of this study is to determine PCUs at roundabouts by measuring occupancy time and contrasting the findings with those obtained using the lagging headway technique. The results showcased that the occupancy time method yields rational outcomes that are reflective of real-world conditions. The findings of this study can be useful for traffic engineers in selecting an appropriate PCU estimation method based on traffic conditions. The study also suggests using a dynamic value to measure PCUs at roundabouts instead of a static value. As such, this dynamic approach not only aligns with the varying traffic dynamics encountered in roundabouts but also promises a more accurate representation of the actual traffic flow.
Keywords: Roundabout, Occupancy time, Lagging headway, PCU, Conflicting zone.

1. Introduction

A wide range of car types necessitates flexibility in transportation systems for emerging nations. They have different operating mechanisms and also have different physical features. This makes it difficult for traffic planners to simulate them and determine how much capacity a given facility has. One goal of a traffic survey should be to normalize the current chaotic blend of traffic patterns. A PCU factor multiplied by the amount of each vehicle class yields the desired result. The PCU is a measure of the capacity of a road network, and it is used to estimate the number of vehicles that can be accommodated on a particular road segment. PCU values are typically determined based on the vehicle's size, speed, and other factors that influence its effect on traffic flow. Infrastructure in developing nations must accommodate a diverse variety of vehicles. Not only do they function differently, but they also have vast physical differences (Dhamaniya and Chandra 2013). To take into consideration the impact of buses and other heavy vehicles

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on the traffic flow, the idea of PCU was first presented in the 1965 version of the Highway Capacity Manual (HCM). It described PCU as the number of vehicles that are taken out of the traffic flow and replaced by a lorry or bus under the current circumstances on the road (Highway Capacity Manual 1965). In the past, when dealing with large trucks on multi-lane roads on flat grounds, a static number of 2 was used (Highway Capacity Manual 1950). Over the past decades, this metric has undergone significant changes and refinements. The HCM (2010) defined PCU as the number of passenger cars that will create the same working conditions as a single heavy vehicle of a certain class under specific route, traffic, and control conditions (HCM 2010). Overall, the PCU metric has evolved from a relatively simple generalization to a more sophisticated and nuanced tool for transportation planning and operations.

The next enigma is whether to use constant PCU factors or dynamic PCUs that adapt to new circumstances. The past ten years of study have focused on developing methods for accurately estimating the dynamic PCU values of various vehicle classes, as outlined by (Joshi and Vagadia 2013). Van Aerde and Yagar claim that the main difference between PCU studies is the assessment of the same PCU factors for capacity, pace, platooning, and other types of research (Aerde and Agar 1984). A significant benefit of dynamic PCU factors is the method's flexibility to adapt to changing transportation conditions. In light of the fact that the traffic scenario at any particular time would differ between locations, this guarantees reasonable PCU values for vehicles at an investigation site. For this reason, PCU values would vary geographically.

Another important consideration when trying to calculate the PCU values for vehicle classes at roundabouts is what estimation method to use and which traffic measure to factor in. Elefteriadou et al. in their study concluded that PCU values for all facility types should be decided by the same performance measure as the LOS labels (Elefteriadou *et al.* 1997). Mallikarjuna and Rao used a density adjustment factor termed Area Occupancy to determine PCU values (Mallikarjuna and Rao 2006). In comparison to a standard car, the dimensions and speed of a vehicle class are factored into the dynamic PCU model suggested by Chandra and Kumar (Chandra and Kumar 2003). They hypothesized that the PCU values would rise with the speed ratio and drop with the area utilization ratio when comparing vehicles in heterogeneous traffic conditions. Li et al. gave PCU values for a variety of vehicle types in China based on the amount of area occupied by each. They stated that as the number of lanes grew and the service rating decreased from "A" to "E," the PCU values would also increase (Li *et al.* 2006). Basu et al. calculated the speed of the stream to figure out what a passenger car would be like. PCU levels were found to be higher when there was more traffic. For commercial vehicles (Trucks), the amount of traffic was the most important thing that affected PCU (Basu *et al.* 2006). Chandra and Sikdar's study shows that the amount of a certain vehicle in the general flow of traffic has a bad effect on that vehicle's PCU value. They identified the PCU based on how fast the vehicle was going and how big the area was (Chandra and Sikdar 2000). Except for larger vehicles, Dey et al. found that PCU decreases with a rising proportion in the traffic stream and volume-to-capacity ratio. The size and extra weight of large vehicles on the road is a possible contributing factor. Using data on travel times and road widths, they determined PCU values (Dey *et al.* 2008).

According to literature analysis, insufficient research has been done to reliably estimate PCU factors at unsignalized intersections like roundabouts, owing to the fact that most of the studies were conducted on homogeneous traffic conditions. The existing approach of PCU assessment proposed by Indo-HCM 2017, IRC-65 2017 (Indo 2017, IRC-65 2017) employs Lagging headway to evaluate the headway between successive vehicles. The absence of lane discipline and movement priority in developing nations makes assessing the headway aspect of PCU determination even more difficult. In summary, some of the existing literature on roundabouts mostly uses data from homogenous traffic circumstances. It's inappropriate to apply these research conclusions and findings to India's varied traffic. As most earlier studies were focused on delay time, the present study estimates PCU values for heterogeneous traffic conditions at roundabouts using occupancy time. The study thus aims to address the gap in the existing literature regarding the thorough examination of PCU factors for various vehicle classes at roundabouts, particularly in emerging nations where inefficient lane management is a common issue. By comparing the occupancy time and lagging headway methods, the research also seeks to identify the more appropriate approach for estimating PCU factors that accurately reflect real-world traffic conditions at roundabouts.

2. Research objectives and contribution of the study

The primary objectives of this study are threefold, which are stated below as:

- The study aims to determine the PCU factors at roundabouts by measuring the occupancy time of different vehicle classes. This approach offers a more dynamic and realistic representation of the traffic flow characteristics compared to the commonly used lagging headway technique.
- The study seeks to conduct a comparative analysis of the PCU factors obtained using the occupancy time method and those derived from the lagging headway approach. This comparative evaluation will shed light on the relative strengths, limitations, and applicability of each PCU estimation technique in the context of roundabouts.
- Finally, the research investigates the feasibility of using dynamic PCU values, as opposed to static values, to better represent the varying traffic dynamics encountered at roundabouts.

The study offers a practical application for transportation researchers, while also providing valuable insights for methodologists in the field. The findings from the research are expected to inspire further investigation and stimulate meaningful discussions within the broader scientific community.

3. Study sites and data acquisition

This study is based on data collected from a high-traffic urban road network in Chandigarh city of India. Five roundabouts were selected for the data collection. The roundabouts examined in this study adhered to a standardized design, featuring a central circular island surrounded by four radial approach legs. Each approach leg consisted of dedicated entry and exit roadways, enabling the continuous flow of traffic around the central island. This geometric layout is a common configuration for modern roundabouts, facilitating the efficient movement of vehicles through the intersection. The roads leading up to the roundabouts had no grades. When it comes to traffic flow, the roundabouts selected were unrestricted and free of any side interference that might be caused by transit stops, stopped vehicles, or similar obstructions. The traffic data were collected using a video camera (SONY Alpha ZV-E10 Camera), and the data were processed using a computer vision technique (Kinovea 0.5.9) to identify and track individual vehicles as shown in Figure 1. Both inventory and traffic flow data were collected. The surveys were conducted in the month of June 2023. Peak hours were defined as 8:00 AM to 10:00 AM and 4:00 PM to 7:00 PM. This approach ensured a comprehensive representation of traffic dynamics across different times of the day. The data that provided information on the movement of traffic were obtained from a video camera that was positioned at a sufficiently high location, which was typically a curb-side high-rise structure so that it could encompass the intended region of the intersection. Specifications of the roundabout's geometry, such as its circulating carriageway width, entrance width, and central island diameter, are included in the inventory data. Table 1 (Dhamaniya and Chandra 2013) shows how traffic data involving vehicles were classified into five separate types based on their operating features and physical dimensions. These include motorized two-wheelers (2W), three-wheelers (3W), standard cars (SC), big cars (BC), and heavy vehicles (HV).

For homogeneity and comparability of data across study sites, all five roundabouts studied were located in urban areas within the same metropolitan region, with similar traffic flow characteristics. The data collection periods for each roundabout overlapped to minimize the impact of temporal variations. Traffic volume, vehicle mix, and environmental particularly weather conditions were monitored and found to be consistent across all sites during the study period. Furthermore, homogeneity checks, including statistical tests like ANOVA, confirmed that traffic data from the five roundabouts were comparable, enabling unified analysis, as discussed in the next section.

Table 1: Vehicle classes and their physical features

Vehicle type	Vehicle symbol	Vehicles included	Length (m)	Width (m)
Motorized Two-wheelers	2W	Motorbikes, ES*	1.87	0.64
Three wheelers	3W	Auto-rickshaw	3.20	1.40
Standard cars	SC	Car, SUV**	3.72	1.44
Big cars	BC	Van, Maxi Cab	4.58	1.77
Heavy vehicles	HV	Bus, Truck	10.10	2.43

*ES= Electric Scooty, **SUV = Small Utility Vehicle


(a)


(b)


(c)


(d)


(e)

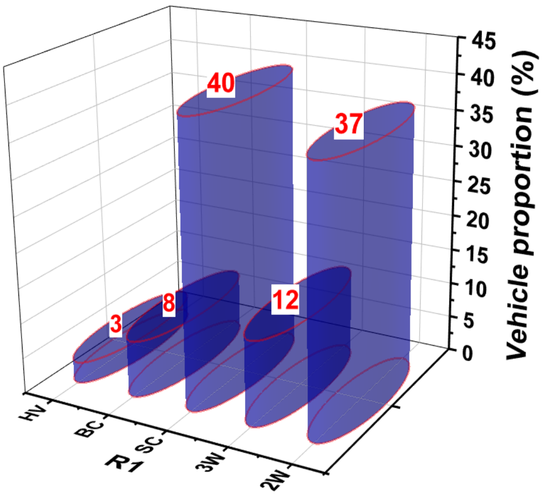
Figure 1: Camera view of study sites: (a)R1; (b)R2; (c)R3; (d)R4; (e)R5.

Table 2: Roundabout inventory statistics and sample size of vehicle types

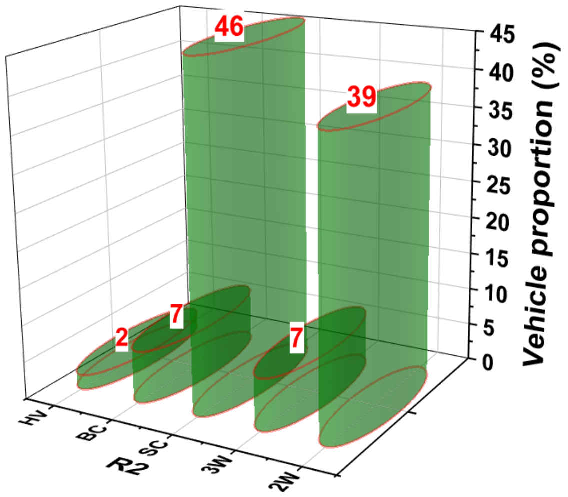
Roundabout ID	Location	Diameter (m)	Circulating width (m)	Entry width (m)	Sample size					CTV*
					2W	3W	SC	BC	HV	
R1	Sector 35-36	25	8	7	418	165	674	151	53	1932
R2	Sector 42-43	37	9.5	8.5	657	150	969	182	90	2795
R3	Sector 53-54	49	10	13	384	68	530	128	46	2055
R4	Sector 52-53	51	10	12	392	106	514	90	77	2405
R5	Sector 16-17	85	12.5	9.3	954	120	1147	225	102	2569

*CTV = Circulating Traffic Volume

Table 2 shows inventory data along with the sample size and circulating vehicle flow (Veh/h) of vehicle categories at selected roundabouts. Also, the traffic composition of vehicle types in accordance with roundabout ID has been demonstrated in 3D bar charts as shown in Figure 2.



(a)



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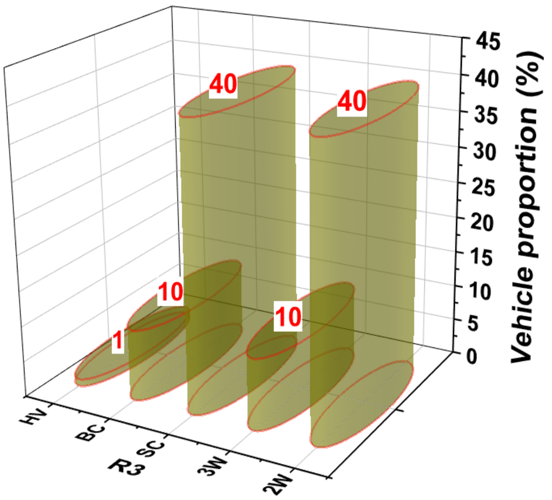

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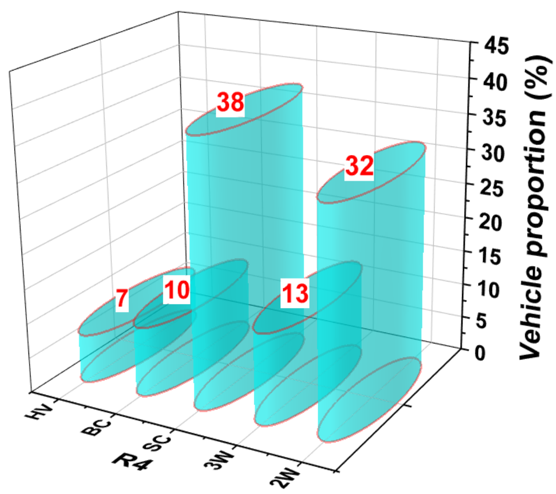

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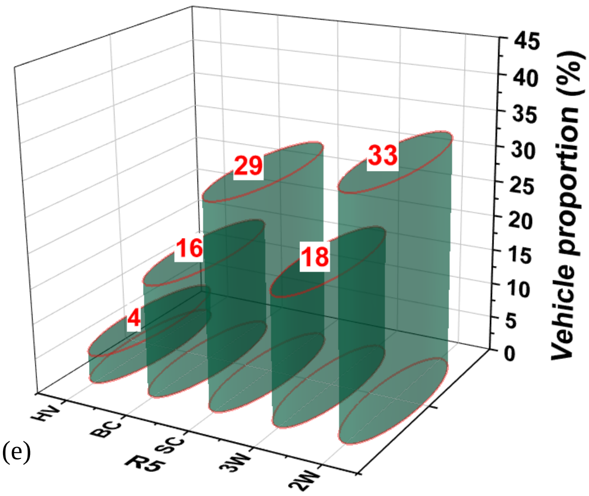

(e)

Figure 2: Vehicle traffic composition (%) at roundabout: (a)R1; (b)R2; (c)R3; (d)R4; (e) R5

3.1 Data processing

The raw video recordings were analyzed using Kinovea 0.5.9, to extract the data for analysis. The data were subjected to a comprehensive cleaning process to identify and eliminate anomalies. Traffic volumes were then aggregated into a 15-minute interval period and normalized by peak hour volume (PHV) to ensure comparability across sites. To ensure the comparability of traffic data across the five studied roundabouts (R1 to R5), a one-way Analysis of Variance (ANOVA) test was conducted using adjusted data with more consistent traffic volumes. This test evaluated whether the mean traffic volumes differed significantly among the roundabouts. The null hypothesis (H_o) posits no significant differences in mean traffic volumes across the roundabouts ($\mu_{R1} = \mu_{R2} = \mu_{R3} = \mu_{R4} == \mu_{R5}$). The ANOVA results are summarized in Table 3.

Table 3: Statistical results from one-way ANOVA test

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-Value	p-Value
Between Groups	537.18	4	134.29	1.27	0.283
Within Groups	15281.01	145	105.39		
Total	15818.19	149			

The calculated p-value of 0.283 (> significance level, α = 0.05) indicates that the null hypothesis cannot be rejected. This result suggests there are no statistically significant differences in mean traffic volumes across the five roundabouts. Hence, the data are homogeneous. The lack of statistically significant differences in traffic volumes supports the assumption that the data collected from R1 to R5 are comparable. This homogeneity validates the subsequent pooled analyses and ensures that any observed variations in performance metrics are due to differences in operational or geometric characteristics, not inconsistencies in data collection.

3.1.1 Tukey's Post-Hoc Analysis

To further investigate the mean differences in traffic volumes among the five studied roundabouts (R1 to R5), a Tukey's Honest Significant Difference (HSD) post-hoc analysis was conducted. While the one-way ANOVA test indicated no statistically significant differences in mean traffic volumes ($p = 0.283 > 0.05$), the post-hoc analysis aimed to evaluate pairwise comparisons between roundabouts to confirm the homogeneity of the data. Tukey's HSD test compares the mean traffic volumes of each pair of roundabouts and accounts for multiple comparisons to control the family-wise error rate. The results of the analysis, including the mean differences, confidence intervals, and significance levels, are summarized in Table 4.

Table 4: Tukey's HSD Test Results

Pairwise Comparison	Mean Difference ($\Delta\mu$)	95% Confidence Interval (CI)	p-Value	Significance (α = 0.05)
R1 vs. R2	2.31	[-3.87, 8.49]	0.823	Not Significant
R1 vs. R3	-1.45	[-7.63, 4.73]	0.932	Not Significant
R1 vs. R4	3.17	[-2.91, 9.25]	0.675	Not Significant
R1 vs. R5	-0.89	[-6.07, 4.29]	0.985	Not Significant
R2 vs. R3	-3.76	[-9.94, 2.42]	0.450	Not Significant
R2 vs. R4	0.86	[-5.32, 7.04]	0.997	Not Significant
R2 vs. R5	-3.20	[-9.38, 2.98]	0.590	Not Significant
R3 vs. R4	4.62	[-1.56, 10.80]	0.210	Not Significant
R3 vs. R5	0.56	[-5.62, 6.74]	0.999	Not Significant
R4 vs. R5	-4.06	[-10.24, 2.12]	0.367	Not Significant

The results of Tukey's HSD test indicate that none of the pairwise comparisons show statistically significant differences in mean traffic volumes ($p > 0.05$ for all pairs). The confidence intervals for all comparisons include zero, further supporting the conclusion that the data are homogeneous across all roundabouts.

These findings reinforce the results of the one-way ANOVA test, validating the assumption that the observed traffic volume data are comparable across the studied sites. Consequently, any differences in subsequent performance metrics can be attributed to variations in operational or geometric characteristics rather than inconsistencies in traffic volumes.

4. PCU estimation methodologies at the intersection

The concept of PCU is extremely important for research on intersections that have to deal with different types of vehicles. There are several methods available to estimate PCU values, but the two most commonly used methods at unsignalized intersections are the occupancy time method and the lagging time method. The utilization of the occupancy time method at roundabouts has not been studied and then compared so far. The main objective of this study is to compare these two methods to arrive at an evident conclusion regarding their suitability for use in analyzing data from a real-life application.

According to research carried out by Arasan and Arkatkar, Greenshields et al., and Werner and Morrall, (Greenshields B, Schapiro D 1947, Werner and Morrall 1976, Arasan and Arkatkar 2010), the variables that are most frequently used are distance, vehicle area, and vehicle speed. When analyzing these different variables, the operation of roundabouts is taken into consideration. Due to the fact that people using a roundabout travel across it at roughly the same pace. In order to determine PCU values on roundabouts, using vehicle speed is not advised due to the minor change in speed. It follows that a strategy focused on speed cannot be employed. To evaluate the PCU values at roundabouts in Indian traffic conditions, the lagging headway method is presently used, but this article provides an occupancy time method for determining the PCU values at roundabouts and then compares the findings to the lagging headway method. The subsequent sections of this paper will provide a detailed examination of both the occupancy time and lagging headway approaches to PCU estimation at roundabouts.

4.1 Lagging Time method

The lagging time method estimates the PCU by measuring the time it takes for a vehicle to reach a particular point after the preceding vehicle has passed that point. This method assumes that the size and speed of the preceding vehicle have a direct impact on the capacity of the road. For a vehicle type 'i', the following equation (1) has been presented to calculate PCU by this method.

$$PCU_i = f_i \times \frac{H_i}{H_c} \quad (1)$$

Where, PCU_i= PCU of vehicle type 'i',
H_i = mean lagging headway of vehicle type 'i' in the circulating stream,
H_c = mean lagging headway of standard passenger car 'c' in the circulating stream,
f_i = width factor for vehicle type 'i'
Also.

$$f_i = \frac{W_i}{W_c} \quad (2)$$

W_i = width of the vehicle type 'i' and W_c = width of standard passenger car 'c'

4.2 Occupancy Time method

The occupancy time method estimates the PCU by measuring the time that a particular vehicle type occupies a particular section (conflict zone) of the intersection (Mohan and Chandra 2018). Occupancy times are proportional to the length of the vehicle, so larger vehicles, such as buses and trucks, will have a greater occupancy period. These vehicles will have a greater impact on other vehicles in the conflicting zone as compared to smaller vehicles. The driver behavior also has an effect on the occupancy period for a vehicle, such as the aggressive driving results in lower occupancy time. The smaller size of vehicles owing to their high maneuverability usually have less occupancy period. One can quantify this impact by looking at the ratio of the time that one class of vehicle is present in a conflict zone to the time a normal passenger car is occupied. Occupancy duration can be used to calculate the PCU, which is provided by equation (3)

$$PCU_i = \frac{OT_i}{OT_c} \times \frac{W_i}{W_c} \quad (3)$$

Where, PCU_i= PCU of vehicle type 'i'
OT_i = Occupancy time of vehicle type 'i' in the conflict zone.
OT_c = Occupancy time of standard passenger car 'c' in the conflict zone.
W_i = width of the vehicle type 'i' and W_c = width of standard passenger car 'c'.

Figure 3 shows the schematic diagrams for the implementation of these two methods at the roundabout. The lagging headway methodology is represented by a single reference line, while for the occupancy time methodology, two reference lines are required to compute the period for which a subject vehicle occupies the conflict zone at the roundabout. Furthermore, to provide clear visual insights into the delineation of the conflict zone at the roundabout, Figure 4 has been included in the study. This schematic diagram illustrates the spatial demarcation of the conflict zone and calculates the occupancy time of vehicles traversing the roundabout.

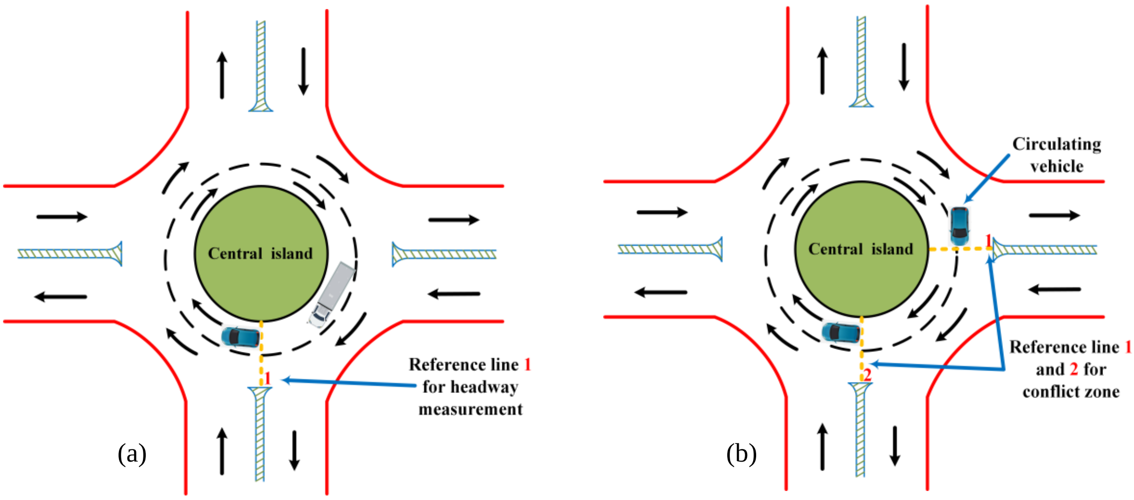

Figure 3: Schematic diagram at the roundabout: (a) Lagging headway method and (b) Occupancy time method.

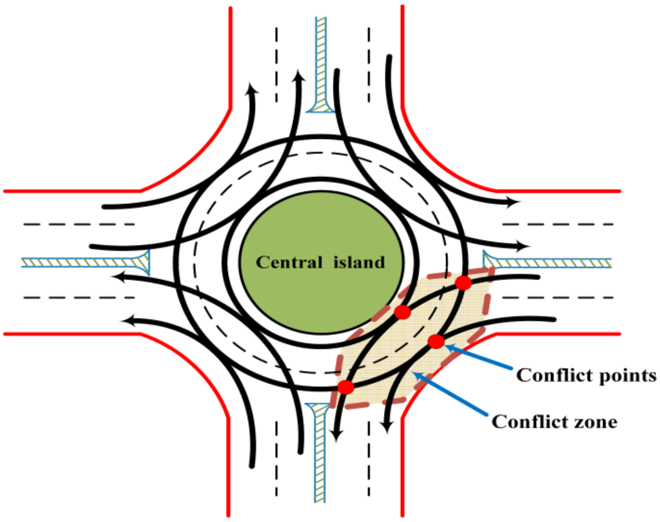

Figure 4: Representation of conflict zone at roundabout.

5. Results and Analysis

5.1 Assessment of PCU Value

The PCU concept is vital to the evaluation of intersections where traffic volumes fluctuate frequently. In an effort to better comprehend the effects of roundabouts on distinct vehicle categories, an alternative method of quantifying PCU values was adopted than what is currently used (lagging headway).

The data were analyzed using statistical methods to determine the PCU values for each vehicle type using both the occupancy time method and the lagging headway method. Table 5 depicts the occupancy time and lagging headway values calculated for each vehicle type.

Table 5: Occupancy time and Lagging headway of the subject vehicle

	Occupancy Time (seconds)					Lagging Headway (seconds)				
Roundabout ID	2W	3W	SC	BC	HV	2W	3W	SC	BC	HV
R1	7.29	10.26	14.13	15.19	16.55	2.31	2.70	2.85	2.97	4.64
R2	6.35	7.22	8.40	9.49	10.13	1.96	2.72	2.68	3.12	4.94
R3	6.12	7.47	7.13	8.47	10.23	3.10	3.70	3.78	4.24	6.26
R4	7.12	8.10	8.14	8.38	10.27	1.70	2.60	2.57	2.98	5.11
R5	5.31	5.48	7.23	7.28	9.09	1.69	2.24	2.10	2.24	3.40

Table 6 lists the expected mean PCU values for various vehicle classes along with the circulating flow computed in PCU/h calculated as per the values obtained from the occupancy time method in accordance with roundabout ID.

Table 6: PCU values for the subject vehicle by Occupancy time and Lagging headway method along with circulating traffic volume (PCU/h)

	PCU (Occupancy Time Method)					PCU (Lagging Headway Method)					CTV*
Roundabout ID	2W	3W	SC	BC	HV	2W	3W	SC	BC	HV	
R1	0.23	0.71	1.00	1.32	2.11	0.36	0.92	1.00	1.28	2.75	1343
R2	0.34	0.84	1.00	1.39	2.18	0.32	0.99	1.00	1.43	3.11	1971
R3	0.38	1.02	1.00	1.46	2.59	0.36	0.95	1.00	1.38	2.80	1900
R4	0.39	0.97	1.00	1.27	2.28	0.29	0.98	1.00	1.42	3.35	1999
R5	0.33	0.74	1.00	1.24	2.55	0.36	1.03	1.00	1.31	2.73	1946

*CTV = Circulating traffic volume (PCU/h)

5.2 Model development

For a better understanding and visualization of PCU values at roundabouts and to answer our query as stated in the introductory part of this article, the PCU values from both techniques were correlated with the geometrical and traffic flow parameters of roundabouts. A statistical approach called correlation analysis was used to determine the existence and strength of a relationship between the factors of interest. The results of the correlation analysis are shown in Table 7.

Table 7: Correlation coefficients between variables

	Central diameter (m)	Circulating width (m)	Entry width (m)	Circulating flow (PCU/h)
PCU_{2W}	0.911	0.791	0.595	0.960
PCU_{3W}	0.803	0.780	0.804	0.833
PCU_{BC}	0.827	0.708	0.276	0.620
PCU_{HV}	0.944	0.905	0.242	0.712

The results from Table 7 indicate that the PCU values obtained by employing the occupancy time method for all the vehicle classes at the roundabout shall not be treated as static in nature, but are rather subjected to change i.e. dynamic in nature and have a strong correlation with the central diameter and circulating flow in comparison to other parameters taken for analysis.

Furthermore, given the strong correlation of the occupancy time of subject vehicles with the central diameter and circulating flow (PCU/h) at roundabouts, it was intended to develop a mathematical relationship between these two parameters with the occupancy time and consequently compared with that of the lagging headway method. It was observed that a logarithmic relationship exists between occupancy time and the central diameter of the roundabout and an exponential relationship between occupancy time and circulating flow (PCU/h) with an acceptable coefficient of determination (R^2) value in comparison to lagging headway. The relationship of how the occupancy time varies with the central diameter of the roundabout is represented by equation (4)

$$OT_i = \alpha_i - kln(\beta) \tag{4}$$

The above-obtained equation is a linear-log regression model where OT_i is the response variable, and represents the occupancy time of subject vehicle 'i', 'β' is the predictor variable in the equation and represents the geometric parameter of the roundabout (central diameter), the constant 'α_i' and, 'k' are known as regression coefficients, and they refer to the base value of occupancy time for vehicle type 'i', and, the factor which acts as an adjustment to the central diameter of roundabouts respectively.

Similarly, the relationship obtained for variation of occupancy time with circulating flow (PCU/h) is given by equation (5) as

$$OT_i = \sigma e^{(kf)} \tag{5}$$

The above equation delineates that the variation of occupancy time with circulating traffic flow is exponential in nature in which OT_i is the response variable, and represents the occupancy time of subject vehicle 'i', 'f' is the predictor variable which represents the circulating flow (PCU/h) at the roundabout, and 'k' is the adjustment factor to circulating flow. The relationship for occupancy time has been depicted in Table 8 and Table 9 for central diameter and circulating flow (PCU/h) respectively.

Table 8: Relationship between Occupancy time (s) and Central diameter (m)

Vehicle type	Relation	R^2
	$\mathbf{OT_i = \alpha_i - kln(\beta)}$	
2W	$OT_{2W} = 11.8 - 1.4\ln(\beta)$	0.63
3W	$OT_{3W} = 20.8 - 3.4\ln(\beta)$	0.80
SC	$OT_{SC} = 29.3 - 5.3\ln(\beta)$	0.67
BC	$OT_{BC} = 33.3 - 6.2\ln(\beta)$	0.79
HV	$OT_{HV} = 32.4 - 5.5\ln(\beta)$	0.68

Table 9: Relationship between Occupancy time (s) and Circulating flow (PCU/h)

Vehicle type	Relation	R^2
	$\mathbf{OT_i = \sigma e^{(kf)}}$	
2W	$OT_{2W} = 10.9\, e^{(-3\times10^{-4}f)}$	0.57
3W	$OT_{3W} = 24.3\, e^{(-6\times10^{-4}f)}$	0.87
SC	$OT_{SC} = 35.9\, e^{(-7\times10^{-4}f)}$	0.82
BC	$OT_{BC} = 43.1\, e^{(-8\times10^{-4}f)}$	0.93
HV	$OT_{HV} = 39.1\, e^{(-7\times10^{-4}f)}$	0.94

The variation of occupancy time and lagging headway with the central diameter and circulating flow (PCU/h) are shown in Figures 6 and 7 respectively. As both occupancy time and lagging headway have similar variations with the central diameter and circulating flow (PCU/h) at the roundabout, it can be seen that occupancy time follows a strong trend of variation with a satisfactory R^2 value.

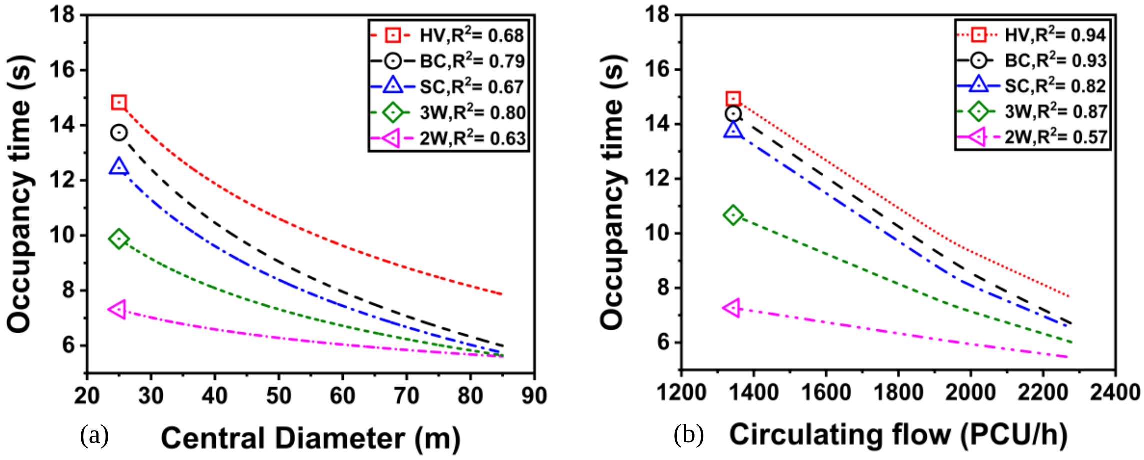

Figure 6: Variation of Occupancy time with: (a) Central diameter; (b) Circulating flow (PCU/h).

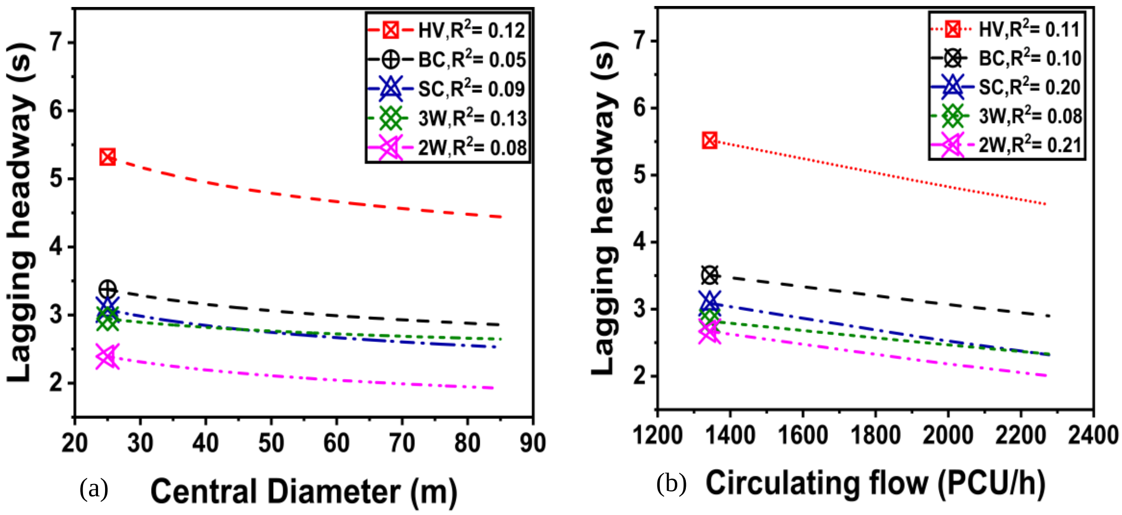

Figure 7: Variation of Lagging headway with: (a) Central diameter; (b) Circulating flow (PCU/h).

Figures 8(a) and 8(b) show a linear relationship existing between the occupancy time of 2W and the central diameter of the roundabout and circulating flow (PCU/h) as represented in equations (4) and (5) respectively. To validate and establish these relationships, the regression analysis of the transformed variables was employed. Prior to performing regression, standard assumptions were checked, including linearity, independence, homoscedasticity, and normality of residuals, to ensure the validity of the regression model. The coefficients (α, k) and (σ, k) served to quantify the strength and nature of the linear relationships between occupancy time and the key influencing factors of central diameter and circulating flow, respectively. The coefficients (α, k) and (σ, k) can be found using best-fit regression analysis. Then the proposed formulation for Occupancy Time (OT) with circulating flow is given in equations (6) and (7). Moreover, Figures 8(a) and 8(b) depict the fitting lines representing the relationships between occupancy time and central diameter, as well as occupancy time and circulating flow, with corresponding best-fit R^2 values of 0.63 and 0.57, respectively. These values are consistent with the results presented in Tables 8 and 9, further validating the derived models. A similar approach was used for other vehicle classes also.

$$ln(OT) = \ln(\sigma) + kf \quad (6)$$

$$Thus, \; OT = \sigma e^{(kf)} \quad (7)$$

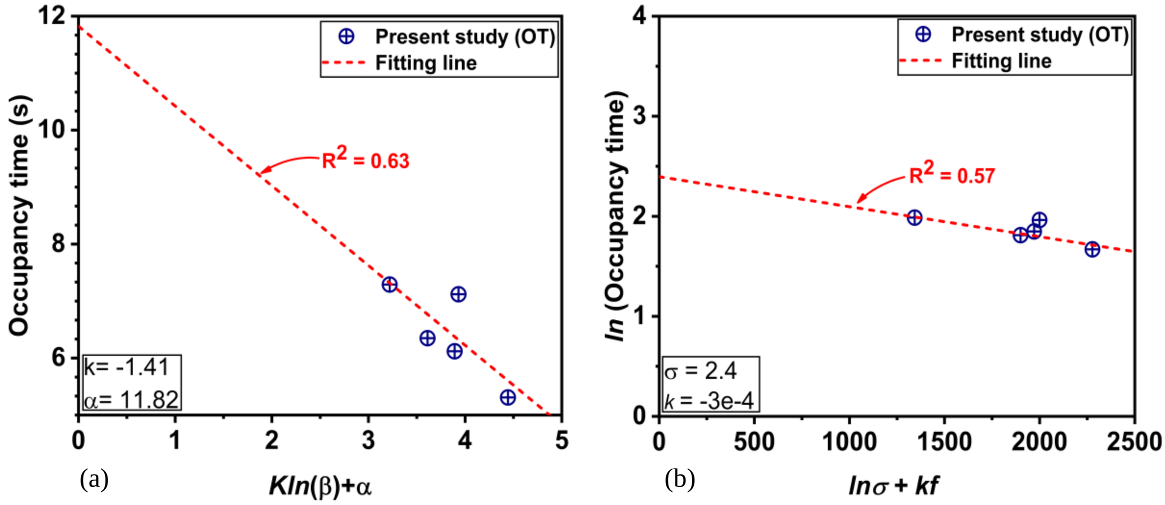

Figure 8: Best-fit regression equation for the determination of coefficients.

6. Conclusions

For the study of facilities in diverse traffic conditions, PCU factors are of paramount significance because they allow for the conversion of various vehicle categories into an equal number of passenger cars. PCU calculation at unsignalized intersections has received very little attention despite the fact that many studies have been done on the measurement of these variables at signalized intersections and along roadways.

The paper presents an attempt to adopt a different methodology (Occupancy time method) than what is being currently used (Lagging headway method) and compares it with the same. For this study, five urban roundabouts were selected in the city of Chandigarh, India that were operating under heterogeneous traffic conditions. The selected roundabouts were free from any sort of side friction, bus stops, and gradients. It was observed that the occupancy time of subject vehicles relied more on the geometrical and traffic flow parameters than the lagging headway, as the same was calculated and a correlation analysis was found. It was further investigated that the occupancy time of subject vehicles had a strong correlation with the central diameter and circulating flow calculated in PCU/h with the corresponding roundabout. Consequently, a mathematical relationship was developed with the central diameter and circulating flow (PCU/h), and it was observed that occupancy time varied logarithmically with the central diameter of the roundabout and exponentially with the circulating flow (PCU/h) at the roundabout.

The PCU of a vehicle is a complicated metric that is determined by all of the variables that have an effect on the way a vehicle behaves in the flow of traffic. The manner in which it was derived is another factor to consider. It was also thus concluded that PCU values determined by occupancy time are dynamic in nature and varied with the specifications of individual roundabouts. Taking into cognizance of lane indiscipline under heterogeneous traffic scenarios, the occupancy time presents better, more logical, and rational values of PCU than lagging headway.

7. Limitations and future scope

The proposed predictive models for occupancy time were developed based on linear relationships, which, while effective for initial approximations, may oversimplify the intricate interactions among geometric, traffic, and driver behavior factors at roundabouts. Additionally, the study did not explore the influence of critical variables such as vehicle composition, driver characteristics, or environmental conditions, which could significantly affect occupancy time and PCU values. Future research could address these limitations by developing more sophisticated predictive models capable of capturing nonlinear and interactive effects of various factors, thereby improving accuracy and robustness. Moreover, investigating the impacts of vehicle composition, driver characteristics, and environmental conditions could provide valuable insights and facilitate the integration of these variables into advanced modeling frameworks. Conducting sensitivity analyses and field validations would further enhance the reliability and transferability of these models across diverse geographic regions and traffic conditions. Such efforts would not only strengthen the predictive power and applicability of the models but also contribute to a more comprehensive understanding of roundabout performance under varying real-world conditions.

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