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RESEARCH ARTICLE

Passenger Car Unit Estimation at Signalized Intersection for Non-lane Based Mixed Traffic Using Microscopic Simulation Model

Gowri Asaithambi[1*], Hayjy Sekhar Mourie[1], Ramaswamy Sivanandan[2]

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Abstract

In India, traffic on roads is mixed in nature with widely varying static and dynamic characteristics of vehicles. At intersections, vehicles do not follow ordered queue and lane discipline. Different vehicle types occupy different spaces on the road, move at different speeds, and start at different accelerations. The problem of measuring volume of such mixed traffic has been addressed by converting different vehicles categories into equivalent passenger cars and expressing the volume in terms of Passenger Car Unit (PCU) per hour. The accurate estimation of PCU values for different roadway and traffic conditions is essential for better operation and management of roadway facilities. Hence, the objective of the present study is to estimate the PCU values at signalized intersection in mixed traffic and to study the influence of traffic volume, traffic composition and road width on PCU values.

For this purpose, a mixed traffic simulation model developed specifically for a signalized intersection was used. The model was calibrated and validated with the traffic data collected from a signalized intersection in Chennai city. Simulation runs were carried out for various combinations of vehicular composition, volume levels and road width. It was observed that presence of heavy vehicles and increase in road width affects the PCU values. The obtained PCU values were statistically checked for accuracy and proven to be satisfied. The PCU values obtained in this study can be used as a guideline for the traffic engineers and practitioners in the design and analysis of signalized intersections where mixed traffic conditions exist.

Keywords

Passenger Car Unit, Signalized Intersection, Mixed Traffic, Non-lane Discipline, Microscopic Simulation

[1]Department of Civil Engineering
National Institute of Technology Karnataka, Surathkal
Mangalore-575025, India
[2]Department of Civil Engineering,
Indian Institute of Technology Madras,
Chennai-600036, India
[*]Corresponding author, e-mail: gowri_iitm@yahoo.co.in

1 Introduction

Traffic volume is an important input required for planning, analysis, design and operation of roadway systems (Tettamanti et al., 2015). Highway capacity values and saturation flow is used for planning, design and operation of roadways, in most of the developed countries, pertain to fairly homogeneous traffic conditions comprising vehicles of more or less uniform static and dynamic characteristics. But the traffic conditions in developing countries like India differs significantly from the conditions of developed countries in many respects. In India, traffic is highly mixed in nature with vehicles of widely varying static and dynamic characteristics. Under these conditions, it becomes difficult to make the vehicles to follow traffic lanes. Consequently, the vehicles tend to occupy any available road space and particularly, smaller size vehicles use the gap between large vehicles. Under the said traffic conditions expressing traffic volume as number of vehicles passing a given section of road per unit time will be inappropriate and some other suitable method needs to be adopted for the purpose. The problem of measuring volume of such mixed traffic has been addressed by converting the different types of vehicles into equivalent passenger cars and expressing the volume in terms of Passenger Car Unit (PCU) per hour.

Intersections are locations on road networks with varying geometry where diversity can be observed in the case of vehicle manoeuvres, and in parameters related to signal phasing like shared lanes. The signal cycle and the corresponding green times are decided by many factors, out of which saturation flow is the most important. The saturation flow is usually expressed in vehicles per hour of green time. This unit causes difficulty in quantifying the flows at signalized intersections in cases where heterogeneity is high. Establishing a common platform is necessary for the representation and estimation of traffic characteristics like saturation flow, and this is accomplished by passenger car units at intersections. Since the traffic flow phenomenon is influenced by several stochastic variables of random nature, micro simulation technique has been found to be a versatile tool to model complex traffic systems for study of their characteristics over a wide range of operating conditions.

This study attempts to develop PCU values by analyzing the typical nature of mixed traffic at signals using a microscopic simulation model with the following specific objectives:

- To estimate the PCU values at signalized intersection using microscopic simulation model
- To study the effects of traffic volume, composition and road width on PCU values
- To check the accuracy of estimated PCU values

The rest of the paper is structured as follows: Section 2 focuses on the detailed review of literature on PCU studies. Section 3 describes the simulation model and the logics. Section 4 explains the calibration and validation of the model from the data collected from a signalized intersection in Chennai city, India. Section 5 describes the procedure for determination of PCU values for the signalized intersection and also, discuss about the effect of volume, composition and road width on PCU values. Section 6 explains the procedure for checking the accuracy of PCU values followed by summary and conclusions section.

2 Review of Earlier Studies

From the literature review, it was found that there are various approaches available for estimation of PCU values for mixed traffic conditions such as time headway method (Saha et al., 2009), simulation method (Arasan and Krishnamurthy, 2008), regression method (Adams et al., 2014), optimization method (Radhakrishnan and Mathew, 2011) and other methods (Shalini and Kumar, 2014). Arasan and Vedagiri (2006) estimated the saturation flow based on classified count and studied the effect of width on saturation flow using a simulation model. Radhakrishnan and Mathew (2011) analyzed saturation flow at a microscopic level. In this paper, a new model for saturation flow is developed and PCU values are estimated using the optimization method. The emphasis of this paper is more on the methodology for obtaining dynamic PCU values and saturation flow model than on the PCU values and the model themselves. Arasan and Arkatkar (2008) studied the effect of volume and road width on PCU of vehicles under mixed traffic on mid-block sections using a simulation model. The problem of measuring traffic volume is discussed and the PCU estimation is done based on speeds. The PCU values estimated for different types of vehicles, for a wide range of traffic volume and roadway conditions, have proven that the PCU value of a vehicle significantly changes with change in traffic volume and width of roadway.

Parvathy et al. (2013) compared two methods (time headway method and regression method) for estimation of PCU values. Firstly, an attempt was made to learn the characteristics of mixed traffic flow at signalized intersections and then an empirical study was carried out to determine the PCU values for various types of vehicles. They concluded that for signal design purpose or to determine the saturation flow rate, PCU values applicable to current conditions need to be developed instead of depending on the old PCU values given in Indian Road Congress (IRC) code. Adnan (2011) described whether the passenger car equivalent factors used in mixed traffic environment are the right numbers. PCE factors are estimated based on four methods such as time headway based method, traffic stream speed based, method based on multiple regression analysis and headway and values obtained are compared with each other. Out of the four methods the time headway method and speed method are found to be more appropriate. However further investigations are recommended to be necessary to examine behaviour of different type of vehicles, which may lead to appropriate values of PCE factors.

The review of literature reveals that PCU studies were carried out mostly for mid-blocks and only limited studies on signalized intersections were done under mixed traffic conditions. However, there are only few attempts to study the impact of various factors such as traffic volume, road width and composition on PCU studies. Hence, the present study focuses on estimation of PCU values at signalized intersection using microscopic simulation model and to study the influence of traffic volume, composition and road width on PCU values.

3 Simulation Model

The road traffic in India is highly mixed comprising vehicles of wide ranging static and dynamic characteristics and all vehicles share the same road space. There is a lack of lane discipline and vehicles occupy any lateral position on the road depending on the availability of space. The available simulation model (Asaithambi et al., 2009) specifically developed for a signalized intersection under mixed traffic conditions was used. The model was implemented in C++ programming language using Object Oriented Programming (OOP) concepts. Basic logical aspects involved in the program (Fig. 1) are explained in the following sections:

3.1 Vehicle Generation

Vehicles are generated at the starting point of the simulation road stretch based on semi parametric distribution. The type of vehicle is identified based on a random number generated and compared with the cumulative composition of each type of vehicle. The generated vehicle is assigned with the type of turning movement (straight through, left turning and right turning vehicles) by generating a random number and compared with the cumulative composition of each type of turning movement. The generated vehicle is assigned with free speed. The speed of vehicles on the simulation road stretch is based on two assumptions: (a) vehicle speeds will not be allowed to exceed their free speeds in the entire stretch, and (b) the vehicles are entering the simulation stretch at their free speeds. The free speeds of vehicles follow normal distribution. The standard normal deviates are generated using Box-Muller transformation method.

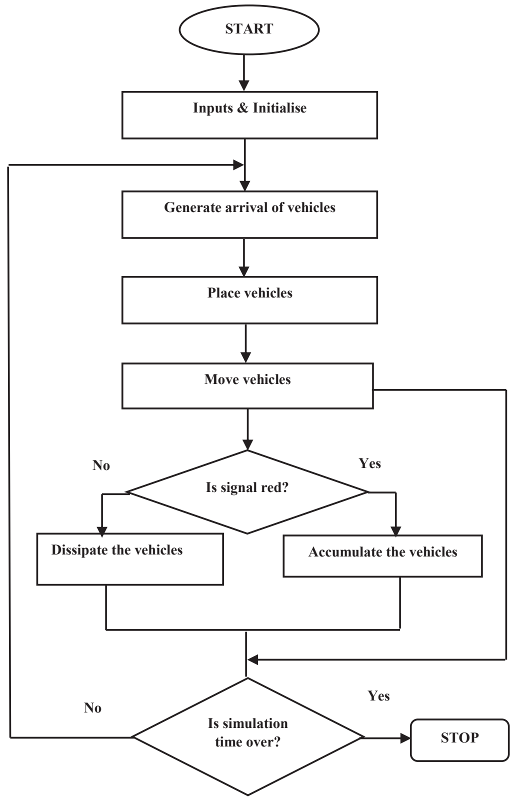


Fig. 1 Overview of the Simulation Framework

3.2 Vehicle Placement

Vehicle placement is based on availability of longitudinal and transverse spacing's. Vehicles can move more freely and faster nearer to the median. So, they are placed from right edge to left edge of the road stretch. Longitudinal and transverse spaces of vehicles are determined based on their current speeds. The vehicles check the longitudinal and transverse spaces progressively from right edge to left edge of the road stretch. The vehicle first looks for longitudinal and transverse spaces in right most section of the road stretch. If spaces are inadequate, it looks for similar spaces towards the left. If spaces are insufficient here too, then the subject vehicle reduces its speed to that of its leader based on car following rule. Again, similar checks for spaces are made, beginning from right-most edge.

3.3 Vehicle Movement

In this simulation model, vehicle accelerates up to free speed if there is no slow vehicle in front of it. The position of vehicle is updated based on the equations of motion.

When there is a slow moving vehicle in front of the subject vehicle overtaking logic is invoked. Left or right overtaking is performed based on the position of centre line of overtaking vehicle. If the centre line of the overtaking vehicle is on the right side of the centre line of the overtaken vehicle, then the overtaking vehicle looks for availability of transverse and longitudinal spaces on the right side of the overtaken vehicle. If spaces are adequate on the right side, right overtaking is performed; if not, the overtaking vehicle looks for availability of such spaces on the left side, and if available, left overtaking is performed. If lateral spacing is inadequate on both sides, overtaking is not performed and car following logic is invoked. In car following logic, the speed of the subject vehicle is reduced to the speed of lead vehicle, maintaining a safe spacing from it.

3.4 Vehicle Accumulation

When the vehicles approach the intersection, their behavior is based on the direction and status of signal (red or amber or green). If the intersection signal is red, the vehicles arriving near the intersection accumulate on the road based on the avail¬ability of spacing and type of turning movement. Logic used in the accumulation process is based on the assumption that vehicles will try to occupy positions as closer to the stop line as possible. Since vehicles in mixed traffic do not generally stick to their lanes, left turning, straight through and right turning vehicles accumulate on the approach haphazardly, ignoring designated lanes. The vehicles are placed on the road to occupy logical positions starting from the left side of the road, except right turning vehicles. If the signal is amber, then those vehicles which have already entered the intersection accelerate and clear the intersection. The vehicles which are before the stop line will start to decelerate based on their deceleration rates.

3.5 Vehicle Dissipation

If the intersection signal is green, vehicles waiting at the intersection approach start dissipating. Initially, the current speed of all the accumulated vehicles is zero. The position of all the vehicles is updated using equations of motion. Three maneuvers are possible for individual vehicles when the vehicles clear the intersection area: free movers, overtakers and followers.

4 Model Calibration and Validation

Data for this study were collected at a signalized intersection in Ashok Nagar intersection, Chennai city, India (Fig. 2). The data was collected using video graphic method during peak periods on three consecutive week days. Traffic composition of the intersection shows that two wheeler proportion is higher (71%) followed by cars (17%) for the observed volume of 4000 veh/h. The total cycle time of the study intersection is 135 seconds and the actual green time available is 55 seconds, amber time is 4 seconds and red time is 76 seconds.

The parameters such as free speeds, deceleration data, dissipation data, longitudinal spacing and vehicle accumulation, have been used to calibrate the model. The model was validated by examining the observed and simulated values of saturation flow (number of vehicles crossing the stop line during saturated green time) for a volume level of 4000 veh/h for 25 signal cycles. Table 1 gives a comparison of simulated and observed values. The critical value of statistic (t critical) for 0.05 level of significance and 24 degrees of freedom from standard distribution table is ±2.064. It is seen that the value of t statistic

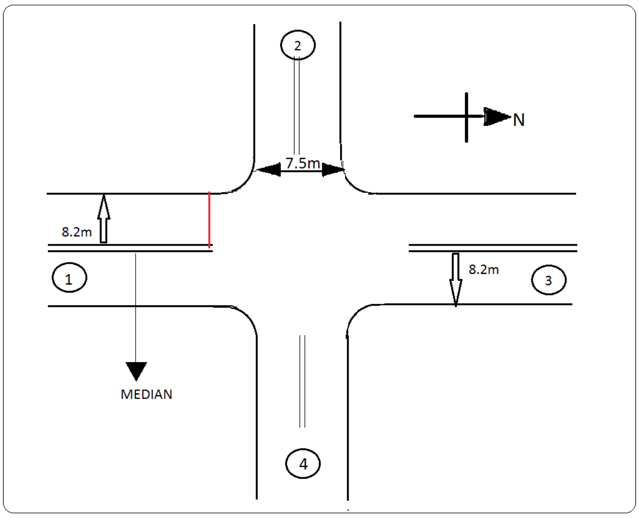


Fig. 2 Layout of the study intersection located at Chennai city

Table 1 Comparison between observed and simulated values of saturation flow

Signal Cycle	Saturation Flow		Difference
	Observed	Simulated	
1	104	124	20
2	95	125	30
3	84	143	59
4	94	104	10
5	105	119	14
6	115	126	11
7	118	132	14
8	110	124	14
9	114	148	34
10	138	118	-20
11	117	139	22
12	117	123	6
13	132	131	-1
14	120	122	2
15	137	131	-6
16	115	125	10
17	98	125	27
18	109	121	12
19	121	117	-4
20	135	151	16
21	178	156	-22
22	138	157	19
23	160	124	-36
24	114	123	9
25	156	128	-28
Sum			**212**

d_{mean} = Mean of observed difference = 212 / 25 = 8.48
t statistic of observed values, $t_0 = d_{mean} / (s_d / \sqrt{n})$,
where, n = no.of observations = 25
s_d^2 = 11958 / (n-1) = 11958 / 24 = 498.3
Where s_d is the standard deviation; s_d = 22.32
$t_0 = d_{mean} / (s_d / \sqrt{n})$
Therefore, $t_0 = 8.48 / (22.32 / \sqrt{25}) = 1.89$

calculated based on the observed data (t_0) is between the corresponding table values. This shows that the simulated are not significantly different from the observed values.

5 Determination of PCU Values

The PCU values were estimated using time headway method with the help of simulation model. In this method, headways of the vehicles crossing the stop line of the intersection are used to calculate the PCU values. The following condition should be satisfied to calculate the PCU values by the headway ratio method (Saha et al., 2009). It involves a comparison of two sides of Eq. (1) as below:

$$h_{c-c} + h_{x-x} = h_{c-x} + h_{x-c} \tag{1}$$

Where, h_{c-c} = Average headway of a car followed by a car; h_{c-x} = Average headway of a car followed by a type x vehicle; h_{x-c} = Average headway of a type x vehicle followed by a car; h_{x-x} = Average headway of a type x vehicle followed by a type x vehicle.

For those headway samples that do not exactly fulfil the independence condition, a corrective factor needs to be applied. The corrective factor (C) using the least square method is given in Eq. (2):

$$C = \frac{abcd(w-x-y-z)}{abc+abd+acd+bcd} \tag{2}$$

Where, a = Number of headways for car following car; b = Number of headways for car following type x vehicle; c = Number of headways for type x vehicle following car; d = Number of headways for type x vehicle following type x vehicle; w = Mean headways for car following car; x = Mean headways for car following type x vehicle; y = Mean headways for type x vehicle following car; z = Mean headways for type x vehicle following type x vehicle.

Equation (3) represents the adjusted mean headways for a car following a car:

$$h_{A(c-c)} = U - \frac{C}{No.\ of\ headways\ car\ following\ car} \tag{3}$$

Where, ($h_{A(c-c)}$) = Adjusted mean headways for car following car;U = Uncorrected mean headway; and C = Correction factor

The adjusted mean headways for vehicle type x following vehicle type x can be represented as in Eq. (4):

$$h_{A(x-x)} = U - \frac{C}{No.\ of\ headways\ vehicle\ type\ x\ \ following\ vehicle\ type\ x} \tag{4}$$

Where, ($h_{A(x-x)}$) = Adjusted mean headways for vehicle type x following vehicle type x

Note that passenger car unit for through vehicles compares the headways for a given vehicle type with cars travelling straight through the intersection. Hence, the PCU is calculated using Eq. (5):

$$PCU_{(x-x)} = \frac{h_{A(x-x)}}{h_{A(c-c)}} \quad (5)$$

Where, ($h_{A(c-c)}$) = Adjusted Mean headway of a car followed by a car; ($h_{A(x-x)}$) = Adjusted Mean headway of a type x vehicle followed by a type x vehicle.

Table 2 represents the PCU values for observed volumes using the procedure explained above. Comparing the PCU values of IRC values (IRC SP-41, 1994), it can be observed that the values are different and there are variations based on size of vehicle.

Table 2 Observed values of PCU

Type of Vehicle	Current study	IRC
Two Wheelers	0.40	0.5
Auto-Rickshaws	0.73	1.0
Light Commercial Vehicles	1.3	1.4
Heavy Vehicles	2.06	3.0

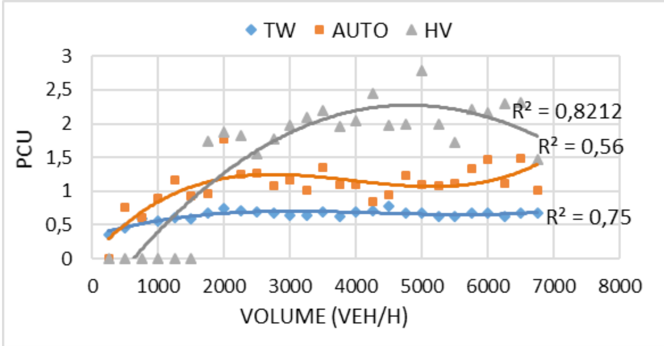
The effect of following factors on PCU values were studied using sensitivity analysis:

1. Total approach volume: varied from 250 veh/h to 4000 veh/h in increments of 250 veh/h.
2. Four level of compositions (Asaithambi et al., 2012)
   I. Composition 1 (C1):70% two-wheelers (TW), 17% cars, 11% auto-rickshaws (AUTO), 2% heavy vehicles (HV) -observed
   II. Composition 2 (C2): 50% two-wheelers, 14% cars, 34% auto-rickshaws, 2% heavy vehicles
   III. Composition 3 (C3): 30% two-wheelers, 50% cars, 15% auto-rickshaws, 5% heavy vehicles
   IV. Composition 4 (C4): 30% two-wheelers, 45% cars, 10% auto-rickshaws, 15% heavy vehicles
3. Three lane widths: 1.Two lane (8.2 m) 2. Three lane (10.5 m) 3. Four lane (14 m)

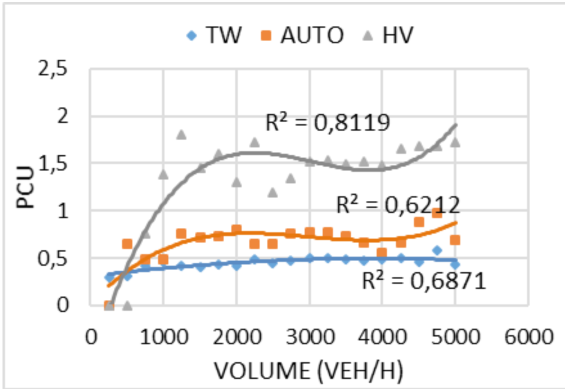
5.1 Effect of Volume on PCU Values

The PCU values of different categories of vehicles were estimated by simulating traffic flow with different compositions and different lane widths with volume levels varying from 250 veh/h up to the capacity in increments of 250 veh/h. PCU values versus traffic volume for the observed composition 1 and three road widths are plotted and shown in Fig. 3.

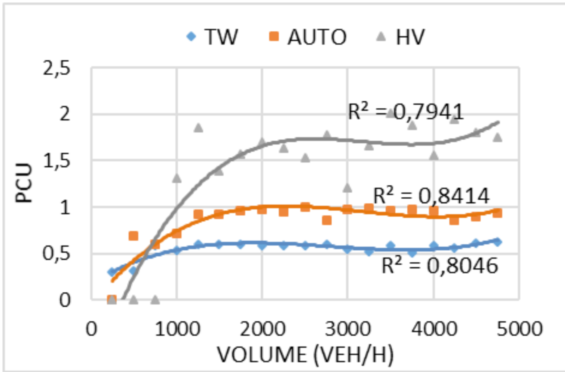
The percentage composition of the light commercial vehicles, buses and trucks were lower, so these three vehicle categories are combined and taken as heavy vehicle. It can be observed that for two-wheelers and auto-rickshaws, PCU values increases gradually with increase in traffic volume up to certain volume and after that it starts decreasing for all road widths and compositions. For all road widths and compositions 1 and 2, PCU values of heavy vehicles, two-wheelers and auto-rickshaws follow the same pattern but for composition 3 and composition 4, the trend is reverse. This is observed due to presence of higher percentage of heavy vehicles in traffic. The graphs plotted between volume and PCU followed a third degree polynomial relation.



a) Road Width – 8.2 m



b) Road Width – 10.5 m

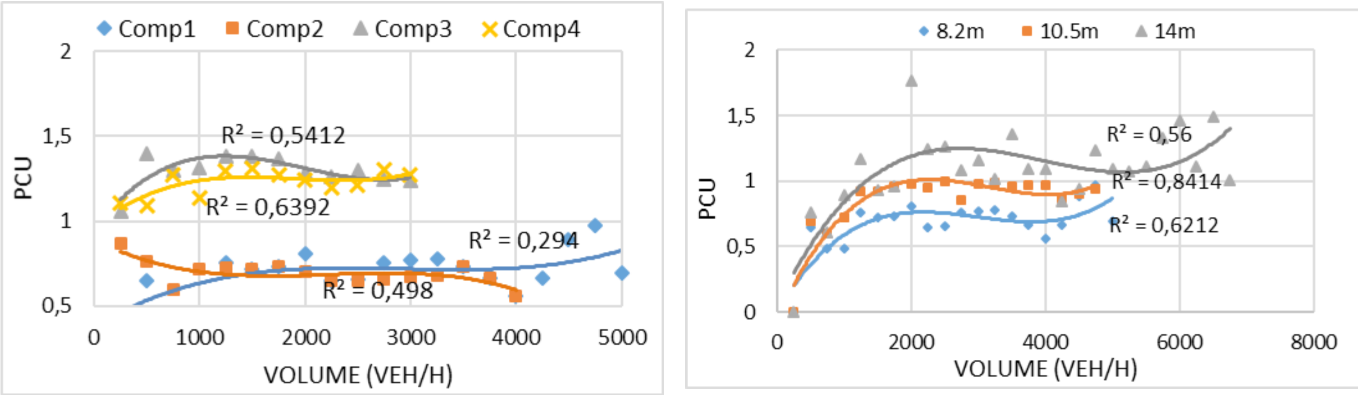


c) Road Width-14.0 m

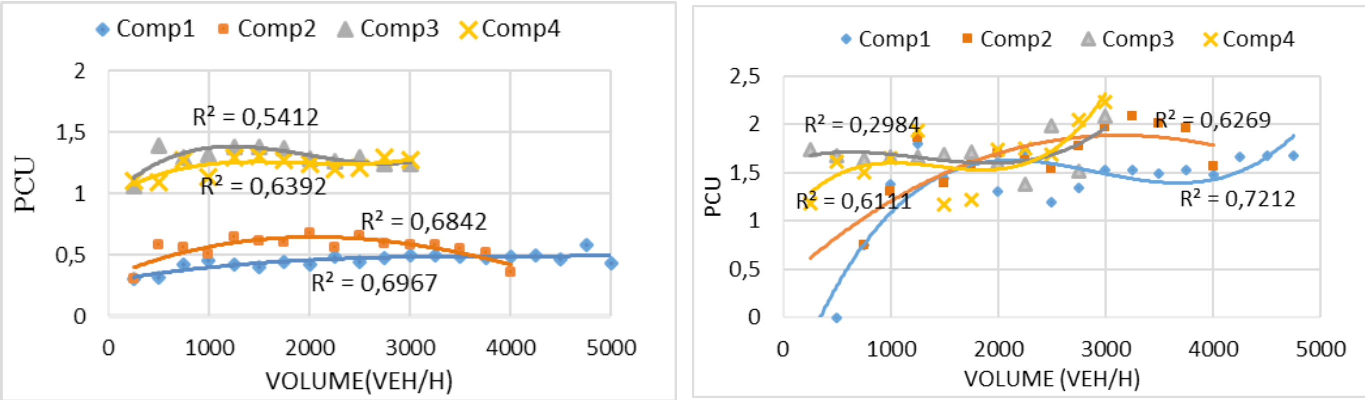
Fig. 3 PCU Values Vs Volume for Composition 1

5.2 Effect of Composition on PCU Values

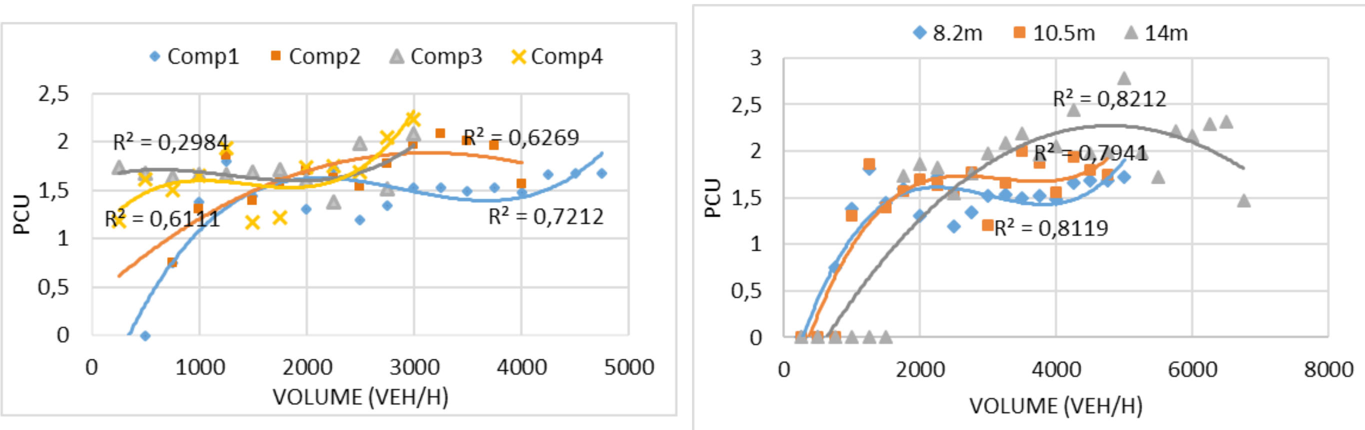
From past researches, it is clear that the traffic flow parameters were influenced by the degree of heterogeneity of traffic stream. The change in the traffic condition makes the vehicles to offer varying amount of impedance to the movement of adjacent vehicles in the traffic stream, depending upon the varying



a) Two wheelers



b) Auto rickshaws



c) Heavy vehicles

Fig. 4 PCU values Vs traffic composition for 8.2 m road width

composition. The PCU values of the different categories of vehicles were estimated by simulating traffic flow with compositions 1, 2, 3 and 4 for different lane widths and varying volume levels. Figure 4 shows the PCU values for various vehicle types for different compositions on 8.2 m road width. Graphs plotted followed a third degree polynomial relation.

In this analysis, it can be seen that the PCU of two wheelers decrease with increase in the percentage of two wheelers (due to higher number of lateral movements by two-wheelers) and increase with increase in percentage of heavy vehicles (due to lower operating characteristics and reduction in number of lateral movements) for all road widths (8.2 m, 10.5 m and 14 m). In compositions 1 and 2, due to larger number of lateral movements of two-wheelers, PCU values are lower compared to compositions 3 and 4, where the PCU values are higher due to larger proportion of heavy vehicles and cars. In case of auto-rickshaws for compositions 3 and 4, PCU values are higher compared to compositions 1 and 2 due to their higher proportion. By comparing the different compositions, it can be said that at higher compositions of heavy vehicles, the PCU values for heavy vehicles are high.

5.3 Effect of Width on PCU Values

Since the capacity of a roadway section varies with its width, the PCU values on these roads needs to be compared based on some common traffic flow criterion. For this purpose, volume is selected as the traffic flow criterion common to different widths of roads. In order to make the above comparison, the PCU values of different vehicle types were estimated for varying volumes (250 veh/h to capacity) corresponding to the composition and road width.

At a given volume level, PCU value of a vehicle type increases with increase in width of road. There has been marginal increase in magnitude of PCU values on 14 m road width when compared to the corresponding values on 10.5 m road. Similarly, there is marginal increase in the PCU values on 10.5 m wide road when compared with 8.2 m road. The relationship between road width and PCU followed a third degree polynomial relation. It was found that for the given volumes, PCU values increase with increase in the width of road space. The reason for this may be attributed to the fact that when vehicles do not follow traffic lanes and occupy any lateral position on the road space, the manoeuvering process becomes relatively easier on wider roads facilitating faster movement of vehicles in turn creating larger gaps. The increase in width of roadway invariably provides relatively higher manoeuvrability for all vehicle types on wider roads.

5.4 Multiple Linear Regression Model for PCU Estimation

The results obtained from simulation model can be used to estimate the PCU values of different classes of vehicles in mixed traffic, given the traffic volume, traffic composition and road width. For each road width, the simulation model was run to get the PCU values of each category of vehicle for each of the four sets of compositions and three levels of road widths. PCU is considered as a dependent variable and variables corresponding to traffic composition and road width were considered as independent variables. The functional relationship is given as follows:

$$PCUi = ai + b1i.TV + b2i.\ TW + b3i.\ Car + b4i.\ AUTO + b5i.HV + b6i.RW \tag{6}$$

Where PCU*i* – PCU value of the vehicles of class *i*; *TV* – traffic volume in vph; *TW* – the proportion of two-wheelers in %; *Car* - the proportion of cars in %; *AUTO* – the proportion of auto-rickshaws in %; *HV* – the proportion of heavy vehicles in %; *RW* – the road width in m*; b1i, b2i, b3i, b4i, b5i, b6i* –coefficients corresponding to the independent variables.

Different functional forms were tested for regression models and linear regression provided reasonable goodness-of-fit. The results of multiple linear regression models relating the PCU of different vehicle classes to traffic volume, traffic composition and road width corresponding to the goodness of fit are shown in Table 3 indicating that the value of determination coefficient (R^2) is high and the models are statistically significant. The model parameters were also found to be statistically significant using the t-test at 5% significance level. When the road width increases, PCU values of vehicles are getting increased for all types of vehicles. When the volume increases, the PCU values are getting decreased in the case of TW and Auto-rickshaws whereas it increases for heavy vehicles. When the proportion of each category of vehicles increase, PCU values are getting decreased generally. The coefficients indicate that PCU value for two-wheeler and auto-rickshaw does not depend on the proportion of cars similarly PCU value of heavy vehicles does not depend on proportion of heavy vehicles.

Table 3 Regression Model - Estimated coefficients and Statistics

PCU Value	Variables	Coefficients	t-stat	p-value	R^2
TW	Constant	2.07	27.192	0.000	0.90
	Volume	-0.00002	-3.241	0.001	
	TW	-0.02	-27.859	0.000	
	AUTO	-0.02	-16.160	0.000	
	HV	-0.01	-4.003	0.000	
	Road Width	0.03	7.755	0.000	
AUTO	Constant	1.77	18.222	0.000	0.77
	Volume	-0.00001	-1.793	0.070	
	TW	-0.02	-13.288	0.000	
	AUTO	-0.02	-15.415	0.000	
	HV	-0.02	-3.708	0.000	
	Road Width	0.04	7.724	0.000	
HV	Constant	2.20	4.555	0.000	0.44
	Volume	0.00007	5.094	0.000	
	TW	-0.01	-2.670	0.008	
	Car	-0.01	-1.296	0.200	

6 Check for Accuracy of PCU Values

The check for the accuracy of PCU estimates is done by simulating homogeneous (cars-only) traffic and mixed traffic flows for all three road widths and four compositions. For this purpose, cars-only traffic flow and mixed traffic were simulated on 8.2 m wide road space for composition1. The volumes obtained for cars-only traffic was 2670 cars per hour and for mixed traffic was 2680 vehicles per hour. Similarly, the cars-only traffic volume and mixed traffic volumes are generated for all volume levels up to the capacity level for three road widths and four compositions.

The volume of mixed traffic in PCU per hour were obtained by multiplying the number of vehicles in each category with the corresponding PCU values. From the analysis, it was observed that the mixed and homogeneous traffic flow values are closely related to each other indicating PCU estimates made are fairly accurate. To explain the accuracy of estimates on statistical basis, paired t test was done at 5% level of significance by relating the flow in number of cars per hour with the corresponding mixed traffic flow expressed in PCU per hour. Table 4 shows the t test values for different combinations of road width and compositions. From the table, it can be observed that observed t value (t_0) lies between the range obtained from standard t-distribution table ($t_{critical}$) except for cases where lesser headways obtained for autos and heavy vehicles at low volume levels. Based on the statistical test, it was concluded that the estimated PCU values are accurate. This implies that, there is no significant difference between the traffic volumes measured in terms of passenger cars and in PCU.

Table 4 *t*-test values for comparison of mixed traffic and cars only traffic

Road Width (m)	Composition	t_0	$t_{critical}$
8.2	C1	2.02	±2.101
	C2	2.15	±2.131
	C3	-0.47	±2.201
	C4	-2.18	±2.201
10.5	C1	1.99	±2.201
	C2	2.03	±2.110
	C3	-2.12	±2.160
	C4	-1.42	±2.179
14	C1	2.20	±2.056
	C2	3.10	±2.060
	C3	-2.02	±2.093
	C4	-2.03	±2.093

7 Summary and Conclusions

A microscopic simulation model is used to estimate the passenger car units (PCU) for different types of vehicles at signalized intersections in mixed traffic using the time headway ratio method. The model was calibrated and validated with the field data collected at a signalized intersection located in Chennai city, India. PCU values for three vehicle categories such as two wheelers, auto rickshaws and heavy vehicles were estimated. Then, the effect of traffic volume (low volume to high volume), composition (four levels) and road width (8.2 m, 10.5 m and 14 m) on PCU values were studied. A multiple linear regression model was developed to predict the PCU values of each class of vehicle for known traffic volume, composition and road width. The check performed to ascertain the accuracy of the PCU estimates (by comparing the flow of cars only and the PCU equivalent of mixed traffic) for different compositions and road widths indicate that the estimates are fairly accurate. The key conclusions drawn based on this study are:

1. The PCU estimates obtained for the different types of vehicles of mixed traffic and wide range of traffic volume levels indicate that the PCU value of a vehicle significantly changes with change in traffic volume.
2. It was found that at low volume levels, the PCU value of vehicles increases with increases in traffic volume, whereas under higher volume conditions the PCU value decrease with increase in traffic volume.
3. From the study of effect of compositions on PCU, it was observed that the values of PCU values are affected as the percentage of heavy vehicles increase.
4. The study of effect of road width on PCU values indicate that for any vehicle type in mixed traffic, the PCU value increases with increase in the width of road space.

The study findings concluded that PCU values of a vehicle type has to be treated as a dynamic value rather than a static value. The dynamic PCU estimates obtained from this study will be useful to estimate the capacity of signalised intersections with similar roadway and traffic characteristics under Indian traffic conditions. Also, these insights will be useful to the traffic engineers and practitioners in studying the variations of saturation flow and capacity at a signalized intersection.

References

Adams, C. A., Zambang, M. A. M., Boahen, R. O. (2014). Passenger car unit values for urban mixed traffic flow at signalized intersections on two lane dual carriageways in the Tamale metropolis, Ghana. *International Journal of Engineering and Science*. 3(5), pp. 41-49.

Adnan, M. (2014) Passenger car equivalent factors in heterogeneous traffic environment – are we using the right numbers? *Procedia Engineering*. 77, pp. 106 – 113. https://doi.org/10.1016/j.proeng.2014.07.004

Arasan, V., Arkatkar, S. (2008). Micro simulation study of effect of volume and road width on PCU of vehicles under heterogeneous traffic. *Journal of Transportation Engineering*. 136(12), pp. 1110-1119. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000176

Arasan, V. T., Krishnamurthy, K. (2008) Effect of traffic volume on PCU of vehicles under heterogeneous traffic conditions. *Road and Transport Research Journal*. 17(1), pp. 32–48.

Arasan, V. T., Vedagiri, P. (2006) Estimation of saturation flow of heterogeneous traffic using computer simulation. *ECMS 2006 Proceedings*. (Borutzky, W., Orsoni, A., Zobel, R.). pp. 393-398. European Council for Modeling and Simulation. Bonn, Germany, May 28-31, 2006. https://doi.org/10.7148/2006-0393

Gowri, A., Venkatesan, K., G, Sivanandan, R. (2009) Object-oriented methodology for intersection simulation model under heterogeneous traffic conditions. *Advances in Engineering Software*. 40(10), pp. 1000-1010. https://doi.org/10.1016/j.advengsoft.2009.03.015

Gowri, A., Kanagaraj, V., Srinivasan, K., Sivanandan, R. (2012) Characteristics of mixed traffic on urban arterials with significant volumes of motorized two-wheelers: role of composition, intraclass variability, and lack of lane discipline. *Transportation Research Record*. 2317, pp. 51–59. https://doi.org/10.3141/2317-07

IRC SP 41(1994) Guidelines for the design of at grade intersections in rural and urban areas. Indian Road Congress, India.

Parvathy, R., Sreelatha, T., Koshy, R. .Z. (2013) Development of new PCU values and effect of length of passenger cars on PCU. In: International Conference on Energy and Environment 2(1), pp. 344-351. URL: http://www.ijirset.com/upload/2013/special/environmental/46_DEVELOPMENT.pdf

Radhakrishnan, P., Mathew, T. V. (2011) Passenger car units and saturation flow models for highly heterogeneous traffic at urban signalized intersections. *Transportmetrica*. 7(2), pp. 141-162. https://doi.org/ 10.1080/18128600903351001

Saha, P., Hossain, Q. S., Mahmud, H. M. I., Islam, M. Z. (2009) Passenger Car Equivalent (PCE) of through vehicles at signalized intersections in Dhaka Metropolitan City, Bangladesh. IATSS Research. 33(2), pp. 99-104. https://doi.org/10.1016/S0386-1112(14)60248-X

Shalini, K., Kumar, B. (2014) Estimation of the passenger car equivalent: A review. *International Journal of Emerging Technology and Advanced Engineering*. 4(6), pp. 97-102.

Tettamanti, T., Horváth, M. T., Varga, I. (2014).Road Traffic Measurement and Related Data Fusion Methodology for Traffic Estimation. *Transport and Telecommunication Journal.* 15(4), pp. 69-279. https://doi.org/10.2478/ttj-2014-0023