COMPARATIVE ANALYSIS OF DELAY AND SATURATION FLOW USING VARIOUS PCU ESTIMATION METHODS

Arya Sali, Dr Ajitha T*

Department of Civil Engineering, Rajiv Gandhi Institute of Technology, Kottayam, Kerala, India

* Corresponding author

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ABSTRACT

A Passenger Car Unit (PCU) is a metric used in traffic engineering to quantify the influence of various vehicle types on traffic flow, expressed as a ratio relative to a standard passenger car. PCU factors are crucial for intersection design, as they allow for accurate estimation of traffic capacity and performance by standardizing the effects of different vehicles. Traditionally, static PCU values have been used for design purposes. However, advancements in vehicle technology over the past few decades necessitate a re-evaluation of these values through field studies. This research provides an empirical analysis aimed at determining dynamic PCU values for various vehicle types, enabling a comparison with the factors recommended by the Indian Highway Capacity Manual (Indo-HCM). Data collection took place at two signalized intersections, utilizing the headway ratio method and the queue clearance rate method to estimate PCUs for different vehicle categories. Field data on delay and saturation flow were collected following Indo-HCM guidelines, employing both static and dynamic PCU values. A comparative analysis of these values was conducted to highlight discrepancies and offer insights into the relevance and accuracy of dynamic PCU values in assessing traffic flow.

1. Introduction

Roads play a vital role in a nation's socio-economic development, and a well-structured road system can enhance this progress. In developing countries, urban traffic flow is heterogeneous, with various vehicles of differing sizes, weights, and power sharing the same lanes (Saha et al., 2009). Accurate information on traffic volume is critical for the planning, analysis, design, and operation of roadway systems (Montal et al., 2020). Most existing planning theories and design methodologies are tailored for homogeneous traffic conditions, making them inadequate for heterogeneous scenarios. In India, this mixed traffic primarily includes passenger cars, motorcycles, auto rickshaws, buses, trucks, light commercial vehicles, slow-moving vehicles, and a small number of animal-drawn carts. To analyze this diverse traffic, Passenger Car Unit (PCU) values are employed (Koshy et al., 2013). While PCUs help quantify the presence of various vehicle types on the road, their applicability in India may be limited due to the country's unique traffic dynamics and the necessity for different lane allocations.

The concept of the Passenger Car Unit (PCU) was first introduced in the Highway Capacity Manual (HCM) 3 to assess the influence of trucks and buses on traffic flow (Mohan et al., 2016). The Indian Highway Capacity Manual provides recommendations for static PCUs for various vehicle classes based on the traffic mix in India. PCUs serve to compare different vehicle types against standard passenger cars, helping to understand their effects on traffic under various conditions. It is defined as the relative interaction between a vehicle and the traffic stream in specific scenarios.

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While the Indo HCM (2017) guidelines primarily focus on static PCU values for different vehicle types, the concept of dynamic PCUs is essential for accurately modeling and designing road networks. This dynamic approach facilitates more precise assessments of capacity, congestion, and overall traffic performance by considering the diverse range of vehicles on the road. In urban road networks, intersections often represent critical capacity bottlenecks, and their design significantly impacts efficiency, safety, speed, operational costs, and overall capacity. Understanding delay and saturation flow is vital for signalized intersections, as the volume of traffic passing through is influenced by both the types of vehicles present and their quantity.

The study aims to establish PCU values that reflect the current roadway and traffic conditions in Kerala and India. The number and composition of vehicles are changing daily, influenced by factors such as lane markings, traffic signals, insufficient pedestrian facilities, inadequate parking, and poor road surface conditions. These elements are crucial for analyzing capacity and conducting traffic engineering research (Parvathi et al.). To mitigate the impacts of increasing vehicle numbers and diversity on the operation of signalized intersections, it is essential to determine PCU values based on the present conditions.

Delay and saturation flow are vital components in the design of signalized intersections, directly affecting traffic efficiency and safety. Delay refers to the time vehicles spend waiting at red lights, impacting overall travel times and congestion levels. Saturation flow indicates the maximum rate at which vehicles can pass through during a green signal, which is critical for optimizing signal timings to ensure efficient traffic flow, reduce delays, and improve intersection performance. To accurately estimate saturation flow, it is necessary to convert heterogeneous traffic into homogeneous traffic using appropriate PCU factors. Dynamic PCU values yield more reliable results for assessing design effectiveness.

2. Literature Review

The study on Passenger Car Units (PCU) at signalized intersections involves reviewing and analyzing previous research conducted in this area. Salam et al. (2021) estimated dynamic Passenger Car Unit (PCU) values for various vehicle categories at signalized intersections under mixed traffic conditions. They found that the number of vehicles increases with the proportion of 2 wheelers, LCVs, buses, and heavy vehicles at every junction. In India, static PCU values are set based on traffic types, but these values don't reflect the real picture when vehicle composition and flow rate change. Chitaria et al. (2020) connected PCU values to varying vehicle traits for a more dynamic approach. Alex et al. (2015) used TRAFFICSIM to study PCU values over time, finding that PCU values shift significantly depending on vehicle types and speed. Raju et al. (2016) found a strong relationship between vehicle composition and PCU values, with saturation flow increasing with the increase in two-wheelers, three-wheelers, LCVs, and HCVs, and decreasing with standard cars and big cars. Mohan et al. (2017) found that two-wheelers scored the lowest PCE values due to their smaller size.

Mohan et al. (2017) introduced the Queue Clearance Rate (QCR) method to estimate the Passenger Car Equivalent (PCU) at unsignalized intersections in heterogeneous traffic conditions. This approach calculates the ratio of the number of vehicles in the queue to the time taken for the queue to clear the conflict area. They also presented a technique to determine PCE factors based on the time taken and composition of a vehicle queue to completely clear an intersection. Mondal et al. (2020) focused on saturation flow at signalized intersections, using various PCU estimation methods in mixed traffic environments. Biswas et al. (2017) further explored the queue clearance rate method to estimate the PCE at signalized intersections.

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Hurdle et al. (2019) identified accurate PCU values for different vehicle types at signalized intersections with mixed traffic in Delhi. Saha et al. (2009) conducted an empirical study to determine the PCU of various vehicle types, accurately reflecting the traffic conditions in Dhaka Metropolitan City. Biswas et al. (2017) and Salam et al. (2021) utilized regression technique to analyze traffic streams with different vehicle types. Biswas compared the PCE using the QCR method and found that regression was similar to the converted flow from an all-car stream's capacity. Salam et al. (2021) developed a math model using the estimated dynamic PCU by Area occupancy, making it easy to estimate dynamic PCU values based on current conditions. Mondal et al. (2020) analyzed saturation flow at signalized intersections with mixed traffic using various estimation techniques.

3. Objectives

The primary objective of this study is to examine the reliability of the PCU values provided in the Indo-HCM under current traffic and road conditions. In alignment with this goal, the research aims to develop new dynamic PCU values applicable to selected signalized intersections using various PCU estimation methods. Furthermore, the study seeks to compare these dynamic PCU values with static PCU values to assess their differences and implications. Additionally, the research will determine and compare delay and saturation flow using the dynamic PCU values to evaluate their impact on intersection performance.

4. Methodology

In this study, the PCU values at signalized intersections were determined using two different approaches, the time headway approach and the queue clearance rate method. The following is the description of both approaches' procedures.

4.1 Time headway method

The headway ratio method measures vehicle headway using video recording of events in the observed lane. PCU values are obtained by finding the ratio of adjusted mean headways for different vehicle types (Saha et al., 2009). The procedure is recommended to ensure the effect of a certain type of vehicle is independent of the type preceding and following it. To calculate PCU using the headway ratio method, the condition must be met by comparing two sides of the equation.

$$h(c-c) + h(x-x) = h(c-x) + h(x-c) \quad (1)$$

If the above equation is satisfied, then the PCU value of the x type vehicle can be found using Equation

$$PCU\ (x-x) = h(x-x)/h(c-c) \quad (2)$$

The least square method is used to find the corrective factor (C) if the original equation is not satisfied.

$$C = (abcd(w-x-y-z))/(abc+abd+acd+bcd) \quad (3)$$

Where,

Let h(c−c) represent the average headway when a car is followed by another car, and h(x−x) represent the average headway when a type x vehicle is followed by another type x vehicle. The variables are defined as follows: a is the number of headways where a car follows another car, b is the number of headways where a car follows a type x vehicle, c is the number of headways where a type x vehicle follows a car, and d is the number of headways where a type x vehicle follows another type x vehicle. Furthermore, w denotes the mean headway for a car following another car, x is the mean headway for a car following a type x vehicle, y is the mean headway for a type x vehicle following a car, and z is the mean headway for a type x vehicle following another type x vehicle.

Adjusted mean headways for car and vehicle type x are

$hA(c-c) = U - (C\ /No\ of\ headways\ for\ car\ following\ car)$
(4)

$hA(x-x) = U - (C\ /No\ of\ headways\ for\ x\ \ following\ x)$
(5)

4.2 Queue clearance rate method

The Queue Clearance Rate (QCR) method is a tool used to estimate PCE factors at unsignalized and signalized intersections in areas with high traffic variation. It estimates the time it takes for a line of vehicles to clear the area, considering the type of vehicles in the line. The QCR is defined as the ratio between the number of vehicles in the queue and the time taken to clear the conflict area (Mohan et al., 2016), as given by Eq.6

$$Q = N/T \quad (6)$$

The equation relates the number of vehicles in a queue to the time it takes to clear the intersection area, with the numerator from Eq. 7.

$$N = \sum_{j=1}^{k} nj \frac{Wcar}{Wj} PCEj \quad (7)$$

The equation (6) reveals that poor lane discipline in mixed traffic situations is due to vehicles squeezing in between larger ones. To address this, Equation (7) considers the ratio of vehicle width compared to a standard car. By using Equations (6) and (7) and treating passenger car equivalence as a variable, a linear programming model can be created to minimize the coefficient of variation in queue capacity ratio.

Objective function: Zmin is coefficient of variation (QCR of different queues)

Subject to constraints: PCEj > 0 and PCEcar = 1

The optimization problem can be addressed using the solver function in MS Excel to determine PCE values for different members of the queue. This approach offers an advantage over other methods for estimating PCE at signalized intersections, as it does not rely on saturation flow values, which can be difficult to measure in heterogeneous traffic conditions.

5. Site Selection

The selection of research sites was influenced by factors such as the presence of high-rise buildings near the intersections, the geometry of the intersections themselves, and the necessity to manage significant vehicle flows during peak operational times. Two locations were identified for this study: the Vengalloor intersection in the Idukki district and the Angamaly intersection in the Ernakulam district. Both towns are experiencing rapid growth in their respective regions. Data collected from both junctions is presented in Table 1.

Table 1: Details of intersections selected for the study

Intersection and Approaches	**Width of lane (m)**	**Green time (sec)**	**Yellow time (sec)**	**Traffic volume (PCU/hr)**	**Percentage composition of vehicles (Car:2W:Auto:Bus:LCV:HCV)**
			Vengalloor intersection		
Pala	**6.5**	**20**	**2**	**264**	
Adimaly	**8.5**	**15**	**2**	**175**	**45 : 39 : 9 : 2 : 4 : 1**

Thodupuzha	**6**	**40**	**2**	**727**	
Muvattupuzha	**4.25**	**40**	**2**	**500**	
			Angamaly intersection		
Aluva	**9**	**90**	**2**	**897**	
Thrissur	**9**	**90**	**2**	**2163**	**37 : 44 : 2 : 4 : 7 : 6**
Angadikadav	**4**	**30**	**2**	**426**	
Malayattoor	**7.3**	**30**	**2**	**497**	

6. Data Collection

Traffic surveys were conducted at the study intersections, collecting peak period data on a specific weekday. The signals at these locations are pre-timed. Digital video cameras were employed to gather field data, strategically positioned to capture clear views from all angles near the intersection. However, some obstructions during recording prevented full coverage of queues on certain approaches; in those instances, the focus was directed solely at the stop line. The recording lasted approximately 90 to 120 minutes during peak traffic hours. The number of approaches was noted, and manual data collection included signal timing details such as cycle lengths, the number of phases, and green light durations, which were timed using a stopwatch. The widths of the approaches were measured using appropriate instruments. Saturation flow was determined by categorizing all vehicles that crossed the stop line during the green light phase as one continuous group. Counting commenced when the vehicles began to move and ceased when the flow was interrupted. The delay survey was initiated at the start of the red phase, with counts of waiting vehicles on the approach recorded every few seconds.

7. Development Of New PCU Values

The present condition of the roads and traffic at each intersection was noted and examined. New PCU values are created using the current traffic data by utilizing the queue clearance rate and time headway methods. PCU was calculated using eq 2 of the time headway approach. The vehicle type, the end of saturation flow, the start of the amber and red period, and the rear axle's passage were noted, in addition to the fact that the first car in the queue frequently stops over the stop line. The headway average and headway count for various vehicle categories were gathered from both intersections. Queue Clearance Rate (QCR) method is based on the time that a queue of vehicles will incur in completely clearing the conflict area of the intersection (area common to different movements) and the composition of the queue. The results obtained in two methods are shown in Table 2 and Table 3.

8. Comparison Of Delay and Saturation Flow

The estimation of field delay and the field saturation flow rate for each approaches of intersections are carried out by using the Indo HCM 2018 guideline, where static PCU values recommended by Indo HCM are used. Accurate Passenger Car Unit (PCU) values are vital for determining delay and saturation flow at intersections because they translate diverse vehicle types into a standardized measure. The determination of delay and saturation flow at an intersection using dynamic Passenger Car Unit (PCU) values involves adjusting the PCU values based on real-time traffic conditions. The table 4 contains the saturation flow and delay

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values computed using static PCU values and dynamic PCU values determined by time headway method and queue clearance rate method for Vengalloor and Angamaly intersections.

9. Results and Discussions

The analysis of data collected from the two signalized intersections in Vengalloor and Angamaly city revealed significant variations in PCU values when comparing static values recommended by Indo-HCM 2017 with the dynamic values obtained through the time headway and queue clearance rate methods. The observed dynamic PCU values in Table 2 and Table 3 were generally higher than the static values, indicating that the static PCU factors may underestimate the actual impact of different vehicle types in heterogeneous traffic conditions. This discrepancy is particularly pronounced during peak traffic hours, where variations in vehicle dimensions, weight, and power contribute to fluctuating headways and clearance times. The dynamic PCU values more accurately reflect the real-time conditions, thus providing a more reliable basis for traffic analysis and intersection design.

Table 2: Dynamic PCU values using Time headway method

Type of vehicle	**Dynamic PCU for intersections**	
	Vengalloor	**Angamaly**
Car	**1**	**1**
Two - wheeler	**0.46**	**0.45**
Auto-rickshaw	**0.78**	**0.80**
Bus	**2.20**	**2.16**
LCV	**1.3**	**1.28**
HCV	**2.25**	**2.25**

Table 3: Dynamic PCU values using Queue clearance rate method

Type of vehicle	**Dynamic PCU for intersections**	
	Vengalloor	**Angamaly**
Car	**1**	**1**
Two - wheeler	**0.25**	**0.18**
Auto-rickshaw	**0.43**	**0.21**
Bus	**3.77**	**3.6**
LCV	**2.08**	**1.6**
HCV	**3.46**	**3.08**

Furthermore, the comparison of field delay and saturation flow estimates using static and dynamic PCU values are mentioned in Table 4, the values highlighted the importance of incorporating dynamic measures into traffic management practices. The field delays calculated using dynamic PCU values were consistently lower than those computed with static values,

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suggesting that dynamic PCU factors offer a more efficient utilization of intersection capacity. Saturation flow rates, estimated using dynamic PCU values, were higher, reinforcing the need for regular updates to PCU values to accommodate advancements in vehicle technology and changes in traffic composition. These findings underscore the necessity of adopting dynamic PCU values in the design and evaluation of signalized intersections to enhance accuracy in traffic flow assessments and improve overall traffic management strategies.

Table 4: Comparison of Saturation flow and Delay Using Various PCU Values

Intersection	Approach	Saturation flow (PCU/Hr)			Delay (s/PCU)		
		Static PCU	PCU from Time headway method	PCU from Queue clearance rate method	Static PCU	PCU from Time headway method	PCU from Queue clearance rate method
Vengalloor	Adimaly	2097	2330	2286	48.13	47.5	46.85
	Thodupuzha	1996	2291	2369	61.01	48.6	50.05
	Muvattupuzha	2832	3145	3147	58.18	54.14	69.23
	Pala	2081	2310	2236	40.86	49.26	50.26
Angamaly	Aluva	3258	3025	3015	51.99	38.62	52.15
	Thrissur	3654	4031	3898	96.17	96.49	99.09
	Angadikadav	2520	1947	1728	78.45	72.58	69.52
	Malayattoor	2757	2570	2446	81.60	65.00	78.26

10. Conclusions

Field data on delay and saturation flow were collected in accordance with Indo-HCM guidelines, utilizing both static and dynamic PCU values. Dynamic PCU values were developed using the time headway method and the queue clearance rate method, resulting in higher values than the static PCU estimates. This indicates that static PCU values are not reliable for current roadway and traffic conditions. By utilizing dynamic PCU values, saturation flow and delay were assessed, showing variations from the estimates based on static PCU values. When comparing the dynamic PCU estimation methods, the time headway method involves non-lane-based traffic, which introduces multiple leaders and followers for each vehicle, leading to potential inaccuracies. In contrast, the queue clearance rate method does not rely on saturation flow values and estimates PCU based on the time required for the queue of vehicles to clear the intersection, as well as the number of each vehicle category in the queue. Consequently, the queue clearance rate method provides more accurate results.

Conflict of Statement: "The authors declare that they have no conflicts of interest related to this research."

References

1. Alex, S., & P. Isaac, K. (2015). Dynamic Pcu Values At Signalised Intersections in India for Mixed Traffic. International Journal for Traffic and Transport Engineering, 5(2), 197 209. https://doi.org/10.7708/ijtte.2015.5(2).09
2. Biswas, S., Chandra, S., & Ghosh, I. (2017). Estimation of Vehicular Speed and Passenger Car Equivalent Under Mixed Traffic Condition Using Artificial Neural Network. Arabian Journal for Science and Engineering, 42(9), 4099–4110. https://doi.org/10.1007/s13369-017-2597-9
3. Bomzon, U., Sherpa, U. K., Sarkar, S., Chettri, S., Jyoti Das, D., & Sushib, R. (2021). Determination of PCU values for mixed traffic conditions along the hilly road of East Sikkim. IOP Conference Series: Earth and Environmental Science, 796(1). https://doi.org/10.1088/1755-1315/796/1/012025
4. Indian Highway Capacity Manual (2017), Sponsored by Council of Scientific and Industrial Research(CSIR), New Delhi.
5. Jaladhi V. Chitaria, J. D. R. (2020). Estimation of Dynamic PCU values at Signalized Intersection in Ahmedabad city. 7(1), 138–141.
6. Joshi, R. S., & Goliya, H. S. (2021). Capacity And Dynamic Pcu Estimation Of Urban Roads For Heterogeneous Traffic: A Case Study In Indore City. International Research Journal of Engineering and Technology. www.irjet.net
7. Mahidadiya, A. N., & Juremalani, J. (2016). Estimation of Passenger Car Unit value at Signalized Intersection. 2(2), 1317–1324.
8. Mohan, M., & Chandra, S. (2017). Queue clearance rate method for estimating passenger car equivalents at signalized intersections. Journal of Traffic and Transportation Engineering (English Edition), 4(5), 487–495. https://doi.org/10.1016/j.jtte.2016.12.003
9. Mondal, S., Arya, V. K., Gupta, A., & Gunarta, S. (2020). Comparative analysis of saturation flow using various PCU estimation methods. Transportation Research Procedia, 48, 3153–3162. https://doi.org/10.1016/j.trpro.2020.08.168
10. Parvathy.R, Sreelatha.T, Reebu Z Koshy (2013)," Development of new PCU values and effect of length of passenger cars on PCU", International Journal of Innovative Research in Science, Engineering and Technology, Volume 2
11. Pal, D., Sen, S., Chakraborty, S., & Roy, S. K. (2020). Effect of PCU Estimation Methods on Capacity of Two-Lane Rural Roads in India: A Case Study. Transportation Research Procedia, 48, 734–746. https://doi.org/10.1016/j.trpro.2020.08.075
12. R. Prasanna Kumar, G. Dhinakaran (2012)" Estimation of delay at signalized intersections for mixed traffic conditions of a developing country" July 2012
13. Raju, M. M. (2016). Estimation of PCU And Saturation Flow for Mixed Traffic Condition at Urban Signalized Intersections.
14. Saha, P., Hossain, Q. S., Mahmud, H.M.I., Islam, MD.Z. (2009). "Passenger Car Equivalent (PCE) of through vehicles at signalized intersections in Dhaka metropolitan city, Bangladesh". IATSS Research, 33(2).
15. Salam, S. (2021). Determination of Dynamic PCU values at the signalized intersection for mixed traffic conditions. 7(4), 324–328.
16. SU Yuelong, WEI Zheng, CHENG Sihan, YAO Danya, ZHANG Yi, LI Li (2009), "Delay Estimates of Mixed Traffic Flow at Signalized Intersections in China" Tsinghua Science and Technology, 14(2).

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