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Different methods for estimation of dynamic passenger car units – a review.

Diferentes métodos para la estimación de unidades dinámicas de turismos: una revisión.

Ameena M, Vignesh Dhurai

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

Corresponding author's email (in order): ameenamajeed717@gmail.com; dvignesh005@gmail.com

ABSTRACT

In India, heterogeneous traffic conditions are prevailing due to a variety of vehicles with different static and dynamic characteristics. It is necessary to convert mixed traffic into homogeneous traffic by using Passenger Car Unit (PCU) values. Roadway and traffic conditions on urban roads vary considerably across the cities which generally affects the PCU values of different vehicles and the capacity of the roadway. This shows the dynamic nature of PCU values. PCU values are widely used in traffic capacity analysis, determination of Level of Service (LOS), saturation flow rate, signal design and coordination, and development of traffic flow models. Because of these wide applications, the accuracy of dynamic PCU values is very important. Many researches have been carried out on the estimation of dynamic PCU values. This paper presents different methods for estimating dynamic PCU appropriate for heterogeneous traffic conditions on Indian roads. The challenges in estimating PCU values and future directions for improving the PCU estimation methods are also presented in this paper.

Keywords: Dynamic Passenger car unit, Passenger car unit (PCU) estimation methods, Mixed traffic, urban mid-block section.

RESUMEN

En la India prevalecen condiciones de tráfico heterogéneas debido a una variedad de vehículos con diferentes características estáticas y dinámicas. Es necesario convertir el tráfico mixto en tráfico homogéneo utilizando valores de Unidad de Vehículos de Pasajeros (PCU). Las condiciones de las vías y del tráfico en las vías urbanas varían considerablemente entre las ciudades, lo que generalmente afecta los valores de PCU de los diferentes vehículos y la capacidad de la vía. Esto muestra la naturaleza dinámica de los valores de la PCU. Los valores de PCU se utilizan ampliamente en el análisis de la capacidad del tráfico, la determinación del nivel de servicio (LOS), el índice de flujo de saturación, el diseño y coordinación de señales y el desarrollo de modelos de flujo de tráfico. Debido a estas amplias aplicaciones, la precisión de los valores dinámicos de la PCU es muy importante. Se han llevado a cabo muchas investigaciones sobre la estimación de valores dinámicos de PCU. Este artículo presenta diferentes métodos para estimar la PCU dinámica apropiada para condiciones de tráfico heterogéneas en las carreteras de la India. En este artículo también se presentan los desafíos en la estimación de

los valores de PCU y las direcciones futuras para mejorar los métodos de estimación de PCU.

Palabras clave: Unidad dinámica de turismos, Métodos de estimación de unidades de turismos (PCU), Tráfico mixto, sección urbana a mitad de manzana.

INTRODUCTION

Traffic flow characteristics are different in developed and developing countries. In developed countries, the traffic flow is homogenous in nature, follows a simple and orderly traffic flow pattern and is composed of predominantly cars and a small number of other vehicles. But the traffic flow in developing countries is referred to as heterogeneous and it comprises a wide variety of vehicles with different static and dynamic characteristics. For efficient planning and implementation of road projects, traffic flow must be quantified accurately. While considering the heterogeneous traffic condition, expressing traffic flow in terms of vehicles passing a given section per unit time will be inappropriate. Problems of expressing the heterogeneous traffic volume can be solved, if the impacts of each vehicle type can be stated in terms of some common units called Passenger Car Unit (PCU) or Passenger Car Equivalent (PCE).

The term PCU can be described in many ways; PCU was first used in the U.S. Highway Capacity Manual (HCM) to describe volume or capacity in terms of passenger cars per hour per lane. PCU was described in the Highway Capacity Manual (Highway Research Board 1965) as "the number of passenger cars displaced in the traffic flow by a truck or a bus, under the existing roadway and traffic conditions”. Based on traffic composition, the Indian Roads Congress (IRC, 1990) recommends static PCUs for various vehicle classes in India. PCU is also described as "the measure of relative interaction between a vehicle and a traffic stream with respect to a standard passenger car under a given set of highway and traffic conditions" by CSIR - Central Road Research Institute in 2017.

Estimation of PCU of various vehicle types should be accurate to determine the desired Level of Service. Inappropriate estimation of PCU may lead to unexpected congestion. Many researchers considered the PCU as a static value. The guidelines offered by the Indian Roads Congress for the estimation of PCU are also based on the static properties of the vehicles; however, the dynamic features were not taken into consideration. But the PCU values of a vehicle type vary with traffic characteristics (traffic volume, traffic composition, traffic speed, and Level Of service) and road geometric factors (road width, gradient horizontal curvature, and other factors) (MSharma and S Biswas 2020). There are many methods for the estimation of dynamic PCU but there is still confusion regarding the selection of methods for the estimation of PCU. This study brings all the methods together and discussed the advantages and disadvantages of each method.

STATIC PCU VALUES

PCU is a measure of the impact of a vehicle type on traffic flow compared to a singlepassenger car. Usually, it is used for expressing highway capacity. Initially, a factor is multiplied by the number of heavy vehicles

to make it equivalent to the number of passenger cars and this factor is considered constant for a vehicle type. In 1965, Highway Research Board named this factor PCU. At first, PCU values are considered as constant rather than a variable that is sensitive to traffic and other factors. In Indonesian Highway capacity manual, they also provided the static PCU values. The manual does not include any examples of a PCU determination approach. On multilane urban expressways in Singapore, Fan (1990) and Yeung et al. (2015) estimated PCU for various vehicle classifications using a multiple linear regression-based technique. Significant differences between estimated PCU and those advised in the Highway Capacity Manual were discovered. The suggested use of PCU is therefore only appropriate in that circumstance.

DYNAMIC PCU VALUES

The heterogeneous traffic flow consists of different types of vehicles with varying static and dynamic characteristics. Vehicles occupy different spaces on road at different speeds. The influence of neighboring vehicles on a subject vehicle is also different in a heterogeneous traffic condition. Hence the PCU values may also get affected by the traffic and geometric condition. It is very difficult to measure PCU in field conditions due to numerous influence factors. But the IRC recommended the PCU values based on the static characteristics of a vehicle without considering the dynamic nature of PCU. The majority of other researchers also provide a single set of PCU values for all traffic conditions. And also, the PCU values estimated by different researchers are different in magnitude. This variability of PCU values may be due to the variation in driving behavior, traffic, and geometric condition. These findings reflect the need for the study of the dynamic nature of PCU. Dynamic PCU applications are widely employed today, according to a number of recent publications (Dhamaniya and Chandra 2013; Mardani et al. 2016). This paper presents the different methods for the estimation of dynamic PCU.

FACTORS INFLUENCING DYNAMIC PCU VALUES

Different parameters should consider while estimating dynamic PCU for the midblock section. Under heterogeneous traffic conditions, parameters such as speed area ratio, headway, area occupancy, time occupancy, influence area, etc. are used for predicting PCU for various vehicle types. The influence of each parameter is different for each facility type. apart from these, PCU is also affected by geometric factors such as road width, directional split, presence of shoulders, the roughness of the road, land use, and type of facility. However, roadside frictions that are not taken into account in the existing practices, such as pedestrian walkways, undesignated pedestrian midblock crossings, bus stops, and roadside parking, also have an impact on the PCU values of vehicles, particularly in mixed traffic situations. The effects of various human and psychological factors (including lane-changing behaviour, overtaking, acceleration and deceleration, desired travel speeds, and driver's PIEV (Perception, Intellection, Emotion, Volition) times) on PCU are very difficult to measure. Furthermore, the data gathered in the field typically suffer from the significant problem of being influenced by multiple factors, which makes it challenging to assess the impact of individual factors on PCU.

METHODS OF ESTIMATING PCU

Various research works have been conducted to address the challenges related to accurate PCU estimation in heterogeneous traffic conditions. On midblock portions, PCU values were estimated using a variety of techniques in mixed traffic scenarios. Inthis section, multiple techniques for estimating dynamic PCUs for midblock sections with mixed traffic situations are discussed.

SPEED MODELING

Chandra et al. (1995) introduced the interesting concept of using speed as a key variable to determine the PCU of vehicles on urban midblock under heterogenous traffic situations. They stated that speed of a vehicle type is an accurate indicator of how the vehicle interacts with other vehicle types generally. In this study, he considered PCU is directly proportional to speed ratio and inversely proportional to projected area ratio with respect to the standard vehicle, as follows:

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

where Vc = mean speeds of car

Vi = mean speeds of vehicle type i

Ac = projected rectangular areas of car

Ai = projected rectangular areas vehicle type i on the road.

The projected area of the vehicles given in Chandra's method is shown in Table 1

Table 1 Projected areas of various vehicle categories.

Category	Vehicles included	Average dimension		Projected rectangular area on ground (m2)
		Length (m)	Width (m)	
Car	Car, jeep	3.72	1.44	5.39
Bus	Bus	10.10	2.43	24.74
Truck	Truck	7.50	2.35	17.62
Light commercial vehicle	Minibus, vans	6.10	2.10	12.81
Tractor	Tractor, trailer	7.40	2.20	16.28
Three-wheeler	Three-wheeler	3.20	1.40	4.48
Two-wheeler	Scooter/motorbike	1.87	0.64	1.20
Cycle	Bicycles	1.90	0.45	0.85
Rickshaw	Pedal rickshaw/cart	2.70	0.95	2.56

Using the following equation, Patil and Adavi (2015) calculated PCUs for urban midblocks in Pune, India, using the mean speed ratio of passenger cars to all other vehicle classes:

$F_u=U_C/U_v$ (2)

where Fu = PCU factor for speed of vehicle class u; Uc = mean speed of car c; and Uv = mean speed of the vehicle class v.

HEADWAY METHOD

Using the following equation, Patil and Adavi (2015) calculated PCUs for an urban midblock in Pune, India:

$$F_t = \frac{t_C}{t_v} \quad (1)$$

where Ft = PCU factor for time headway of vehicle class v; and tc and tv = mean lower time headway of cars and vehicle class v, respectively. Adnan (2014) used the same approach for the arterials in Karachi, Pakistan.

MODIFIED HEADWAY METHOD

Under conditions of heterogeneous traffic flow, a modification to the dynamic technique was made by adding the time headway factor in addition to the speed factor and area factor. Arpan and Srikanth (2017) put forward a modified equation to find the Passenger Car Unit

PCUi = Fv*Ft*Fa (2)

PCUi = PCU value of subject vehicle type, Fv = Speed factor of subject vehicle type, (Fv=Vc/Vi), Ft = Headway factor of subject vehicle type, (Ft=Ti/Tc), Fa = Area factor of subject vehicle type. (Fa=Ai/Ac)

SPACE OCCUPANCY METHOD

On multilane urban roads with mixed traffic, Kumar et al. (2017) concentrated on PCU estimation utilizing area occupancy as a measure of base for various vehicle classes. In a case study by Paul and Sarkar (2013) on urban arterial highways in Delhi City, India, PCU was calculated using speed and influence area as inputs.The conceptual model created by Paul and Sarkar 2013 for calculating PCU values is shown in Fig. 1. In order to estimate PCUs, they adapted Chandra's speed-projected area ratio approach as stated in the following equation:

$$PCU = (A_i x\, V_c)/(A_c x V_i) \quad (3)$$

where Vc = mean speeds of car

Vi = mean speeds of vehicle type i

Ac = influence areas of car

Ai = influence areas vehicle type i on the road.

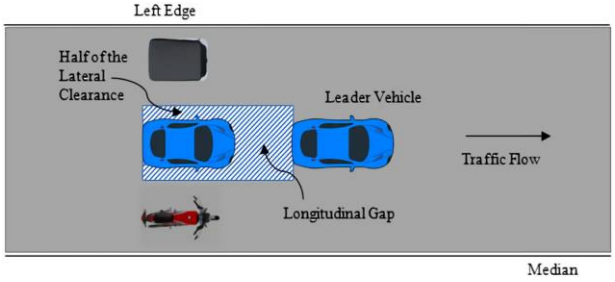

Fig. 1. Model for estimating PCU values (Paul and Sarkar 2013).

EFFECTIVE AREA METHOD

Pooja et al. (2018) calculated PCU for each type of vehicle taking into account speed, the subject's effective area and nearby cars. The fundamental formula created by Chandra and Kumar (1995) has been altered so that the projected area is better reflected by the effective area when the influence of nearby cars is taken into account in mixed traffic situations because of non-lane discipline. The formula used to calculate PCU is provided by

$$PCU = (V_{car}/V_k)/(A_{car}/A_k) \quad (4)$$

where PCUk = PCU of vehicle type k

Vcar = mean speeds of passenger car (small car)

Vk = mean speeds of vehicle type k

Acar =effective area of passenger car

Ak = effective area of vehicle type k

Taking into consideration of surrounding vehicles, different cases (Fig. 2) may be considered such as presence of only subject vehicle (Case 1), subject vehicle with an adjacent vehicle (Case 2), subject vehicle with two adjacent vehicles one on each side (Case 3), subject vehicle following a leader (Case 4), subject vehicle with a leader and an adjacent vehicle (Case 5), and subject vehicle surrounded by leader and two adjacent vehicles one on each side (Case 6) for estimating PCU values. Depending on the conditions of the traffic flow, the effective area of various vehicle types used to calculate PCU values varies. The size of the subject vehicle (SV), leader vehicle (LV), and nearby vehicles on its right and left sides can affect a vehicle's effective area. The method for estimating effective area for different cases is described in Table 2.

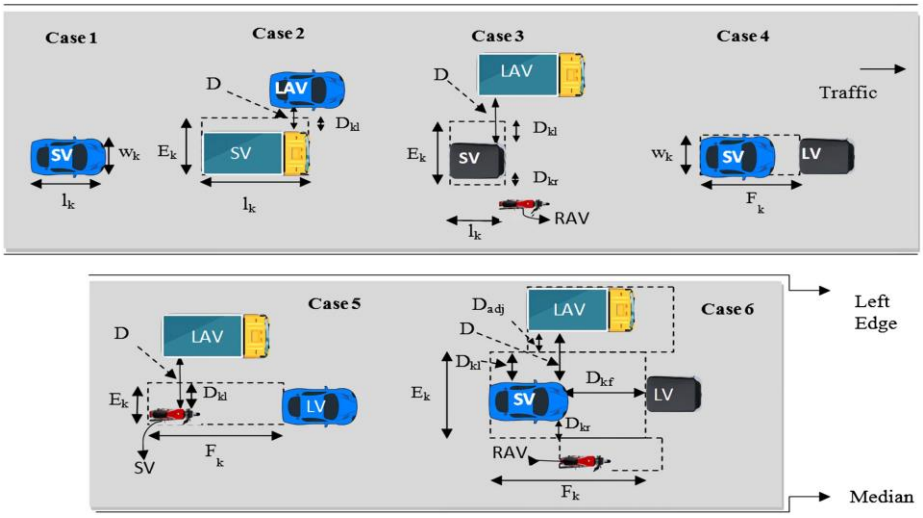

Fig. 2. Different cases (Pooja et al. 2018.)

Table 2. Description of effective area measurement for different cases

Traffic situations	Effective area
Case 1: Only subject vehicle	Area of the subject vehicle (Case 1)
Case 2: Subject vehicle with one adjacent vehicle	Subject vehicle occupies effective lateral gap on one side besides its actual width. Then, effective area is the product of length of subject vehicle and effective lateral gap (Case 2).
Case 3: Subject vehicle with two adjacent vehicles	The subject vehicle occupies distance on its both sides. So, effective area is the product of length of subject vehicle and effective lateral gap (Case 3).
Case 4: Subject vehicle with a leader vehicle	Subject vehicle occupies the virtual space of longitudinal gap. Hence, effective area is the product of effective longitudinal gap and the width of subject vehicle (Case 4).
Case 5: Subject vehicle with a leader and an adjacent vehicle	Effective area is the product of effective lateral gap and effective longitudinal gap (Case 5).
Case 6: Subject vehicle with a leader and two adjacent vehicles	Effective area is the product of effective lateral gap and effective longitudinal gap (Case 6).

MULTIPLE LINEAR REGRESSION METHOD

Many researches employ the regression analysis method to determine PCUs. For estimating PCE, Minh and Sano (2003) arrived at the equation shown below:

$$S = FFS + a1PC + a2BUS + a3MC + a4HV \quad (7)$$

where S = average traffic stream speed; FFS = free flow speed; PC = number of passenger cars in traffic stream; BUS = number of buses in traffic stream; MC = number of motorcycles in the traffic stream; HV = number of heavy vehicles in the traffic stream; and a1, a2, a3, a4 = marginal effect of respective mode on average traffic stream speed. Adnan (2014) calculated PCE factors for various vehicle types on urban arterials using the estimation of the above coefficients from Eq. (9), by dividing the coefficients obtained for each type of vehicle (air) by the coefficient obtained for the reference vehicle, i.e., a passenger car (a1), using the equation:

$$PCU = air/a1 \quad (8)$$

STREAM EQUIVALENCY FACTOR (K) METHOD

In Indo HCM (2017), a new technique is used to convert a mixed traffic stream into a homogeneous traffic stream by using a stream equivalency factor (K) rather than PCU values for vehicle types. It is the ratio of traffic volume in PCU per hour and volume in vehicles per hour. SEF is related to traffic composition and volume on a

road. The V/C ratio on the road, which is used as a measure for evaluating traffic congestion and Level of Service, can be readily estimated using the K factor.

Flow in PCU/hr= SEF* Flow in Veh/hr (9)

MICROSIMULATION MODELS

In order to determine PCU factors on heterogeneous traffic streams for various vehicle categories over a wide range of traffic flow and compositions on four-lane divided urban roads in India, Praveen and Arasan (2013) used the microsimulation model HETEROSIM. This model directly estimates the PCU factors on a homogenous and heterogeneous traffic flow condition for different vehicle categories over a wide rangeof traffic flow and compositions on four-lane divided urban roads in India. Mishra et al. (2017) also studied the PCU values on a multilane urban road using simulation model.

COMPARISON OF VARIOUS METHODS OF PCU ESTIMATION

SPEED BASED MODEL

This approach is simple and effective at capturing the PCU's dynamic character. Additionally, it is appropriate for heterogeneous traffic streams composed of various vehicle types It would be more sensible and accurate when focusing on the "influence area" rather than the "projected rectangular area" (Pooja et al., 2018).

HEADWAY METHOD

The method is simple. It works best in less mixed traffic conditions and at better level of service. Without the use of sophisticated tools or techniques, accurate field measurements of headway are challenging. It is challenging to gather enough samples from vehicles that are more widely distributed. This frequently restricts the method's use in the field. The headway method is applicable in situations where lane discipline is observed.

MODIFIED HEADWAY METHOD

This approach is simple and more effective by considering the speed of vehicle, projected area of vehicle as well as time headway. But the main disadvantage of this method is to measure the headways from field is difficult.

SPACE OCCUPANCY METHOD AND EFFECTIVE AREA METHOD

In midblock sections with mixed traffic, where the projected area of the vehicles does not actually represent the effective area occupied by them due to the influence of surrounding vehicles, the commonly used method for PCU estimation takes into account the relative speed and projected area (length x width) of the vehicles. In order to avoid this problem, a method for PCU estimation for urban midblock sections carrying mixed traffic is proposed. For each type of vehicle, PCU can be estimated while taking into account the subject's effective

area, speed, and neighboring vehicles. The projected PCU values for different types of vehicles may prove to be accurate estimates when taking into account the impact of neighboring vehicles. This strategy may be used for midblock portions of highways carrying mixed traffic in addition to its use in midblock sections in urban areas with mixed traffic since non-lane-disciplined driving behaviour may affect the effective area of the vehicles.

MULTIPLE LINEAR REGRESSION METHOD

The unique multiple linear approach regression method can be used to accurately estimate the equivalency units of individual vehicle types under heterogeneous traffic conditions. The PCU values estimated using this method is found to be realistic and logical under heterogeneous traffic flow conditions. It works with the extremely diverse traffic (Adnan, 2014). Regression coefficients can occasionally turn out to be negative, which results in inaccurate PCU estimation.

STREAM EQUIVALENCY FACTOR (K) METHOD

Without using the PCU factors of individual cars, the simple Stream Equivalency Factor approach can be used to convert non-homogeneous traffic stream volume measured in vehicles per hour to equivalent volume in PCU per hour.

MICROSIMULATION MODELS

Any kind of traffic condition can benefit from simulation techniques since traffic and geometric conditions can be properly managed. It necessitates thorough familiarity with the traffic simulation. Also, it is difficult to validate model as it requires real-world data covering a vast range of traffic and geometries.

Table 3. Summary of different methods for the estimation of PCU

Journal	PCU determination method	Factors considered	Data collection technique	Time of data collection
S Chandra et al. (1995)	Speed based model	Mean speed and projected rectangular area	Videography	
S V Patil and P R Adavi (2015)	Headway Method	Mean lower time headway	Videography	3 hours on weekdays
S. Srikanth and A. Mehar(2017)	Modified headway method	Mean speed, projected rectangular area and mean lower time headway	Videography	3-4 hours on weekdays
M Adnan (2014)	Multiple Linear Regression Method	Free flow speed and number of vehicles	Videography	
P Raj et al.(2018)	Space occupancy method	Mean speeds and Effective area	Videography	6:30 am to 12:30Pm on a typical weekday
S Chandra et al. (2017)	Stream equivalency factor method	Traffic volume and traffic composition	Videography	Weekday from 6:00 A.M. To 6:00 P.M

CONCLUSION

This paper presents different methods for estimation of dynamic PCU values under heterogeneous traffic condition. There are different static and dynamic characteristics influencing the PCU values. Estimation of PCU using these methods has certain advantages and disadvantages. From the literature, the most efficient method of estimation of PCU is effective area method. It considers the dynamic nature of vehicles and influence of surrounding vehicles. But this method doesn't consider the time headway factors. This problem can be solved by modifying the effective area method. Modification to this effective area method can be done by adding the time headway factor is found realistic and logical under heterogeneous traffic flow conditions. The modified approach used for PCU estimation can include speed factor, effective area factor and the time headway factor.

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