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Passenger Car Equivalent Factors in Heterogenous Traffic Environment-Are We Using the Right Numbers?

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Abstract

With increasing urbanization, improved transportation technology and an expanding economy, additional roads and highways are built, in an effort to balance roadway capacity and demand. Knowledge of capacity of a road is essential in planning, design and operation of roads. To ascertain estimates of roadway capacity, Passenger Car Equivalent (PCE) factors are vital as they provide mechanism through which vehicles are converted into reference vehicle (i.e. Car). The paper discusses the case of Karachi (A metropolitan city of Pakistan) traffic environment where degree of heterogeneity is significantly high, and based on the collected data set from 12 different urban arterials of Karachi; presents the estimation of PCE factors from four different existing methods. Obtained PCE factors are then compared with each other and with those which are currently used in different traffic studies of Karachi. Significant differences are found among the values of PCE factors from each method.

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Keywords:Heterogenous Traffic, Passenger Car Equivalents, Roadway Capacity, Urban Arterials

1. Introduction

The composition of traffic found in almost every developing countries is diverse, with a variety of vehicles, motorized and non-motorized, using the same road space [1]. The motorized or fast moving vehicles include passenger cars, buses, trucks, auto rickshaws, scooters and motorcycles; non-motorized or slow moving vehicles

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including bicycles, cycle-rickshaw, and animal drawn carts. Since 1950s, considerable research has been made to develop traffic flow models and analysis procedures mainly for homogeneous traffic, which is representing the traffic conditions found in developed countries. Limited amount of studies have been done to develop an understanding of traffic flow and capacity analysis for non-lane-based heterogeneous or mixed traffic conditions in developing countries. The term “passenger car equivalent” was introduced in the 1965 U.S., Highway Capacity Manual (HCM) and defined as “the number of passenger cars displaced in the traffic flow by other transport modes under the prevailing roadway and traffic conditions. PCE factors are usually used to convert heterogeneous traffic environment into homogenous stream in which it is assumed that only cars are travelling [2]. PCE factors have an important significance in the subject of traffic engineering, as these factors are utilized in many traffic analysis methods and procedures which are developed considering homogeneity in traffic conditions such as capacity analysis, saturation flow rate determination and traffic flow models. PCE are derived from various characteristics of the traffic streams, such as headway, speed and volume along with vehicular and roadway characteristics [3, 4]. As indicated above, PCE factors are dependent on the traffic flow parameters, these values are subject to variations due to the factors influencing the traffic flow parameters. Therefore, it may not be precisely correct to adopt a constant set of PCE values under different roadway and traffic conditions. This is the main reason that development authorities have developed standards on regional basis.

The road traffic in most developing countries such as Pakistan comprises vehicles of wide ranging physical dimensions, weight and dynamic characteristics. Also, the motorized and non-motorized vehicles share the same road space without any segregation. Due to high varying physical dimensions and speeds; it becomes difficult to make the vehicles to follow traffic lanes. Consequently, they tend to choose any advantageous position on the road based on space availability. Also, the extent of vehicular interactions varies widely with variation in traffic mix.Traffic related studies conducted in metropolitan city Karachi, for administration body i.e. Karachi Metropolitan Corporation (KMC) formerly known as City District Government Karachi (CDGK) by the various consultant firms One such study [5] where traffic volume data collection is reported, primarily focuses on establishment of new public transport routes under the name “Confirmatory Green Route Study for Karachi” conducted by Exponent Engineers. This study reported 10 different traffic classes for volume data collection, which is composed of Private Car, Taxies, Auto Rickshaw, Motorcycles, Contract carriage buses, Minibus, Large bus, Light Freight vehicles, Trucks and Trailers. This study nature is such that it main focus is on public transports modes and there is no discussion exist about the classification of modes and the PCE values. Another recent study [6], which has been conducted in collaboration with Japan International Cooperation Agency (JICA) with the name “Karachi Transport Improvement Program” also utilized the classification of transport modes which is composed of the seven (7) classes (representing inconsistency in defining transport modes classes) and the PCE values used for conversion of vehicles into passenger cars are shown in Table 1.

Table 1. PCE Factors used in Traffic Studies relevant to Karachi.

Vehicle Classes	PCE Factors
Car/Jeeps/vans/Taxi	1.00
Motorcycles/Scooters	0.25
Auto Rickshaw	0.50
Pickups	1.50
Mini Buses	2.00
Large Buses	2.50
Trucks and Trailers	3.00

PCE values mentioned in Table 1 have been utilized in other transport development project reports presented to CDGK. PCE values used in these reports are usually not referenced, and if reference is provided, it is indicating quite older reports (some twenty years older) where again it is not discussed the basis for these PCE values [7]. This situation suggests that it is vital to establish PCE values for different types of transport modes exist in Karachi on some scientific notion, which is the focus of this research. Additionally, this study provides comparison basis for PCE factors developed for similar regions such as India, Bangladesh, and Indonesia etc. The paper is structured as follows: second section describes the methods used for estimation of PCE factors, third section presents estimated PCE factors from the different methods and provides comparison of obtained PCE factors, and fourth section discusses the significance and consequences of obtained results followed by concluding remarks.

2. Existing Methods for PCE factors and Collected Data

This section describes estimation methods usually used in the literature to obtain PCE values for different types of transport modes in a study area. As illustrated earlier, the focus of this study is to estimate these factors for mid-block of urban arterials; therefore, methods which are suitable for mid-blocks are discussed only. Tiwari et al [8] reported that there exist many methods for estimation of PCE, among them headway method, multiple regression method, simulation method are more common. The sub-sections below describe some methods which are found more useful for representing heterogeneous traffic conditions of urban arterials especially in developing countries.

2.1. Time Headway based Methods

Time headway based methods are based on the notion that passenger car following larger vehicles may have higher headways compared to time headway between two successive passenger cars at saturated flow conditions. The ratio of these two quantities may give PCE value. This approach has been utilized more commonly in case where PCE factors are determined for a signalized intersection [9]. Time headway based methods are preferred over others as it is utilizing such a dynamic characteristic of traffic stream (i.e. headway) which is able to explain driver behavior, roadway surroundings, traffic volume and speed characteristics through a single parameter [10].Krammes and Crowley [11] analyzed a mixed traffic stream and developed an equation considering headway differences between trucks and other vehicles, which can be applied at midblock section of a road segment for determination of PCE using equation (1):

$$PCE = \frac{(1-p)(h_{px}+h_{xp}-h_{pp})+(ph_{xx})}{h_{pp}} \quad (1)$$

Where,*p* = percentage of trucks at a mixed traffic stream,*hxp*= Mean headway time in seconds for vehicle x following PC;*hxp*= Mean headway time in seconds for PC following vehicle x;*hpp*= Mean headway time in seconds for PC following PC;*hxx*= Mean headway time in seconds for vehicle x following vehicle x.

Cuddon and Ogden [12] presented a sufficient and necessary condition to be fulfilled for applicability of headway ratio method for PCE determination. This condition is shown from the following equation (2), which implies that *effect of a certain type of vehicle is independent of the type of vehicle preceding it and following it*.

$$h_{c-c} + h_{x-x} = h_{c-x} + h_{x-c} \quad (2)$$

Where,h $_{C\text{-}C}$=Average headway of a car followed by a car, h $_{X\text{-}X}$=Average headway of a car followed by a car, h $_{C\text{-}X}$=Average headway of a X-vehicle followed by X-vehicle, h $_{X\text{-}C}$=Average headway of a X-vehicle followed by X-vehicle

Furthermore, Saha et al [10] mentioned that for the given data set, where equation 2 does not holds, the following corrective factor need to be applied, which is shown in equation (3)

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

Where;a=Number of headway for car following car, b=Number of headway for car following X-vehicle, c=Number of headway for X-vehicle following car, d=Number of headway for X-vehicle following X-vehicle, w=Mean headway for car following car, x=Mean headway for car following X-vehicle, y=Mean headway for X-vehicle following car, z=Mean headway for X-vehicle following X-vehicle. By using the value of corrective factor C in equation (4) and (5) will give the adjusted mean headway of car following car and X-vehicle following X-vehicle respectively. Finally the PCE is calculated using adjusted headway in equation (6).

$$h_{A(c-c)} = U - \frac{C}{No.of headway car following car} \tag{4}$$

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

$$h_{A(x-x)} = U - \frac{C}{No.of headway X-vehicle following X-vehicle} \tag{5}$$

Where;$h_{A(x-x)}$ = Adjusted mean headway for X-vehicle following X-vehicle

$$PEC_{X-vehicle} = \frac{h_{A(x-x)}}{h_{A(c-c)}} \tag{6}$$

This paperutilized both of these methods to derive PEC equivalents from the collected data for urban arterial of Karachi.

2.2 Traffic Stream Speed based Method

Traffic stream speed based methods are established on the aspect in which it is quantified the effect of a certain type of vehicle in changing the traffic stream speed compared to passenger cars. Most common method in this regard is known as speed reduction method which has been utilized mostly for determination of PCE factors which are slower in speed than the passenger cars [13]. This method is based on the following expression:

$$PCE_{nmv} = 1 + \frac{S_b - S_m}{S_b} \tag{7}$$

Where,PCE_{nmv} = Passenger car equivalents of non-motorized vehicles, S_b = Average speed of passenger car in the basic flow (km/hr) and S_m = Average speed of passenger car in the mixed flow (km/hr).

Rahman and Nakamura [13]utilized the above method for estimation of PCE values for non-motorized vehicles in the traffic stream. The data is collected in such a fashion that all other type of vehicles (other than car and hand driven rickshaw) exist in the traffic stream is assumed to have insignificant effects on speed reduction of passenger cars due to their lower presence (less than 5%). Speed of the traffic stream was then examined for various proportions of hand driven rickshaw, and then based on the above formulation i.e. equation (7), PCE factors are evaluated for different volume scenarios. This method has a limitation as direct collection of speed reduction in passenger cars due to the presence of another specific type of mode is impractical to collect, especially for traffic stream where degree of heterogeneity is higher. Recently, Cao et al [1]proposed a variant model to estimate PCE factors based on the traffic stream speed. They have used motorcycle as the reference mode and equation (8), through which PCE factors are derived**.**

$$\boldsymbol{MCU_k = \frac{\bar{V}_{mc}}{\bar{V}_k} * \frac{\bar{S}_k}{\bar{S}_{mc}}} \tag{8}$$

Where, MCU_s= motorcycle equivalent unit of type *k* vehicle;*V mc,V k* = the mean speed of motorcycles and type *k* vehicle, respectively (m/s);*S mc*, *S k* = the mean projected space for motorcycles and type *k* vehicle, respectively (m^2). Equation (8) incorporates mean projected space along with the speeds of various vehicle types. The mean effective space was incorporated with the notion that space occupancy of vehicle is a function of operational behavior of a particular vehicle type in the traffic stream. This method is simple in its construct, and direct collected data of speed can be utilized. Additionally, incorporation of road occupancy parameter provides more thoroughness in estimation of PCE factors.

2.3 Method based on Multiple Regression Analysis

Regression analysis method is used in many studies to derive PCE factors[10]. The explanatory variables are always representing the number of vehicles of a particular type considered in the study, and these explanatory variables are used to explain average traffic speed (for deriving PCE at midblock location) or saturation flow rate / lost time (for deriving PCE at intersection location). A study carried out by Minh and Sano [14] incorporated following equation for estimation of PCE, which is given in equation (9):

$$S = FFS + a_{1.}\ PC + a_{2.}\ Bus + a_3.\ MC + a_4.\ HV \quad (9)$$

where: S= Avg. traffic stream speed**,** FFS= Free flow speed**,** PC= No. of Passenger Cars in traffic stream**,** Bus= No. of Bus in traffic stream**,** MC= No. of Motorcycle in the traffic stream**,** HV= No. of Heavy vehicle in the traffic stream**,** a, b, c, d = Marginal effect of respective mode on Avg. traffic stream speed**.**

Based on the estimation of the above co-efficient in the equation, PCE factors for different type of vehicle are derived by taking the ratio of co-efficient obtained for a particular vehicle type with the co-efficient obtained for the reference vehicle (i.e. passenger car). This is given in equation (10):

$$PCE= a_{ir}/\ a_1 \quad (10)$$

The method based on multiple regression analysis is criticized in the literature based on the argument that speed usually not a linear function of volume [14]. However, the method can be utilized for a range of speed where it is behaving linearly with the volume. The computation of PCE factors are derived from this method as well and are presented in section 3.

2.4 Characteristics of Collected Data

Different traffic parameters are observed by recording traffic stream from video cameras. For an appropriate depiction of the Karachi traffic pattern, urban arterials are selected in a manner that all major towns of the Karachi are covered. Midblock stretches of urban arterials are selected following strict constraints on site selection to avoid impact of external factors on vehicular interactions, such as: influence of intersection controls, sharp geometrical features, median and road side openings and pedestrian crossings. The data in the form of recorded videos are collected from 12 different arterials of Karachi. These videos are then processed for obtaining information regarding classified volume, headways and spot speeds. The headway extraction process is based on drawing a transverse line (line perpendicular to the direction of traffic) on transparent paper which is superimposed on monitor screen showing traffic stream. Through “XNote Stop Watch” time duration between the two successive vehicles is recorded who are passing that transverse line. Four basic types of headways are extracted for a particular type of vehicle, to facilitate estimation of PCE from the headway based methods discussed in section 2.1.These parameters are classified in terms of 9 different vehicle types presented in Table 2. In addition to this, vehicular characteristic survey was also performed to obtained physical dimensions of the considered vehicle types and their weight carrying capacity.

Table 2. Vehicle types and their definitions

S.No.	Vehicle Type	Definition
1	Small cars	Car Length < 3500 mm
2	Large Cars	Car Length > 3500 mm
3	Three wheelers	Rickshaw, Qing-Qi, Three wheelers runs on motor power
4	Motorcycles	Two wheelers runs on motor power
5	Buses	Mini Buses and Large Buses (Local public Transport)
6	HCL	HI ace/Coasters/Vans (Private hired vehicles)
7	Pickups	Light freight vehicles
8	Heavy vehicles	Trucks and Trailers
9	Non-motorized	Animal Carts and Bi-cycles

3. Estimated PCE Factors and Comparative Analysis

This section reports results obtained from using different methods described in section 2. Both of the headway based method (presented through equation 1 and 6) requires data in the form of vehicle type based headway, and that is why data related to headway has been processed in this form. Mean values of these vehicle type based headway were used to estimate PCE factors. The speed method which is based on equation (8) required average speed of the vehicles in a traffic stream with projected area of particular vehicle type, the projected area of vehicle type was obtained through additional survey that provide dimension of vehicle type considered here. The Regression method (equation 10) is based on estimation of the co-efficient attached to the parameters that are representing number of vehicles grouped in a particular vehicle type in the traffic stream. Table 3 presents the output of the linear regression analysis, in terms of the co-efficient values and their t-statistics to provide significance of all incorporated variables.

Table 3. Regression Model output based on equation 10

Model Parameters	Constant	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
Co-efficient	70.35	-0.103	-0.181	-0.139	-0.11	-0.383	-0.213	-0.124	-0.201	-0.248
t-statistics	2.154	2.110	1.153	1.897	2.356	7.896	1.783	2.365	1.432	3.651
p-value	0.039	0.043	0.257	0.067	0.025	0.000	0.083	0.024	0.164	0.001

R-Square value of around 0.652 is obtained for the estimated model, showing that 35% of variation in the data is unexplained through the incorporated variables. Usually, this is termed as acceptable value of R-square. However, it should be noted that in the case of constrained nature of Eq. (10) (i.e. speed is only a function of volume of various vehicle classes), this value of R-square is significant. Additionally the purpose of this formulation is not to estimate speed through explanatory variables but to find out marginal effects on speed due to the introduction of certain type of vehicle in the traffic stream (i.e. co-efficient of regression equation), so that PCE factors can be established. For each method, half of the data were used to estimate the PCE factors and the remaining half of the data were used to validate the results. The selection process for particular data points is random.Table 4 presents the estimated PCE factors from the four methods (i.e. using equations 1, 6,8 and 10)considering "**Small Cars**" as reference transport mode.

It can be seen from table 3 that PCE factors estimated from all four methods are plausible and consistent to an extent. Furthermore, through validation exercise, it has been found that two data set that has been separated through random process are able to replicate results, which is evident from lower values of root mean square error (RMSE). In addition to this, method based on Eq. (6) gives lower values of PCE factors compared to result obtained from the method based on Eq. (1). This indicates that method based on Eq. (6) is more sensitive to absolute values of headways as the equation suggested. However, method based on Eq. (1) also incorporates a factor that accounts for weighted headways based on the proportion of a particular vehicle type in the traffic stream.The values obtained from speed method (i.e. from equation (8)) for large dimension vehicles (i.e. category 5, 6 and 8) are higher compared to those obtained from the headway methods. This is attributed to the dominancy of projected area parameter as speed difference between reference vehicles and larger dimension vehicles is not such significant. In addition to this, PCE factors from this method seems more appropriate as they are also able to represents capacity effect through the PCE values (i.e. larger vehicles require larger road space and therefore reduce capacity of the road for other vehicle types). The validation consistency check for this method which is represented through RMSE is also appropriate. The values obtained from regression method are slightly inconsistent especially for motorcycles. This might be because of significant presence of motorcycles in the traffic stream. Furthermore, low value of PCE factor for heavy vehicles compared to buses and HCL categories is also a significant concern.This trend is not appropriate according to the definition of PCE. In addition to this, t-statistics values of many parameters co-efficient are obtained higher than 0.05, which is suggesting inconsistencies in the estimated regression model. Headway method based on Eq. (6) is estimating PCE factors values considerably close to Small Car (i.e. reference vehicle), and because of which the distinction of vehicle type categories seems meaningless. For example, Large Car, Small Car, three wheelers and Pick-up PCE factors are quite close to each other (as difference is less than 10% compared with Small Car), which imply that these vehicle types behave similarly with each other. In this regard, PCE factors based on Eq. (1) under headway method seem more appealing than obtained from Eq. (6). Therefore, in terms of consistencies and plausibility of results, PCE factors obtained from headway method (Eq. 1) and speed method are more appropriate.

Table 4. PCE Factors Estimated from Four Approaches-*Small Cars* as a Reference Vehicle

		PCE Factors Estimation Approaches			
		Headway		Speed	Regression
S. No.	Vehicle Type	Eq. 1	Eq. 6	Eq. 8	Eq. 10
1	Small cars	1	1	1	1
2	Large Cars	1.142	1.086	1.182	1.757
3	Three wheelers	1.387	1.076	0.909	1.35
4	Motorcycles	0.595	0.603	0.453	1.068
5	Mini Buses	1.675	1.212	3.024	3.718
6	HCL	1.526	1.313	2.881	2.068
7	Pickups	1.56	0.925	1.543	1.204
8	Heavy vehicles	2.035	1.461	3.288	1.951
9	Non-motorized	2.271	2.177	3.138	2.408
Validation Consistency (RMSE)		0.063	0.021	0.031	1.568

Comparison of PCE factors obtained from speed method and Headway method (Eq. 1) revealed that later produces values relatively lower except for three wheelers and motorcycles. Additionally, lesser distinction between the categories such as Minibus, HCL and pickups is apparent in headway method. One important notion because of which speed method is more superior is the incorporation of dynamic and static characteristics of vehicle types; on the other hand headway methods are just based on dynamic characteristics of the vehicles.

Table 5. PCE Factors-from different studies

S. No.	Mode	Minh and Sano (2003) Vietnams[14]	Tiwari et al (2000) India [8]	Prastijo (2009), Indonesia [3]	CDGK 2011, Karachi [6]
1	Small cars	1	1	1	1
2	Large Cars	-	-	-	-
3	Three wheelers	-	1.4	0.65	0.5
4	Motorcycles	0.29	0.4	0.3	0.25
5	Mini Bus	2.26	2	2.1	2
6	HCL	-	-	-	2.5
7	Pickups	-	-	-	1.5
8	Heavy vehicles	-	2.4	3.1	3
9	Non-Motorized	-	2.8	1.3	-

Table 5 shows that the PCE factors estimated in this study are consistent with earlier studies reported recently in developing countries. PCE factors for Motorcycles and Three-wheelers in other countries studies are higher compared to what followed in Karachi. This is confirmed through this study as well as higher values are obtained for these two categories from all the four method used. Special feature of PCE factors reported in this study is that this study considered two categories of *Cars*; however, in previous studies Car is represented through only one category which is also a reference category. Therefore, the direct comparison may be questionable in this regard. Though, Table 5 gives good idea of the consistency of the PCE factors reported in this study with recent studies in other similar countries where degree of heterogeneity is high.

The results reported in this paper suggest that further studies are required to be conducted to envisage proper behavior of different vehicle types which are running on arterials of Karachi. In this regard approaches which are based on microsimulation models may provide appropriate results as through these method dynamic PCE factors (PCE factors which are function of traffic composition and volume) may be obtained, which may represent appropriate numbers in complex heterogeneous conditions.

4. Conclusions

This study reported estimation of PCE factors for heterogeneous traffic environment prevailing in urban arterials of Karachi city, Pakistan. Four methods were utilized that have their basis on different notions, and required different data items relevant to traffic stream and vehicles. The results reported are plausible and explainable; however, there are significant differences noted when obtained values are compared for the four methods and what followed in Karachi. It has been found that method that incorporate vehicles speed along with projected area of vehicles are provide appropriate estimate of PCE values. This raises a significant question that, "Are we using the right numbers in traffic studies of Karachi when it comes to PCE values"? The study suggests that further investigations are necessary to examine behavior of different type of vehicles, which may lead to appropriate values of PCE factors.

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