



Modelling passenger car equivalency at an urban mid-block using stream speed as measure of equivalence

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Abstract

The effect of traffic volume and its composition on Passenger Car Equivalency (PCE) of different vehicle types in a mixed traffic stream is investigated taking an urban mid-block section as the case study. The reduction in stream speed caused by marginal increment in traffic volume by a vehicle type is compared with that of caused by an old technology car, for the estimation of PCE of that vehicle type. A Neural Network (NN) approach is explored for capturing the underlying non-linear effects of traffic volume and its composition level on the stream speed. It is found that PCE of a vehicle type varies in a non-linear manner with total traffic volume and compositional share of that vehicle type in the traffic stream. The speed model using NN technique alone could establish the variation of PCE with vehicle type, traffic volume and its composition.

Keywords: Stream Speed; Heterogeneous/Mixed traffic; Neural Network; Passenger Car Equivalency; Measure of Equivalence.

Introduction

The growing congestion level on urban roads and its resulting delay, fuel loss, environmental degradation etc. is a major concern to transportation engineers. Urban traffic in most of the developing countries is heterogeneous in nature. Therefore, conversion of heterogeneous traffic into a stream of homogeneous one by using appropriate Passenger Car Equivalency (PCE) values is an elementary step for analyzing mixed traffic, and formulating traffic management measures for mitigation of congestion on urban roads. Besides this, appropriate PCE values are also used for capacity analysis as well as traffic engineering research and applications.

Highway Capacity Manual (HCM) (TRB 1994, 2000) defines PCE as “The number of passenger cars that are displaced by a single heavy vehicle of a particular type under prevailing roadway, traffic and control conditions”. PCE is also defined as the number of passenger cars having the same impedance effect as a vehicle of a given type under a

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prevailing roadway, traffic and control condition. PCE of a vehicle type is described with reference to prevailing roadway, traffic and control condition (Chandra et al. 1995; HCM 1994; HCM 2000; IRC 1990). The change of PCE with respect to roadway and control condition has been recognized by suggesting different sets of static PCE values for multilane highways, urban arterials, signalized intersections etc. (TRB 2000; IRC 1990). However, for a prevailing roadway and control condition, the effect of traffic volume and its composition on PCE has not been studied adequately. The change in traffic composition is predominant in highly heterogeneous traffic environment prevailing in developing countries. Using fixed PCE values for all traffic volume and composition levels may be misleading while estimating service volumes or formulating traffic management measures. This paper demonstrates a methodology for estimating PCE and studying the effect of traffic volume and its composition on the same for a prevailing roadway and control condition. An urban mid-block in a developing country is considered as a case study for demonstrating the methodology.

Background work

Enormous works have been done on estimation of PCE and capacity of roads in U.K and U.S.A. Other developed countries like Australia and Sweden have also developed their own capacity norms. The HCM 1950 (Highway Capacity Manual) considered a single factor of 2 to account for the impact of heavy vehicles on multilane highways in level terrain, i.e. trucks have same qualitative effects as two passenger cars do (HRB, 1950). Passenger Car Equivalency concept was first inducted in the HCM 1965 to account for the effect of trucks and buses in a traffic stream. After the advent of the concept of PCE in 1965, many researchers have quantified the damage caused by heavy vehicles in comparison with passenger cars by developing PCE values using different methodologies and equivalency criteria.

The HCM (TRB 2000) suggests different sets of PCE values for highway facilities like two-lane, multi-lane, freeways etc. In the process of developing PCE, some of the studies used field data whereas other studies resorted to traffic simulation techniques (Werner 1976; Huber, 1982; Van Aerde and Yagar 1984; Krammes and Crowley 1986; Webster and Elefteriadou 1999). Joseph et al. (1980) suggested a model for determination of PCE by considering actual traffic delays caused and volume of opposing traffic. They reported PCE values, which were significantly lower as compared to the HCM values, but followed same fluctuations. Carroll and Wiley (1982) studied PCE on rural highways by analyzing field data on two and four lane highways. An analytical model was developed to estimate PCE based on speed distribution, traffic volume and vehicle types. Roess and Messer (1984) identified three approaches for estimating PCE namely, constant volume-to-capacity approach, equal-density approach and spatial headway approach. Several investigations on performance of signalized/un-signalized intersections by different types of vehicles were also a special case of quantifying PCE (Branston and Van Zuylen 1978; Branston and Gipps 1981; Benekohal R. F and Zhao.W 1996; HCM, 1985, 1994).

In India, many researchers/organizations have worked out PCE at urban as well as for rural roads and intersections. Bhattacharya and Mandal (1980) developed a generalized model for PCE estimation based on headway at intersection. PCE estimation using headway in mixed traffic flow is not rational as it is difficult to measure headway in

mixed traffic condition under poor lane discipline. Central Road Research Institute (CRRI 1988) adopted linear regression analysis technique to determine PCE for different classes of vehicle. Ramanayya (1988) developed simulation models to depict mixed traffic flow on single-lane one-way, two-lane one-way and two-lane two-way roads. Road User cost Study proposed PCE factors based on the length and speed of a vehicle type relative to those of a car (Kadiyali and Associates 1992). IRC: 106 (1990) recommended two sets of PCE considering compositional effect. It is recognized that the PCE of a vehicle type varied with proportion of that vehicle type in the traffic stream. Madhu et al. (2002) used linear regression technique to estimate PCE at urban signalized intersections.

Attempts have been made by researchers to estimate dynamic PCE values of different vehicle categories in a traffic stream. Chandra et al. (1995) worked on the estimation of dynamic PCE values and capacity of urban roads. Using least square analysis, several alternative forms of variables were tried out to incorporate the effect of influencing parameters on speed of individual vehicle type. Marwah and Singh (2000) analyzed traffic flow on urban roads using a two-lane one-way traffic simulation model. The Level of Service (LOS) experienced by different categories of vehicles were decided when the traffic stream contained 65 percent non-motorized vehicles.

Most of the research works have provided significant insight about mixed traffic operation, but recommended only static PCE values for different roadway and control conditions. For a roadway facility, the PCE of a vehicle type is assumed unaffected by traffic volume and its composition. Sometimes, such assumption may be misleading while estimating service volume of a facility or formulating traffic management measures.

DataBase

In order to demonstrate a methodology for studying the effect of traffic volume and its composition on PCE, an urban mid-block section, M. Karve Road in Mumbai Metro City (India) is considered. M. Karve Road is a four lane divided road with 7.0 m carriageway width in one direction. Classified traffic volumes and speeds of different vehicle types on one side of M. Karve road are recorded using Video-graphic technique. Although, speed and traffic volume data are extracted for every minute interval, the data for an interval of 5 min. is used in the present work after carefully observing the scatter of speed-flow data and the variation of estimated capacity values with different durations of counting (i.e. 1 min, 2 min, ... , 15 min). Four different vehicle types namely, Heavy vehicles (HV), (i.e. combination of Buses and Commercial vehicles), Old Technology Car (OC), New Technology Car (NC) and Two-Wheeler (TW) are considered.

During the last decade, several new models of passenger cars have been launched in the Indian market. These cars are called as “New Technology Cars”. In general, most of these cars are smaller in size with a superior speed capabilities and acceleration/deceleration characteristics as compared to cars which were dominating the Indian market in the past (Kadiyali and Viswanathan 1993). The traditional cars, which are still in use, are referred to as “Old Technology Cars”.

A refined dataset of 330 data points, each representing 5-minute traffic state, is used for analysis. Classified traffic counts, speed of each vehicle type and traffic composition

data are used for the development of database. The stream speed of traffic is calculated based on weighted speeds of different vehicle types.

Proposed approach for PCE estimation

Researchers have considered different Measures of Equivalence (MOE) for the estimation of PCE (Craus et al. 1980; Hubber 1982; Krammes and Crowley 1986). It has been indicated that for a given roadway and control condition, traffic stream alone should account for variation in PCE. Average stream speed is an equivalency criteria commonly used for different roadway facilities (HRB 1965; St. John 1976; Linzer et al. 1979; Van Erde and Yagar 1984; Elefteriadou et al. 1997; HCM 1994; IRC 1990). For urban roads, the stream speed is also used as a Measure of Effectiveness for defining the levels of service (HCM 1994; IRC 1990). Therefore, in the present study, stream speed is considered as a measure of equivalence (MOE) for modeling PCE at urban mid-blocks.

An attempt is made to model stream speed as a function of dynamic control variables like traffic volume and its composition. At any traffic state (defined by traffic volume and its composition), increase in traffic volume separately by each vehicle type is expected to cause different reductions in stream speed. The reduction in stream speed caused by increase in traffic volume by a vehicle type is compared with that of caused by old technology car, for the estimation of PCE of that vehicle type. Old technology car is taken as the reference vehicle for the estimation of PCE. The PCE of a vehicle type 'i' at volume level 'v' and composition 'm', is estimated as shown in (1). The volume level 'v' and composition 'm' are called base volume and base composition respectively. The speed model is used to study the variation of PCE with base volume and composition.

$$PCE_{i,v,m} = \frac{MD_{i,v,m}}{MD_{OC,v,m}} \quad (1)$$

where,

$MD_{i,v,m}$ = Marginal damage on MOE (i.e. reduction in stream speed) caused by a vehicle type 'i' at a base volume 'v' and base composition 'm'.

$MD_{OC,v,m}$ = Marginal damage on MOE (i.e. reduction in stream speed) caused by old technology car at a base volume 'v' and base composition 'm'.

The proposed approach for estimation of PCE requires suitable modeling of stream speed as a function of control variables like traffic volume and its composition. In the present work, modeling of stream speed is attempted using Neural Network (NN) to simulate the non-linear behavior between traffic volume along with its composition and resulting stream speed. There are ample applications of standard back propagation technique for modeling NN in traffic engineering field (Dochy et al. 1996; Dougherty and Cobbett, 1997). Although several supervised NN modeling rules are available, the feed-forward neural network with standard back propagation technique using gradient descent rule is attempted in the present work .

NN as modeling tool

A NN is a massively parallel-distributed information processing system that has certain performance characteristics resembling biological neural networks of the human brain (Heykin 1994). NN has a big role to play in the field of traffic engineering where a high degree of complex non-linear cause-effect relationship exists. In other words, when the possibility of representing the complex relationships is remote in terms of physical or conceptual modeling, NN may play an important role to model this in a more direct way without specifying any mathematical form. NN method is a data driven approaches, which opposes traditional model driven approaches. It is known that modeling process in NN is more direct than any conventional technique. Sometimes NN techniques outperform classical calibration and estimation procedure. The power of NN is that, it imposes fewer constraints on the form of functional relationship between input and output variables than any conventional fitting technique.

The problem of capturing complex non-linear relationships between the causal input vectors of traffic stream and the corresponding output i.e. stream speed falls under the category of pattern mapping and prediction. Although there are numerous types of NN models, by far the most widely used and well suited to the present system is feed-forward NN or multi-layer perceptron, which is organized as layers of computing elements called neurons, connected by weighted connections between layers (see figure 1). Typically, there is an input later, an output layer, and one or more intermediate layers, called hidden layers (Heykin 1994; Kosko 2000). To simulate unknown non-linear behavior of traffic system, sigmoidal function is used as an activation function for NN model development process.

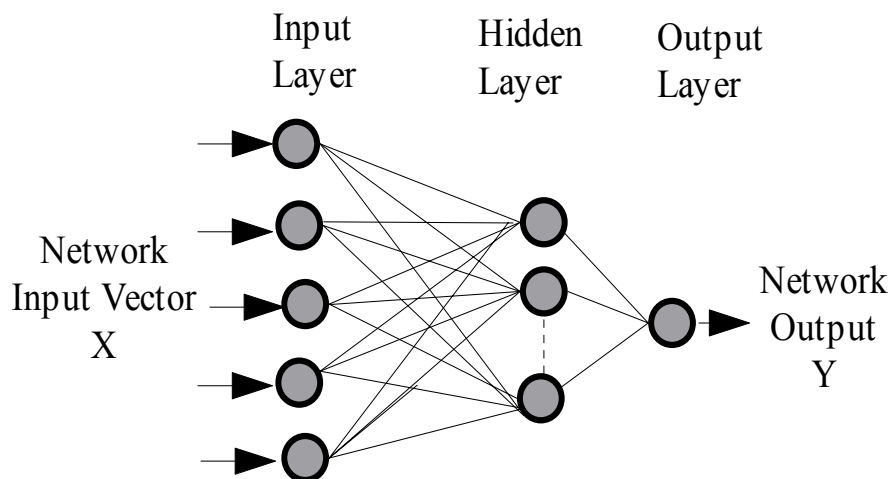


Figure 1: A feed-forward three-layer neural network.

Modeling stream speed using NN

Standard back propagation algorithm is used for training a neural network, which is of feed-forward type. The neural network is trained using 258 patterns (i.e. 78% of the total data). For the testing of the NN model, 72 unseen patterns (i.e. 22% of the total

data) are used. Different NN models are attempted based on nature of input vectors, number of hidden layers, number of nodes per hidden layer, initialization of weight matrix, learning rate, momentum factor, number of training cycles etc. Finally, a 5-4-1 (i.e. 5 input nodes and 1 output node with a single hidden layer of 4 nodes) NN architecture is accepted after carefully observing RMSE, correlation coefficient, nature of variation of stream speed with traffic volume, and sensitivity of NN in estimating stream speed with respect to each vehicle type. In input vector layer, the first one represents the total vehicle volume in equivalent number of old technology car (V_{EQ}), whereas other four nodes represent the composition of four different vehicle types namely heavy vehicle (HV), old technology car (OC), new technology car (NC) and two wheeler (TW) in total volume representation.

V_{EQ} is calculated considering physical plan areas of different vehicle types as compared to that of old technology car as shown in (2). The Physical plan area considered for heavy vehicle (HV), old technology car (OC), new technology car (NC) and two wheeler (TW) are taken as 23 m², 7.82 m², 5.47 m², 1.44 m² respectively.

$$V_{Eq} = N_{HV} * \frac{23}{7.82} + N_{OC} + N_{NC} * \frac{5.47}{7.82} + N_{TW} * \frac{1.44}{7.82} \quad (2)$$

Where,

N_{HV} = Number of heavy vehicles per hour

N_{OC} = Number of old technology cars per hour

N_{NC} = Number of new technology cars per hour

N_{TW} = Number of two wheelers per hour

The training as well as testing performance of the accepted NN model is given in table 1. Variation of stream speed with an increase in traffic volume, as obtained from the selected NN model, is shown in figure 2. It is observed from figure 2. that the variation of stream speed with traffic volume as obtained from the accepted NN model is consistent with the established speed-flow relationship in stable flow zone (Gerlough and Huber, 1975). The base composition of traffic stream used for studying the speed-volume relationship includes 9.57% HV, 51.57% OC, 13.40% NC and 25.46% TW.

Table 1: Training and testing performance of the accepted ANN model.

	<i>On Training Patterns</i>	<i>On Testing Patterns</i>
RMSE	2.059474	2.16912
Correlation Co-efficient	0.964612	0.951291

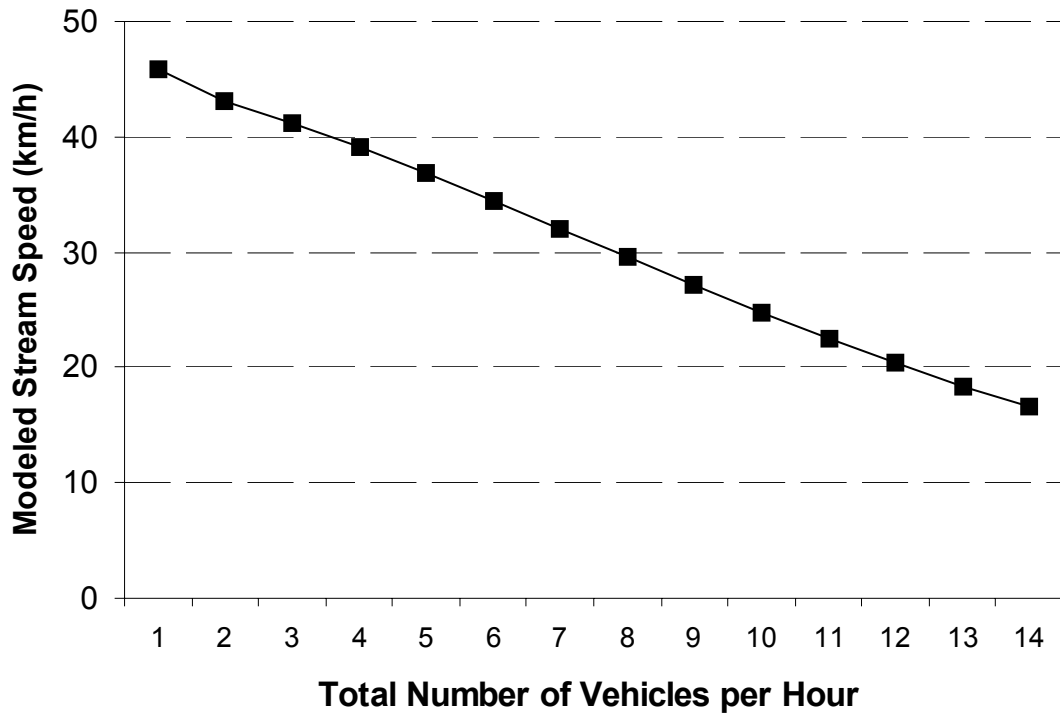


Figure 2: Variation of stream speed with traffic volume.

Estimation of PCE

The NN model is used for estimation of PCE at incremental traffic volumes. The base composition of traffic stream is kept the same as used for the development of speed–volume curve. Different base volumes are generated ranging from 500 to 3250 vehicles per hour with an increment of hourly traffic volume by 250 vehicles per hour. For different base volumes, marginal increment in total traffic volume is done separately by each vehicle type present in the traffic stream. As modeling of stream speed is based on 5-min traffic data, marginal increment in base volume implied addition of 12 vehicles of a type in hourly traffic volume.

PCE of each vehicle type at different base volumes is estimated and plotted as shown in figure 3. Heavy vehicles considered in the present work largely consist of city buses, which are in good operating condition and drivers are also familiar with route condition. Therefore, at or near free flow, there is hardly any speed damage to traffic stream due to the presence of buses and accordingly PCE of heavy vehicles is estimated even lower than unity. However, as volume increases, the physical dimensions and low maneuverability of heavy vehicles become dominating and therefore, heavy vehicles become more detrimental to the traffic stream as compared to all other vehicle types. New technology cars are smaller and have better speed capabilities than old technology cars, which justifies lower PCE value for new technology cars. Two-wheelers being the smallest vehicle have the least detrimental effect on the traffic stream at all flow levels.

Also, the effect of traffic volume is predominant on PCE of heavy vehicles, and negligible on PCE of two wheelers. New technology cars remain in between.

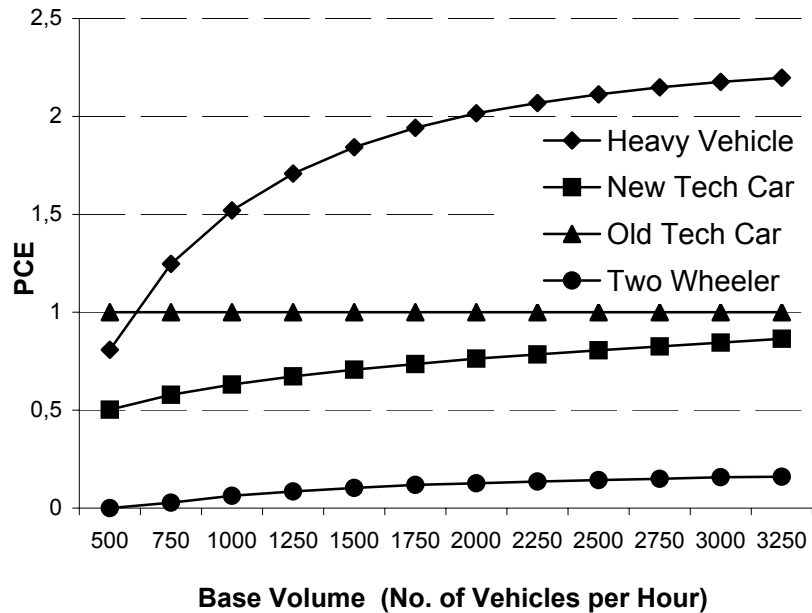


Figure 3: Modeled PCE values for different vehicle types.

Effect of composition and traffic volume on PCE

The variation of PCE with traffic volume as shown in figure 3 corresponds to a base composition of traffic stream. The effect of change in compositional share of a vehicle type on PCE of that vehicle type is also studied at different base volume levels. For this purpose different base compositions of traffic stream are assumed by varying composition of each vehicle type within the observed range. The change in share of a vehicle type is adjusted by appropriate increment or decrement in share of old technology cars to keep the total proportion as unity. Base compositions used for different vehicle types are summarized in Table 2. It may be observed from Table 2 that the effect of compositional share of heavy vehicles on the PCE of the same vehicle type is studied for 5%, 10% and 15% share of heavy vehicles in the traffic stream. Similarly, new technology cars' PCE is estimated for 45%, 50% and 55% share of new technology cars in the traffic stream, whereas two wheelers' PCE is estimated for 20%, 25% and 30% share of two wheelers in the traffic stream. The effect of compositional share of heavy vehicles, new technology cars and two wheelers on PCE is shown in figure 4, 5 and 6 respectively.

Table 2: Different compositions of traffic stream.

Target Vehicle Type	Assumed Proportion of Different Vehicle Types			
	Heavy Vehicle (HV)	Old Technology Car (OC)	New Technology Car (NC)	Two Wheeler (TW)
Heavy Vehicles (HV)	0.05	0.57	0.13	0.25
	0.1	0.52	0.13	0.25
	0.15	0.47	0.13	0.25
New Technology cars (NC)	0.1	0.55	0.1	0.25
	0.1	0.5	0.15	0.25
	0.1	0.45	0.2	0.25
Two Wheelers (TW)	0.1	0.57	0.13	0.2
	0.1	0.47	0.13	0.3
	0.1	0.52	0.13	0.25

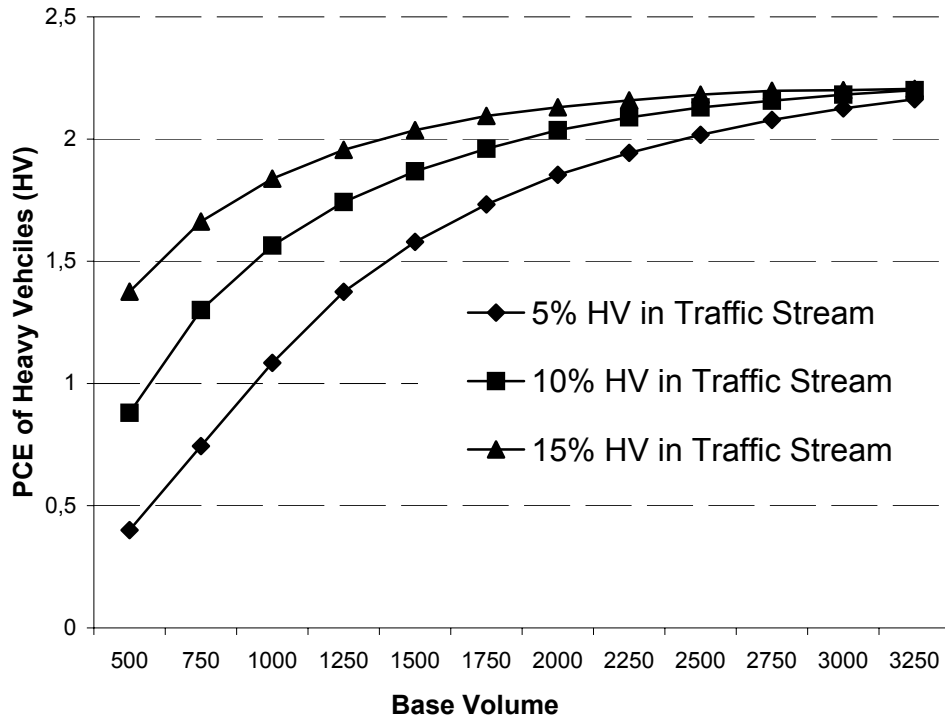


Figure 4: Effect of compositional share on PCE of heavy vehicles.

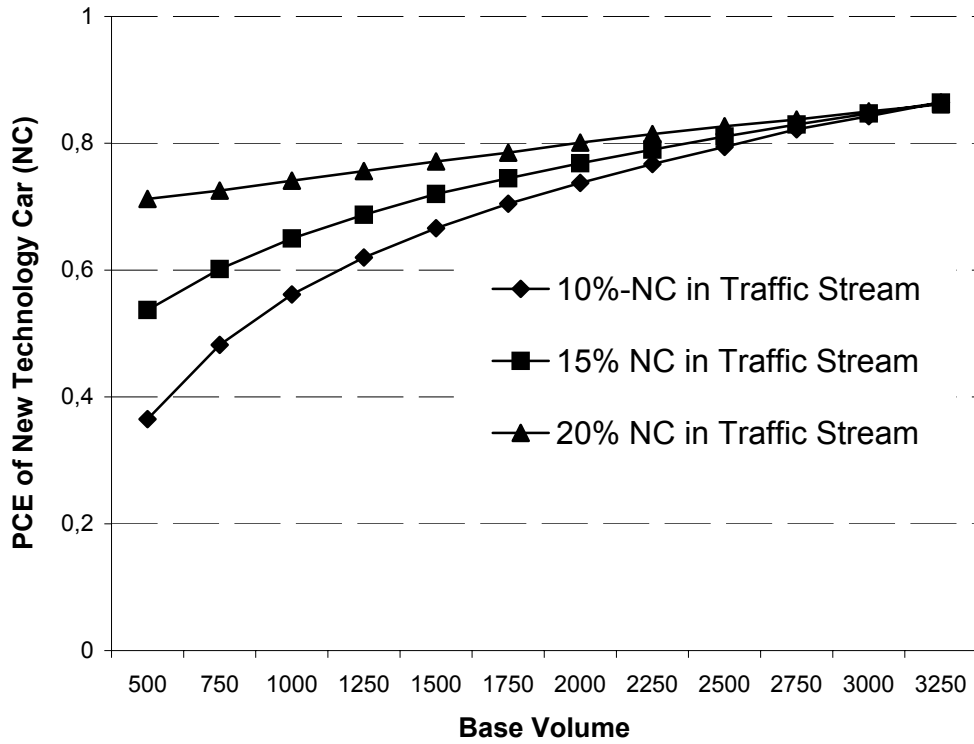


Figure 5: Effect of compositional share on PCE of new technology cars.

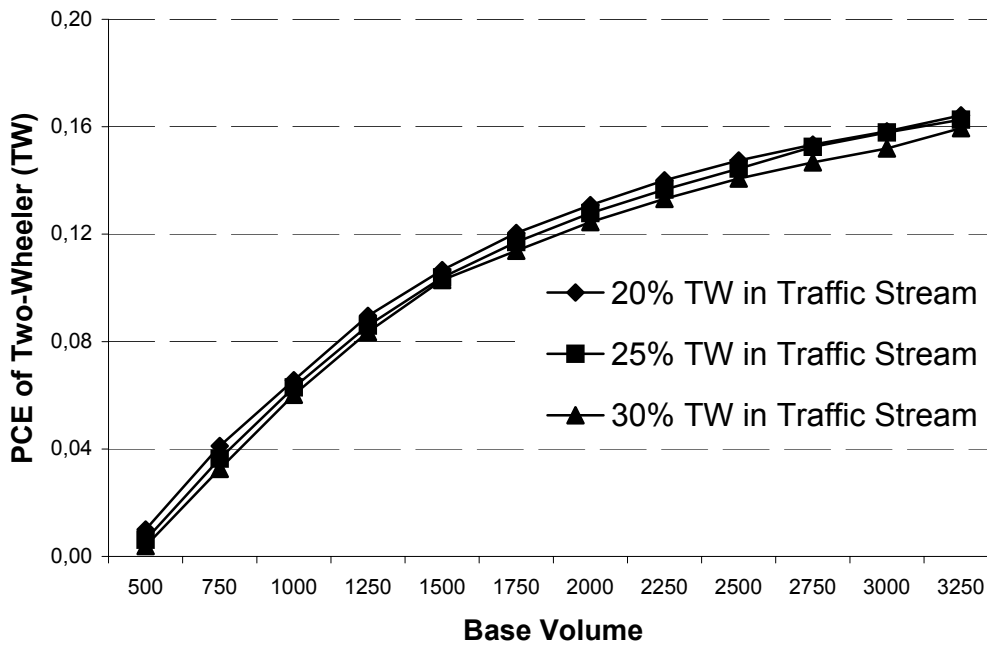


Figure 6: Effect of compositional share on PCE of two-wheelers.

It is observed that PCE of heavy vehicles or new technology cars increases with an increase in its share in total traffic volume. For these vehicle types, the effect of compositional variation on PCE is generally significant at lower traffic volumes. As the volume increases, the effect of share of heavy vehicles or new technology cars on the PCE of respective vehicle types becomes insignificant. Although PCE of both heavy vehicles and new technology cars are affected by the share of corresponding vehicle type in traffic stream, the effect is significant for heavy vehicles. On the other hand, PCE of two-wheelers is least affected by the change in compositional share of two wheelers in the traffic stream. Although PCE of two wheelers is found to decrease marginally with an increase in share of two wheelers in traffic stream, the change in PCE is practically insignificant.

The effect of share of a vehicle type on PCE of the same vehicle type is found to be compatible with the size of vehicle and its maneuverability as well as speed capability. Also, a single NN model could capture the non-linearity in PCE of each vehicle type with respect to traffic volume and its composition. The observed variation of PCE establishes the fact that PCE of a vehicle type varies with traffic volume and its composition.

Closure

In the present paper, the effect of traffic volume and its composition on Passenger Car Equivalency (PCE) is studied. Taking the stream speed as Measure of Equivalence (MOE), a methodology is demonstrated for the estimation of PCE. For the estimation of PCE, the reduction in stream speed caused by marginal increment in traffic volume by a vehicle type is compared with that of caused by an old technology car. Old technology car is taken as the reference vehicle for the estimation of PCE. For modeling stream speed, a NN approach is explored. Speed model using NN technique alone could establish the variation of PCE with traffic volume and its composition.

The case study presented in the paper reveals that PCE is affected by traffic volume and its composition. For all vehicle types, PCE values are found to increase with an increase in traffic volume. However, the effect of traffic volume on PCE is predominant for heavy vehicles. For heavy vehicles and new technology cars, PCE values are also found to increase with an increase in compositional share of respective vehicle types in the traffic stream. The PCE of two wheelers practically remains unaffected by its compositional share in the traffic stream.

The results presented in the paper are case specific but encouraging for further application of the proposed methodology on an enhanced database. Although, a feed-forward neural network with standard back propagation technique using gradient descent rule performed satisfactorily, it may be necessary to explore other supervised NN modeling rules for developing a more rational NN model on an enhanced database.

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