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Artificial Neural Network Model for Passenger Car Equivalent of Bus

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Abstract

The Passenger Car Equivalent (PCE) or Passenger Car Unit (PCU) number is critical for any traffic flow analysis. PCE depends on many factors such as pavement width, shoulder conditions, directional split, percentage of slow-moving vehicle etc. The objective of this study is to develop a model based on Artificial Neural Network (ANN) for the estimation of PCE values for buses. Different road sections of Khulna Metropolitan City were selected as the study area for this research. The speed of the buses was taken by speed gun from the selected sections of the roads. The ANN toolbox of MATLAB was used to simulate the problem. PCE value obtained from ANN model for different road sections is 3.68, 2.91, 4.32, and 3.38 for Satkhira road, Rupsha road, Daulatpur road and Fulbarigate road respectively. The result showed that ANN model gives more accurate, authentic and rapid results compared to other methods to estimate the PCE value at different sections of road which can be used in signal design, saturation flow measurement, traffic capacity analysis etc.

Keywords: *Passenger car equivalent; saturation flow; artificial neural network; bus.*

1 Introduction

In Bangladesh and many other developing nations, local urban roadway traffic is extremely heterogeneous. The public frequently uses the road as a form of transportation. The country's diverse road networks are utilized by travelers to get from one region to another, by businesses to supply services on time, and by individuals to move goods around the nation. If volume information is not provided alongside the traffic composition, expressing traffic volume in terms of the number of vehicles traversing a certain segment of a roadway per unit time will be nonsensical under such circumstances. In order to analyze the mixed traffic, it is necessary to convert the heterogeneous traffic into a stream of homogeneous traffic by utilizing the proper passenger car equivalent (PCE). For both capacity analysis and research in traffic engineering, the proper PCE are also used.

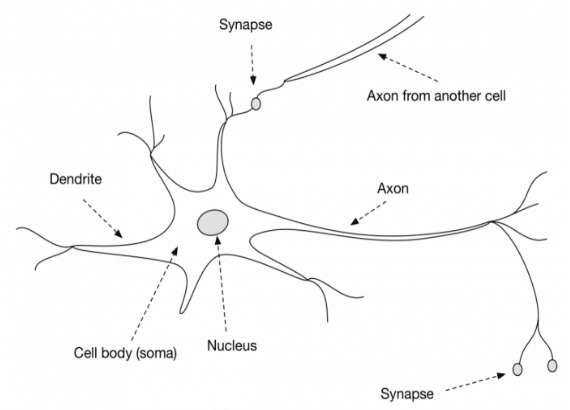
The term "Passenger Car Equivalent" (PCE) was originally used to analyze mixed traffic by translating various vehicle types into an equivalent number of passenger cars in the Highway Capacity Manual (HCM) (Transportation Research Board (TRB, 2000). Therefore, the majority of traffic analysis depends on these PCE numbers. On freeways and multilane highways, PCE reported by the HCM for trucks and buses represents their effect when traffic is operating at peak efficiency. When determining traffic volume/capacity and level of service (LOS), an accurate and simple assessment of PCE factors for various vehicles is helpful. This can simplify the decision-making process for future highway and road expansion (widening and improvement). Therefore, for an accurate calculation of traffic volume, all PCE value-affecting elements should be appropriately taken into account. The majority of traffic engineers might analyze various situations using the only set of PCE parameters provided in the US HCM (TRB, 2000), omitting acknowledged influencing elements that result in a significant percentage of mistake in traffic/capacity ratio evaluations. Therefore, it is required to calculate the PCE based on the current state of the roads and traffic in Khulna Metropolitan City (KMC), Bangladesh. Passenger car equivalent is crucial for research on the allocation of roadway costs as well as capacity issues. The objective of this study is to develop an Artificial Neural Network (ANN) based model for estimating the passenger car equivalent (PCE) of bus of different locations in Khulna Metropolitan City. ANN-based models are significant for a variety of independently influencing aspects.

2 Literature Review

The impact of trucks and buses in the traffic stream, the term "passenger car equivalent" (PCE) was first introduced in US HCM (TRB, 2000). PCE is defined as "the number of passenger cars that are displaced by a single heavy vehicle of a particular type under existing roadway, traffic, and control conditions" in the most recent edition of the US Highway Capacity Manual (TRB, 2016). On two-lane highways with level terrain, trucks have the same impact as two passenger vehicles (PC), according to the Highway Capacity Manual (TRB, 2016). Two factors—operating speed and volume-to-capacity ratio—were used to define LOS. Many academics have attempted to quantify the impact of heavy vehicles on traffic flow since the introduction of the PCE concept in 1965 by constructing HCM-like PCE factors using various approaches and equivalence criteria (John and Glauz, 1976).

PCE values are used in the US HCM analysis and other design processes to take into consideration the presence of diverse vehicles in the traffic stream (TRB, 2000). The diverse mixtures of vehicles in a traffic stream can be expressed as a homogenous, standardized traffic stream of passenger cars using these PCE values. As a result, the majority of traffic assessments depend on these PCE numbers. In mixed traffic situations, it can be demonstrated that a variety of factors influence the PCE value (Chandra *et al.*, 1995). Most traffic engineers and other transportation specialists might inadvertently use the only set of PCE factors included in the US HCM (TRB, 2000) for analyses in various situations. This is primarily because of traffic and road conditions have an impact on the speed, cycles of acceleration and deceleration, and freedoms of maneuver that all affect PCE parameters. Because future highway widening decisions and Level of Service (LOS) enhancement plans are depended on current LOS and highway volume/capacity ratio. These PCE values should be appropriately taken into account for an accurate assessment of traffic volume.

Neural networks are a computational approach which is based on a large collection of neural units and modeling the way a biological brain solves problem with large clusters of biological neurons connected by axons. Figure 1 shows a typical biological neuron. Basically, they are made up of inputs (like synapses), which are multiplied by weights (the potency of the corresponding signals), and determined by a mathematical function that defines the neuron's activation. The output of the artificial neuron is computed by another function (which could be the basic identity), sometimes in dependency on a specific threshold. Artificial neural networks (ANNs) integrate artificial neurons to analyze data.



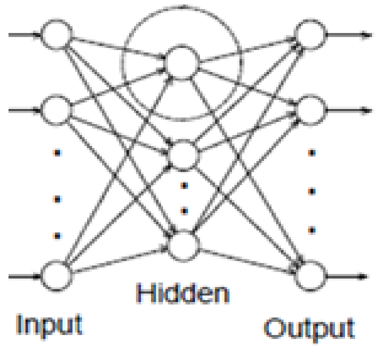


Figure 1. A Typical Biological Neuron

Figure 2. An Artificial Neural Network

There are many different ANN types and applications. Hundreds of different models that are regarded as ANNs have been produced since the first neural model by McCulloch and Pitts (1943). The Back-propagation method (Rumelhart and McClelland, 1986) is one of the most often used models in ANNs and is the foundation for many others. It is clear that a neural network gets its processing power from two sources: first, its massively parallel distributed topology, and second, its capacity for learning and generalization (Freeman and Skapura, 1991). A much of the language used in artificial neural networks, which replicate the functioning of the human brain, comes from the field of neuroscience. A biological neuron essentially takes inputs from other sources, mixes them in some fashion, runs a generally nonlinear operation on the result, and then outputs the result. The structure and operation of ANNs have been extensively discussed by numerous writers (e.g., Hecht-Nielsen, 1990; Maren et al., 1990; Zurada, 1992; Fansett 1994). Figure 2 shows a neural network include an input layer, an output layer, and one or more hidden layers. Equation 1 and Equation 2 provide a summary of the processing unit in a neural network.

$I_j = \sum(Wij\ xi + \theta j)$……………………..summation………..(1)

$y_j = f(I_j)$ ……………………………..…transfer……..……….(2)

The performance of the trained model must be validated using an independent testing set after the model's training phase has been completed successfully. The scope of this work does not include specifics on the development and process of ANN modeling. With one input, one output, no hidden layer nodes, and a linear transfer function, ANNs can create the simple linear regression model. The threshold 0 and connection weight w in the ANN model.

2.1 Methods of Calculating PCE Value

Some developing countries have extremely different transportation patterns, road systems, and local restrictions than those in developed countries. Therefore, it is essential to identify the various traffic flow factors that are appropriate for the unique features of local urban transportation systems. A passenger car unit, also known as a passenger car equivalent (PCE), was created to evaluate the various vehicle types (Saha *et al.*, 2009). The impact of a particular form of transportation on traffic myths (such as headway, speed, and density) is measured in passenger Car Units (PCUs), which are expressed as a percentage of one standard passenger car. The numerical number assigned to a device to transform a mixed vehicle traffic stream into an equivalent traffic stream made up only of passenger cars or basic vehicles is known as a PCE value. When estimating PCE values for any of the route types found via capacity study techniques, two fundamental rules should be followed. The level of service (LOS) idea is connected to the passenger car equivalency concept via the first premise. The second principle underlines the need of taking into account all elements that affect a concern vehicle's (other than passenger automobiles) total impact on the performance of a traffic stream (Rahman and Nakamura, 2005). The comparable hourly rate of cars passing a point per unit of time is referred to as the traffic flow rate in the field of transportation engineering. According to John and Glauz (1976), PCE is calculated using truck volume to capacity ratio, mixed vehicle flow, and percentage of grade:

$$PCE = \frac{qB - qM(1-pr)}{qM * pr} \qquad (3)$$

Where, q_B = equivalent passenger car only flow rate for a given v/c ratio, qM = mixed flow rate, pr = truck proportion in the mixed traffic flow

Huber (1982) proposed a model for calculating PCE values for vehicles operating in multilane settings with unrestricted flow. The ratio of the volumes of two streams at a certain common level of impedance is connected to PCE-values. The formula used to determine PCE value is

$$PCE = \frac{1}{pr}\left(\frac{qB}{qM} - 1\right) + 1 \qquad (4)$$

A deterministic model of traffic flow was utilized by Rahman and Nakamura (2005) to calculate the impedance-flow relationship. Additionally, it was hypothesized that PCE-values fluctuate depending on the percentage of trucks in the traffic stream and are connected to the speed and length of the subject vehicles. Sumner et al. (1984) improved Huber's approach by incorporating several types of trucks into the traffic stream.

$$PCE = \frac{1}{\nabla P}\left(\frac{qB}{qs} - \frac{qB}{qM}\right) + 1 \qquad (5)$$

Where, qs = additional subject flow rate, ∇P = proportion of subject vehicles

Though it is defined by both density and speed, Rahman and Nakamura (2005) claimed that density is to be the controlling criterion for LOS in the US HCM (TRB, 2000). Mallikarjuna and Rao (2006) and Chari and Badarinath (1983) tried to use areal density to measure density in these circumstances. The total vehicle area projected on the ground divided by the size of the roadway is known as the areal density.

3 Methodology

Different road segments in Khulna Metropolitan City were chosen for this study

3.1 Data collection

The speed of the buses was taken by Speed Gun from the selected sections of the roads. By counting the number of vehicles traveling in both directions, the directional split and percentage of slow-moving vehicles were determined. Rickshaws, bicycles, vans, easy bikes, etc. were chosen as the slow-moving vehicles. The chosen roads' shoulders were rated as very poor, poor, fair, good, and excellent using the numeric values 1, 2, 3, 4, and 5, respectively. Using tape, the roadways' pavement width was measured. Tables 1 and 2 show the dimensions of the vehicles and the various governing parameters for PCE values. The dimension of the vehicles is used to calculate the PCE value (Chandra *et al*, 1995).

Table 1. Vehicle Dimension

	Length(m)	**Width(m)**	**Area(m^2)**
Bus	9.35	2.49	23.28
Passenger car	4.27	1.75	7.48

Table 2. Governing Factors of Different Sections

Section No	**Road Name**	**Pavement Width(ft)**	**Directional Split (%)**	**% Slow Moving Vehicle**	**Shoulder Condition**
1	Satkhira	23.50	60:40	25	Very poor
2	Rupsha	40.00	65:35	30	Fair
3	Daulatpur	30.00	55:45	20	Poor
4	Fulbarigate	28.00	55:45	35	Fair

3.2 Neural Network Model Development

The steps for creating ANN models involve choosing the model's inputs and outputs, dividing and pre-processing the data, choosing the right network and architecture, optimizing the connection weights during training, setting stopping conditions, and validating the model. The ANN toolbox of MATLAB (The MATHWORKS 2014 R2014a) was used to simulate the problem. In order to calibrate and validate the artificial neural network model, a database with four input and one output was made. Very poor, poor, fair, good, and excellent shoulder were used to classify it qualitatively; they were given the numbers 1, 2, 3, 4, and 5, respectively. Figure 3 shows the neural networking of this study. Pavement width, shoulder condition, proportion of two-way traffic split by direction, percentage of slow-moving traffic, grade and its length, surface characteristics, etc. are among the factors that have been identified as determining PCU value. Pavement width, shoulder quality, directional split, and the percentage of slow-moving vehicles are four well-known influencing aspects of PCE that are taken into account as input variables and PCE as the result in the present study.

3.3 Data Division

According to Twimey and Smith (1997), it is standard practice to split the available data into two subsets: a training set for building the neural network model and an independence validation set for estimating model performance in the deployed context. Seventy-five percent (75%) of the data set in this study was used for training, ten percent (10%) for model validation, and fifteen percent (15%) for model testing. In the current study, the target population was attained by attempting a number of random combinations of the training and testing sets until two sets of data which statistically consistent were attained.

4 Results and Discussion

A universal unit called a passenger car unit is utilized everywhere to bring down diverse categories of vehicle under varied traffic conditions. Accurate PCU estimation is a difficult process in and of itself because many different independent parameters might affect a vehicle's PCU value. There are very few studies that take into account the combined effects of all these influencing factors. When determining traffic volume/capacity and level of service (LOS), an accurate and simple assessment of PCU factors for various vehicles is helpful. This can simplify the decision-making process for future highway and road expansion (widening and improvement). According to Ministry of Communications (2005), a PCE value of 3 is used for large Bus but from this study an average value of 3.57 is found which is strongly correlated with the quoted results. PCE value obtained from artificial neural network model for different road section is shown in Table 3.

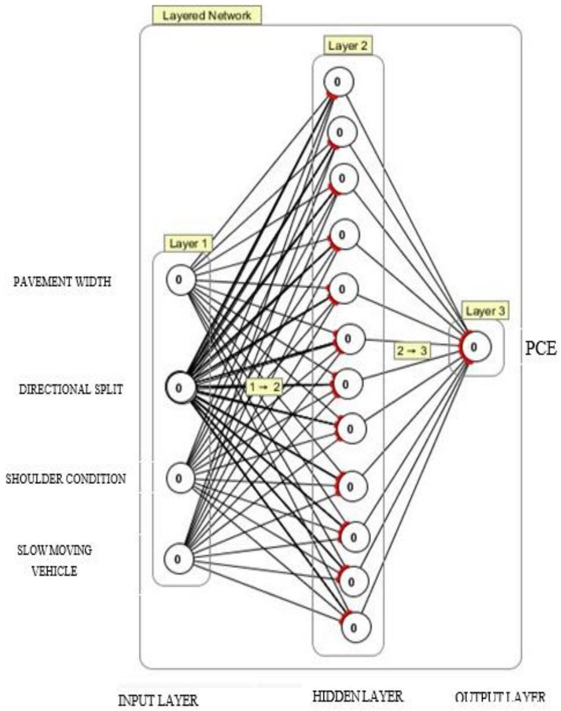


Figure 3. Neural Network

Table 3. PCE Values for Different Road Sections Using ANN

Section No	Section Name	PCE value
1	Satkhira	3.68
2	Rupsha	2.91
3	Daulatpur	4.32
4	Fulbarigate	3.38

The developed model's output is contrasted with the bus unit value quoted for passenger cars. The level of fitness of Neural Network predicted and quoted result of the training set are shown in the Figure 4.

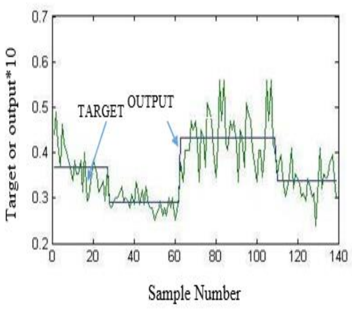


Figure 4. Comparison between Target vs Output

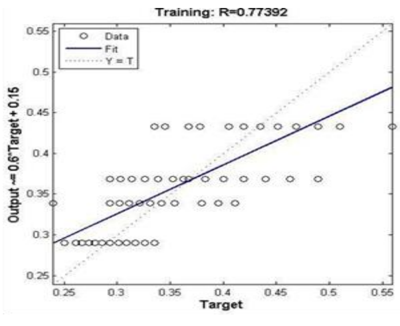


Figure 5. Regression Diagram of Training Set

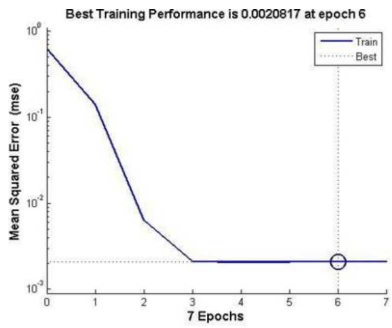


Figure 6. Mean Square Error Diagram

Due to the significant variety in the data and the limited network size, the regression value of the training set data in this study is found to be 0.77392, which is not close to 1. Figure 5 shows the regression diagram of training set.The mean square diagram is shown in Figure 6. It is seen that the iteration is completed at 6 epochs. The curve of the mean square error diagram is not too smooth. It is due to the variation between the dataset.

The key metrics utilized to assess the effectiveness of the ANN model created in this study includes the coefficient of regression (R), mean square error (MSE), mean absolute deviation (MAD), and mean absolute percent error (MAPE). The three errors (used as validation parameters) are found from this study a satisfactory one which are shown in the Table 4.

Table 4. Performance Evaluation

	MSE	**MAD**	**MAPE**
Error value	0.002082	0.000244	0.000692

5 Conclusions

The methods of PCE is used to renovate heterogeneous traffic into equivalent homogeneous traffic. In the current study, a model based on artificial neural networks is created to estimate the PCE value of a conventional vehicle, the bus, utilizing four well-known influencing factors: pavement width, shoulder type and quality, directional split, and traffic composition proportion of slow-moving traffic. 1000 iterations of the Levenberg-Marquardt training algorithm with local minima avoidance were performed. When the data acquired in this way are compared to the results mentioned, a strong degree of correlation is seen. As a result, it may be concluded that modern PCE values should be produced rather than relying on the outdated PCE values provided in code, either for signal design purposes or to estimate the saturation flow rate. This will provide a new avenue for traffic engineers to accurately and easily estimate PCE value and, in turn, traffic volume, capacity, and level of service in any circumstance.

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