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Evaluating Passenger Car Equivalent (PCE) Factors and Traffic Flow Characteristics on Sri Lankan Expressways

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Abstract: This paper investigates Passenger Car Equivalent (PCE) or Passenger Car Unit (PCU) values and traffic flow characteristics of Sri Lankan expressways: Southern (E01), Outer Circular (E02), and Katunayake (E03). The study highlights the importance of considering region-specific traffic parameters due to differences in road traffic systems, vehicle characteristics, and transport infrastructure across countries. PCE values vary based on vehicle dimensions, climatic conditions, and traffic flow. The calculated PCE values for passenger car - small category was found to range between 0.74-0.77, while heavy goods vehicles recorded significantly higher PCE values, ranging from 3.59-3.99. Research on PCE has been widely conducted globally, however limited studies exist in the context of Sri Lankan expressways. This study uses Chandra's method to calculate PCE values for eight vehicle categories, and the accuracy of the results was validated using the R-squared method, with simulations run through PTV VISSIM software. Additionally, the research evaluates traffic flow characteristics such as speed, density, and volume to optimize traffic management and support sustainable transportation. Relationships between speed-density, volume-density, and speed-volume were analysed using the Greenshield model. The average traffic volumes were determined as 911.8, 833.2, and 1884.9 passenger car per hour (pcph) on the three selected expressways. Observed results with the design were compared and revealed lower observed density (36.4 pc/km – 76.8 pc/km) values than the design predictions (160 pc/km) in passenger cars per kilometres. This study provides insights into traffic dynamics on Sri Lankan expressways and contributes to sustainable transport planning by identifying gaps between design assumptions and actual traffic conditions.

Keywords: Expressway Design, Passenger Car Equivalent, Traffic Flow Characteristics

1. Introduction

PCE (Passenger Car Equivalent) introduced in 1965 Highway Capacity Manual (HCM), quantifies the effect of heavy vehicles like trucks and buses on traffic flow. Many countries utilize PCE values for road design to improve traffic efficiency. Studies conducted in various countries have demonstrated the importance of regional-specific PCE values. For example, in Dhaka, Bangladesh, PCE values were updated in 2009 for designing signalized intersections. In Delft, the Netherlands, PCE values guide cyclists' route planning for safety and efficiency [1]. In India, studies in Nagpur revealed the need for PCE values based on lane width, influencing road improvements in 2014. These values have also been applied in intercity and urban road design across the country. In Sri Lanka, Kumarage (1996) first introduced PCE values, and further studies have refined these values for modern highway construction [2].

Traffic flow characteristics are key concepts in transportation engineering that describe vehicular movement using flow, speed, and density [3]. Traffic flow theory plays a significant role in transportation planning and design, with mathematical models used to analyse relationships between speed, density, and volume [4]. Two main approaches to studying traffic behavior are microscopic models, which focus on individual vehicles, and macroscopic models, which assess overall traffic flow [5].

Expressways play a critical role in Sri Lanka's transportation network, facilitating faster movement of passengers and goods. With the trend of increasing vehicle ownership and economic growth, expressways such as E01, E02, and E03 are experiencing rising traffic volumes and a diverse mix of vehicles.

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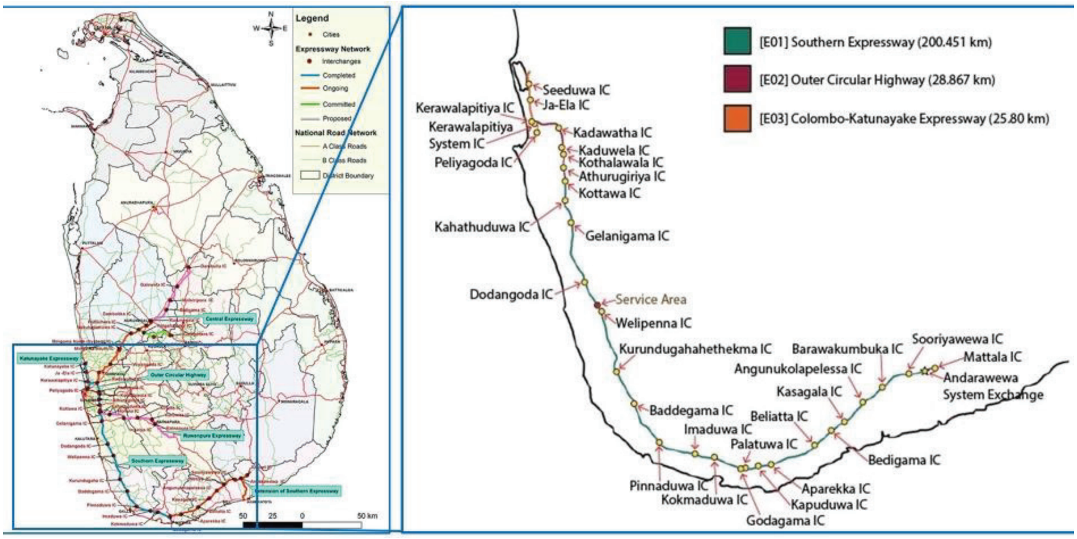

Source – Road Development Authority (RDA) (2024)

Figure 1 - Sri Lankan expressway network as completed by April 2024

Efficient expressway design and traffic management require accurately assessing road capacity and traffic flow characteristics. PCE values are used to represent the impact of different vehicle types in terms of their equivalence to a passenger car. These values are essential for calculating critical parameters such as capacity, selecting number of lanes required, road width, road alignment design, level of service, and density, which guide design and operational management of expressways.

E01, E02 and E03 expressways were totally completed and were in operation by April 2024 where the data collection of the study was made. Ongoing expressway projects such as E04 (Kadawatha to Dambulla), E05 (Colombo to Kandy), E07 (Port access elevated highway project), and E08 (Athurugiriya to New Kelani Bridge) in Sri Lanka will benefit from these findings which are valuable for geometric design. This study contributes to sustainable transportation planning and makes it essential for future expressway designs in Sri Lanka.

Main objectives of the study are to calculate the PCE values for different vehicle categories on expressways, to develop a simulation model for expressway designs, and to analyse the variations of traffic flow characteristics under prevailing traffic conditions.

2. Literature Review

2.1 Methods to Evaluate PCE

There are different methods for calculating PCE such as flow rates and density (John, 1976), headways (Greenshields, 1934), queue discharge flow (Al-Kaisvet, 2002, speed area (Chandra, 1995), delay-based (Werner, 1976c), volume capacity ratio (Fan, 1989), vehicle hours (Summer, 1984), travel time (Keller,1984) and method proposed by HCM (Benekohol,2006). Speed area method was selected for this study because of the suitability of calculating PCE for heterogeneous traffic conditions. Additionally, Chandra's method focuses on the impact of different vehicle types on speed, which is highly relevant for expressways where maintaining high speeds is crucial. As per the method, PCE of any vehicle can be written as follows:

$$PCE = \frac{\left(\frac{V_c}{V_i}\right)}{\left(\frac{A_c}{A_i}\right)} \qquad \ldots(1)$$

where, V_c is the speed of car, V_i is the speed of type i vehicle, A_c is the projected rectangular area of the car and A_i is the projected rectangular area of type *i* vehicle.

2.2 Traffic Simulation

Traffic simulation is a key tool in traffic engineering and planning for analysing traffic behaviour under various conditions. Realistic microscopic traffic simulation is essential for prospective evaluation of the potential impacts of new traffic control strategies [6]. PTV VISSIM, widely used in Asian countries, was chosen for this study due to its effectiveness in simulating heterogeneous traffic compared to other software such as TransModeler, SUMO, MATSim, and AnyLogic [7]. Although the VISSIM software has been used for normal traffic simulation in Sri Lanka, it is hardly used for expressways. In addition, VISSIM software has more functions than other simulation software such as quick and simple setup, detailed and realistic simulation, and accurate.

2.3 Traffic Flow Characteristics

Traffic flow characteristics, including flow, speed, and density, are key concepts in transportation engineering that describe the fundamental aspects of vehicular movement and highway operations. Greenshield (1934) proposed a simple linear relationship between speed and density, with a parabolic relation for volume and density. Other models, such as Greenberg's logarithmic (1959) and Underwood's exponential (1961), offer alternatives, but Greenshield's model provides a simple and effective way to analyse traffic flow on expressways where vehicle interactions are minimal. It requires only basic data, such as free-flow speed and maximum flow, making it useful in situations with limited data or where traffic conditions are stable and predictable. Linear relationship of speed and density has the following form [8]:

$$v = v_f - \left(\frac{v_f}{k_j}\right) k \quad \ldots(2)$$

where, v is the mean speed at density k, v_f is the free flow speed, k_j is the jam density.

While extensive global research has established PCE values, studies specific to Sri Lankan expressways remain limited. Key gaps include the absence of localized PCE values under mixed traffic on E01, E02, and E03 (functioning expressways at the time of the data collection), the lack of studies on traffic flow characteristics and limited understanding of how locally unique vehicles (e.g., truck types, buses) affect PCE values. These gaps have created inaccuracies in capacity and performance evaluations, highlighting the need for context-specific values.

The study addresses the above gaps by developing a model with observed traffic flow relationships, calculating localized PCE values, and integrating them using technical weightages to ensure wider applicability. To date, to the best of our knowledge, Sri Lankan studies have covered only a single expressway segment, with comprehensive traffic flow research is still lacking. Thus, this study provides a novel contribution by examining multiple expressways.

3. Methodology

Data were collected considering Chandra's method of PCE calculation and Greenshield model. Base on the permission requirement for traveling on Sri Lankan expressways, the vehicles were classified into eight categories as follows:

- Passenger Car (PC)
- Passenger Car (Small) (PCS)
- Van
- Medium Bus (MB)
- Large Bus (LB)
- Light Goods Vehicle (LGV)
- Medium Goods Vehicle (MGV)
- Heavy Goods Vehicle (HGV) (3 axles, 4 axles, 5 axles, and 6 axles)

3.1 Projected Rectangular Area

To calculate PCE values for different vehicle categories, the projected rectangular area of vehicles was determined by using their lengths and widths. Vehicle dimensions were obtained from respective official websites and field measurements.

3.2 Average Speed

To calculate vehicle speed across all categories, data such as vehicle entry, exit time, and fixed trap length were collected at specific locations. These locations were selected with the expert knowledge of RDA where the CCTV cameras are located along the respective expressways. Vehicle entry and exit times were recorded using CCTV footage from expressway operation, maintenance, and management divisions at Gelanigama (E01 and E02) and Seeduwa (E03). The study focused on 1-way, 2-lane sections, with data collected for peak two hours per expressway. Table 1 represents the fixed lengths and CCTV locations.

Table 1 - Locations of CCTV and fixed lengths

Expressway	CCTV Locations	Fixed Lengths (km)
E01	Dodangoda, Gelanigama	24.6
E02	Athurugiriya, Kadawatha	16.2
E03	Ja-ela, Peliyagoda	17.3

The average projected area for each category was calculated and shown in Figure 2.

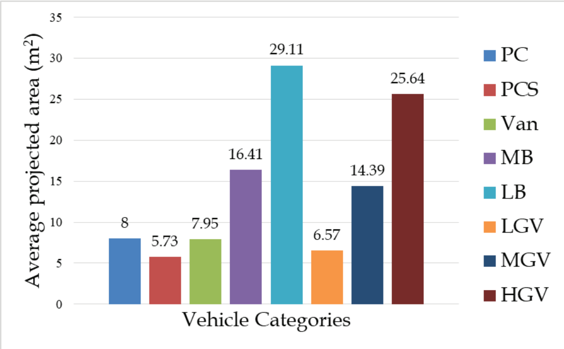

Figure 2 - Average projected area

3.3 Theoretical and Observed Free Flow

To use Greenshield's model for comparing, theoretical and observed density, free-flow speed and maximum flow must be determined. Theoretical free-flow speed was set at 100 km/h, based on the maximum speed limit, while the theoretical maximum flow was selected as 2000 passenger cars per hour per lane (pcphpl) as per RDA standards [9]. For observed free-flow speeds, other traffic flow parameters were calculated as stated in section 3.2. To obtain observed maximum flow, peak hour traffic volumes were gathered from E01 (at Kottawa), E02 (at Kadawatha), and E03 (at Peliyagoda) expressways using CCTV recordings from expressway management divisions at Gelanigama and Seeduwa, focusing on morning and evening peak hours over five consecutive weekdays.

4. Data Analysis and Results

Speeds were calculated by dividing the fixed trap length by the time difference between vehicle entry and exit.

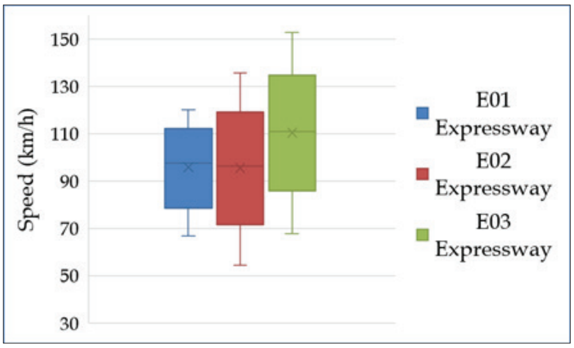

Figure 3 - Speed distribution in expressways

Speed distribution of the three expressways shows median speeds ranging between 95-110 km/h. E01 has a narrow Interquartile Range (IQR), indicating consistent speeds, while E02 and E03 exhibit wider IQRs, reflecting greater speed variability. The broad range in E03 suggests diverse driving conditions due to reduced traffic enforcement. The average speeds for selected expressways are graphically presented as follows.

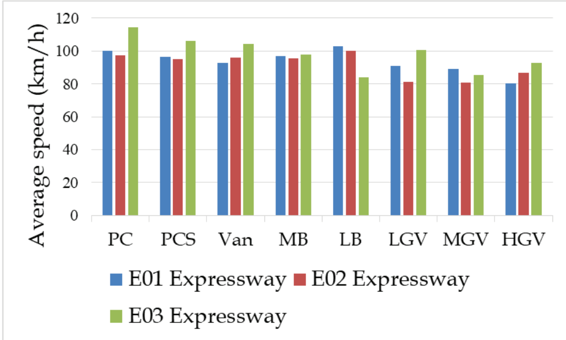

Figure 4 - Average speeds

Calculated average speed values are tabulated in Table 2.

Table 2 - Average speed values

Vehicle Category	Average Speed (km/h)		
	E01	**E02**	**E03**
PC	99.9	97.3	114.2
PCS	96.3	95.2	106.0
Van	92.5	96.0	104.5
MB	96.8	95.3	97.7
LB	103.0	99.9	84.0
LGV	90.9	81.1	100.7
MGV	88.9	80.7	85.4
HGV	80.2	86.9	92.8

Figure 4 indicates that the average speeds for PCs are consistent across all three expressways (≈100 km/h), with E01 and E03 slightly higher than E02. For PCSs, E03 has the highest average speed (114.2 km/h), followed by E01 (99.9 km/h), while E02 (97.3 km/h) has the lowest. Vans show similar speeds across all three expressways, while MBs have close speeds. LBs show significant variation, with E03 having the lowest speed due to limited observations (84 km/h). LGVs maintain similar speeds, with E03 slightly higher (100.7 km/h). MGVs have consistent speeds, with E01 slightly higher (88.9 km/h), while HGVs vary, with E03 showing the highest speed (92.8 km/h).

4.1 Calculation of PCE Values

Data mentioned in Figure 2 and Table 2 were used to calculate PCE values. Sample PCE calculation for E01 expressway for PC and LGV categories are shown below.

Based on the method proposed by Chandra et al. (equation 1), PCE calculation for passenger car category:

$$PCE_{PC} = \frac{\frac{99.9}{99.9}}{\frac{8}{8}} = 1$$

PCE calculation for LGV category:

$$PCE_{LGV} = \frac{\frac{99.9}{90.9}}{\frac{8}{6.57}} = 0.9$$

Calculated PCE values are tabulated in Table 3.

Table 3 - Calculated PCE values

Vehicle Category	E01	E02	E03
PC	1.00	1.00	1.00
PCS	0.74	0.73	0.77
Van	1.07	1.01	1.09
MB	2.12	2.10	2.40
LB	3.53	3.54	4.95
LGV	0.90	0.99	0.93
MGV	2.02	2.17	2.40
HGV	3.99	3.59	3.94

Figure 5 shows the calculated PCE values, which are higher for heavy vehicles such as MBs, LBs, and goods vehicles. The high PCE value for LBs on E03 expressway (4.95) is due to limited observations at lower speeds. Therefore, the PCE value calculated for the LB category for E03 expressway is not recommended for further analysis.

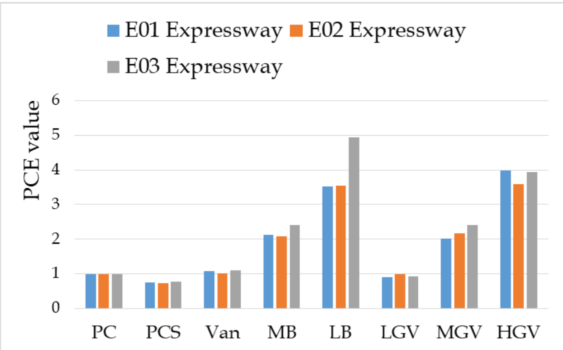

Figure 5 - Calculated PCE

4.1.1 PCE variation with heavy vehicles

Vehicle speed is the key factor influencing PCE. As heavy vehicle percentages increase, overall traffic speed decreases, leading to higher PCE values. This study identified heavy vehicles as:

- Medium Bus
- Large Bus
- Medium Goods Vehicle
- Heavy Goods Vehicle

Heavy vehicle percentages of each expressway are tabulated as follows.

Table 4 - Heavy vehicle percentage

Expressway	Heavy Vehicle Percentage (%)
E01	21.4
E02	13.8
E03	3.9

PCE variation with heavy vehicle percentage is shown in Figure 6.

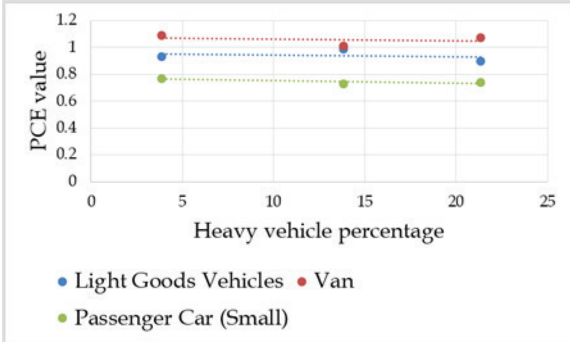

Figure 6 - PCE with heavy vehicle percentage

PCE value for LGVs and vans remains stable around 1.0, showing minimal influence from heavy vehicle percentages. Similarly, the PCE value for PCS is approximately 0.75, with little fluctuation as heavy vehicle percentages increase.

4.1.2 Comparison of PCE values

Table 5 compares PCE values derived for E02 expressway from Dhananjaya et al. (2023) with the results of the current study. Their study, conducted at Athurugiriya, considered a 4-lane road and included a 12-hour traffic survey.

PCE values for vans, LBs and LGVs of our study closely match with the respective findings of Dhananjaya et al. (2023). Commercial vehicles having different capacities and sizes are observed on expressways at present than in the past because of the economic growth of the country. Therefore, having higher PCE values for medium goods vehicles and large goods vehicles in this study is reasonable.

Table 5 - Comparison of PCE

Vehicle Category	Current Study	Dhananjaya et al. (2023)
PC	1.00	1.00
PCS	0.74-0.77	-
Van	1.01-1.09	1.11
MB	2.10-2.40	1.87
LB	3.53-3.54	3.57
LGV	0.9-0.99	1.04
MGV	2.02-2.40	1.90
HGV	3.59-3.99	3.33

Table 6 shows expressway PCE values from different countries. Our study provides a PCE value of 1.01 for vans, highlighting its specific impact on Sri Lankan traffic. LGVs, once a relatively uncommon vehicle category, have now gained popularity in Sri Lanka as a preferred option for small-scale freight transport. The rise in popularity of fuel-efficient LGVs, which are compact in size, is a key factor contributing to their increased usage. It is reasonable for these vehicles to have less PCE value due to their smaller dimensions compared to PCs. In comparison with PCE values derived in Singapore, the values are lower than in India. The factors such as highly heterogeneous traffic conditions, variable lane widths, sharp curves, high volumes of heavy vehicles, diverse range of vehicle sizes and types and usage of older vehicle contribute to increase PCE values in India.

Table 6 - Comparison of PCE values with other countries

Vehicle Category	Bains et al. (2012) India	Jabeena et al. (2015) India	Puvval et al. (2013) India	Fan et al. (1990) Singapore	Yeung et al. (2015) Singapore
PC	-	1.53	-	1.00	1.00
PCS	-	1.00	-	-	-
Van	-	-	-	-	-
Bus	3.59	5.97	3.99	2.70	-
LGV	1.88	3.56	1.33	1.30	1.53
MGV	4.01	5.88	3.18	-	-
HGV	4.59	8.51	-	2.60	2.75

To improve traffic flow accuracy for Sri Lankan expressway designs, weightages were applied to PCE values, considering traffic volume, road design, composition, and environment. This approach ensures realistic, practical representation of real-world conditions on Sri Lankan expressways.

$$w_i = \frac{Traffic\ Volume\ of\ Expressway\ i}{Total\ Traffic\ Volume\ of\ All\ Expressways} \quad (3)$$

Total traffic volume = 3629.9 pcph

Weightage of E01 expressway, $w_{E01} = 0.25$

Weightage of E02 expressway, $w_{E02} = 0.23$

Weightage of E03 expressway, $w_{E03} = 0.52$

The weightages were assigned based on the proportion of total traffic volume on each expressway, reflecting their relative importance and contribution to overall traffic performance. Following expression was used to calculate weighted PCE values.

$$PCE_{weighted} = (PCE_{E01} x W_{E01}) + (PCE_{E02} x W_{E02}) + (PCE_{E03} x W_{E03}) \quad \ldots(4)$$

Respective findings are tabulated in Table 7.

Table 7– Weighted PCE values

Vehicle Category	Weighted Average PCE
PC	1.00
PCS	0.75
Van	1.07
MB	2.26
LB	3.53
LGV	0.94
MGV	2.25
HGV	3.87

4.2 Data Simulation Through VISSIM

Sri Lankan expressways are designed for high-speed travel with controlled access, allowing vehicles to choose lanes based on speed and overtaking needs. In VISSIM software, "Freeway (Free Lane selection)" was chosen as the link behavior type, with vehicle categories and speed ranges calibrated to match Sri Lankan expressway conditions. Traffic flow values were simulated in the software by assigning suitable values for the variables as input data. Once the input data were entered, the VISSIM software provided simulated speed as output. Table 8 details the input data used. Counted traffic flow reduction was mainly due to interchanges between camera locations.

Table 8 - Input data to VISSIM

Expressway	Traffic Flow (veh/h)	Lane Width (m)
E01	261	3.6
E02	565	3.5
E03	68	3.6

Table 9 lists vehicle categories and speed values used for calibration. Desired speed values for lower bound were decided based on average observed speeds of each vehicle category for the three expressways separately. The upper bound desired speed value was selected based on the maximum speed limit assigned to expressways in Sri Lanka.

For the simulation, five trap lengths were randomly selected along E01 expressway (Dodangoda to Gelanigama section) and run for 7200 simulation seconds to calculate travel time (showed in Table 10). Simulated speed was obtained by dividing travel time by the road length, which was limited to less than 1 km due to software restrictions (PTV VISSIM SP 07-Training version). For E02 and E03 expressways, three trap lengths were randomly selected, and simulations were similarly run for 7200 seconds to calculate speeds.

Table 9 - Desired speeds

Vehicle Category	Desired Speed (km/h)			
	Lower Bound			Upper Bound
	E01	E02	E03	
PC	95	100	100	100
PCS	95	95	100	100
Van	90	95	100	100
MB	95	95	95	100
LB	100	100	85	100
LGV	90	80	100	100
MGV	88	80	85	100
HGV	80	85	90	100

Table 10 - Simulated length, travel time and speed

Expressway	Simulated length (m)	Simulated travel time(s)	Simulated speed (km/h)
E01	876.7	33.4	94.5
	887.8	35.1	91.1
	882.7	33.6	94.5
	897.0	34.3	94.2
	894.9	34.5	93.4
E02	934.5	35.5	94.8
	923.0	35.3	94.0
	924.3	37.2	89.6
E03	954.0	35.8	96.1
	948.4	35.5	96.1
	990.9	38.0	93.9

Observed and simulated speeds for the expressways show a close alignment, indicating that the simulation model is accurately reflecting real-world conditions as shown in Table 11.

Table 11 - Observed and simulated speed

Expressway	Observed speed (km/h)	Simulated speed (km/h)
E01	93.5	93.6
E02	91.6	92.8
E03	98.2	95.4

Model's performance was tested based on percentage bias method, Mean Absolute Error (MAE) method, Mean Squared Error (MSE) method, Root Mean Squared Error (RMSE) method and R-squared method as described below.

4.3 Percentage Bias Method

This method assesses whether the simulated speeds overestimate or underestimate observed speeds on average. To evaluate accuracy, percentage bias is calculated using the average observed and simulated speed values.

$$\% \, Bias = \frac{\Sigma(P_i - O_i)}{\Sigma O_i} x100 \qquad \ldots(5)$$

where, P_i are simulated values and O_i are observed values.

Using equation 5,

$$\% \, Bias = \frac{-1.52}{283.28} x100 = -0.54\%$$

Value of -0.54 indicates a very small tendency for the model to underestimate observed values, with simulated speeds being 0.54% lower on average. This negligible percentage bias suggests the model's performance is accurate, as the bias is close to zero.

4.4 MAE Method

This method measures the average magnitude of errors between simulated and observed values.

$$MAE = \frac{1}{n} \sum_{i=1}^{n} |P_i - O_i| \qquad \ldots(6)$$

where, n is the number of observations while the other two terms are same as percentage bias method. Using equation 6,

$$MAE = \frac{4.12}{3} = 1.37 \, km/h$$

Value 1.37 indicates an average difference of 1.37 km/h between simulated and observed speeds. In 50-120 km/h range, this small MAE suggests that the simulated speeds are highly accurate.

4.5 MSE Method

This method quantifies the average squared error, giving a measure of how well the simulation model performs. Following equation is used to calculate MSE.

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^2 \qquad \ldots(7)$$

where the expressions are same as the MAE method. Applying equation 7,

$$MSE = \frac{9.47}{3} = 3.16 \, km^2/h^2$$

Simulated speed has an average squared error of 3.16. For higher observed speeds, a larger MSE is acceptable compared to lower speeds and then MSE of 3.16 is acceptable at 100 km/h but not at 20 km/h as per the literature.

4.6 RMSE Method

RMSE is the square root of MSE and following equation is used to calculate it.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2} \quad \ldots(8)$$

$RMSE = 1.78\ km/h$

$Mean\ observed\ speed = 94.43\ km/h$

As a percentage, $RMSE = 1.88\ \%$

As per the literature, RMSE less than 10% of the mean observed speed indicates a very good fit and RMSE values in the range of 2-5 km/h can be acceptable. Therefore, simulated speeds closely match the observed speed.

4.7 R-squared Method

Here it measures the proportion of variance in the observed data which is explained by the simulated data. It ranges from 0 to 1, and value closer to 1 indicates a better fit.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad \ldots(9)$$

where, $\bar{O}$ is the mean of observed value while other expressions are same as the MSE method.

Applying equation 9,

$$R^2 = 1 - \frac{9.47}{23.16} = 0.59$$

This value indicates that the model explains 59% of the variance in observed data means the model indicates a moderate level of fit between the simulated and observed speeds.

4.8 Calculation of Peak Hour Traffic Volume

Peak hour traffic volumes for each expressway were determined by analysing video recordings provided by expressway management divisions, covering five consecutive weekdays. Morning and evening peak hours were identified separately by collecting 15-minute traffic counts at each location. The average peak hour volumes were calculated over the five days. These volumes were then converted using PCE values from previous studies for E01 expressway and a two-lane road [10]-[11]. Used PCE values and average traffic volumes are listed in Table 12. Accordingly, the maximum observed traffic flows on E01, E02 and E03 expressways are 911.8, 833.2 and 1884.9 pcph, respectively.

4.9 Calculation of Density, Speed and Volume

Since free flow speed is 100 km/hr and maximum flow is 4000 pcph,

Design maximum density is, $k_{max} = 40\ pc/km$.

Table 12 - Average traffic volumes

Vehicle Category	PCE Value	Average Traffic volume (pcph) E01	Average Traffic volume (pcph) E02	Average Traffic volume (pcph) E03
PC	1.00	402.60	370.80	1029.60
PCS	0.75	166.05	175.65	426.45
Van	1.11	95.46	89.02	163.17
MB	1.87	55.35	36.28	95.00
LB	3.57	77.11	52.12	89.25
LGV	1.04	43.47	34.53	29.74
MGV	1.09	55.10	60.80	38.38
HGV	3.33	16.65	13.99	13.32
Total		911.80	833.19	1884.91

Following the Greenshield's model shown in equation 2 and its basic derivations,

Design jam density is; $k_j = 160\ pc/km$

If density is 10 pc/km, speed is $v = 93.75\ km/h$

Then, volume is $q = 937.50\ pcph$

For E01 expressway,

Jam density = 38.97 pc/km

Since free flow speed is 93.6 km/h and maximum flow is 911.8 pc/h.

If density is 10 pc/km, speed is $v = 69.58\ km/h$

Then, volume is $q = 695.82\ pcph$

Calculated values as per the design are tabulated as follows.

Table 13 - Speed, density and volume values as per the design

Density(pc/km)	Speed (km/h)	Volume (pcph)
0	100.00	0.00
10	93.75	937.5
20	87.50	1750.0
40	75.00	3000.0
60	62.50	3750.0
80	50.00	4000.0
100	37.50	3750.0
120	25.00	3000.0
140	12.50	1750.0
160	0.00	0.0

Observed values for E01 expressway are tabulated as follows.

Table 14 - Speed, density and volume values - E01 expressway

Density (pc/km)	Speed (km/h)	Volume (pcph)
0.00	93.60	0.00
5.00	81.59	407.95
10.00	69.58	695.82
15.00	57.57	863.58
19.48	46.81	911.90
20.00	45.56	911.26
25.00	33.55	838.85
30.00	21.54	646.34
35.00	9.54	333.74
38.97	0.00	0.00

Observed values for E02 expressway are tabulated as below.

Table 15 - Speed, density and volume values - E02 expressway

Density (pc/km)	Speed (km/h)	Volume (pcph)
0.00	91.60	0.00
5.00	79.01	395.05
10.00	66.42	664.21
15.00	53.83	807.48
18.19	45.80	833.10
20.00	41.24	824.85
25.00	28.65	716.33
30.00	16.06	481.92
35.00	3.47	121.61
36.38	0.00	0.00

Observed values for E03 expressway are shown below.

Table 16 - Speed, density and volume values - E03 expressway

Density (pc/km)	Speed (km/h)	Volume (pcph)
0.00	98.20	0.00
10.00	85.41	854.10
20.00	72.62	1452.41
30.00	59.83	1794.92
38.39	49.10	1884.95
40.00	47.04	1881.63
50.00	34.25	1712.55
60.00	21.46	1287.68
70.00	8.67	607.00
76.78	0.00	0.00

Graphical relationship of speed vs density according to Greenshield model is presented in Figure 7. It illustrates a linear relationship where speed decreases as density increases. E01 and E02 expressways exhibit similar speed-density behaviour, with a sharp decline in speed as density reaches 40 pc/km. The observed maximum speed, around 90 km/h, is slightly below the design free-flow speed of 100 km/h. E03 expressway shows a more gradual speed reduction as density rises. All expressways have lower maximum densities than their design capacity, indicating that current traffic conditions remain well below their intended capacity.

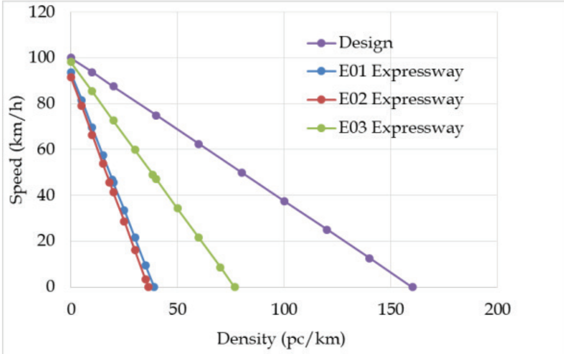

Figure 7 – Variation of speed vs density

Figure 8 depicts the volume-density relationship, with parabolic curves indicating that volume initially increases with density, peaks, and then decreases as density rises further. E01 and E02 expressways show similar patterns, with peak volumes around 950 pcph at 30-40 pc/km density. E03 expressway shows a slightly higher peak volume. All three expressways currently operate below design capacity.

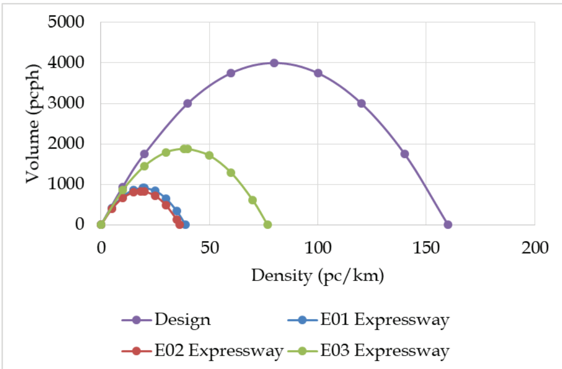

Figure 8 – Variation of volume vs density

Figure 9 illustrates the speed vs volume relationship, showing wide curves. At low traffic volumes, speeds remain near free flow, but as volume increases, speeds gradually decline, reaching a minimum at maximum flow, after which the curve tapers sharply. E01 and E02 expressways exhibit a similar pattern, with speeds dropping rapidly after volumes reach 800-900 pcph. E03 expressway shows a broader curve. Maximum volumes recorded for all expressways are below the design maximum, indicating a significant gap with design capacity.

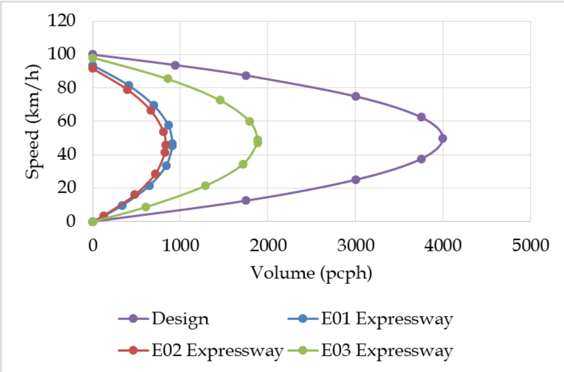

Figure 9 – Variation of speed vs volume

Curves shown in Figures 7, 8 and 9 suggest that the speed-density, volume-density, and speed-volume relationships closely align with the Greenshield model, making it applicable for Sri Lankan expressway designs.

4.10 Comparison of Traffic Volumes with Predicted Values

Current expressway traffic volumes are significantly below the design capacity, making it essential to calculate future traffic volumes. This requires determining predicted vehicle growth rates for accurate comparison with design volumes. Table 17 presents predicted vehicle growth rates, expressed as percentages, based on a study conducted at E01 expressway Kottawa interchange [12].

Vehicle growth rates for E02 and E03 expressways were assumed to match those of E01 expressway due to their similar design standards, operational conditions, and regional influences. In the absence of specific data for E02 and E03 expressways, using E01's growth rates offers a reasonable estimate based on trends from a comparable expressway. However, this assumption is recognized as a limitation, and future research should focus on gathering precise vehicle growth rate data for E02 and E03 expressways.

Following equation is used to estimate future traffic volume, with a sample calculation provided below for the E02 expressway.

$$(Peak\ Hour\ Traffic\ Volume)_{future} = (Peak\ Hour\ Volume)_{present}\ x\ (1+g)^n \quad \dots(10)$$

where, g is the annual growth rate and n is number of years.

Applying equation 10,

Peak hour traffic volume at 2030 for PC is,
= 370.8 x $(1+0.041)^6$ = 471.89 pcph

Similarly, future traffic volumes were calculated for all vehicle categories and total traffic volumes for all three expressways are presented in Table 18.

Traffic forecasts for expressways show a significant increase in volume over time. By 2080, E01 expressway is expected to exceed 5320 pcph, E02 expressway around 4862 pcph, and E03 expressway nearly 11,000 pcph. Traffic is projected to surpass the design capacity by 2070 on E01, by 2075 on E02, and by 2045 on E03 expressways as shown in Figure 10.

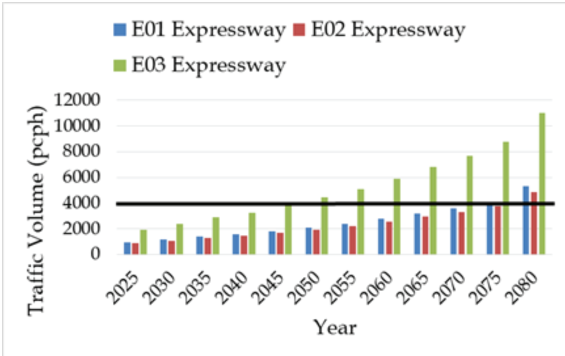

Figure 10 – Forecasted traffic conditions

E01 and E02 expressways exhibit similar traffic volumes, with E02 being slightly lower in certain years, while E03 records the highest traffic volume. Figure 10 emphasizes the importance of strategic capacity planning, particularly for E03 expressway, to manage rising demand effectively.

5. Conclusions

Traffic-related studies are challenging due to the diverse behaviours of different vehicle types, including variations in speed, acceleration, space occupancy, and manoeuvring. PCE values depend not only on vehicle characteristics but also on road type, traffic composition, and environmental factors. Using PCE as a standard measure helps address these complexities, but its accuracy significantly influences traffic analysis outcomes. This issue is particularly critical in developing countries like Sri Lanka, emphasizing the need for precise PCE estimation considering all influencing factors.

Table 17 - Predicted vehicle growth rates

Vehicle category	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080
PC	3.6	4.10	3.95	3.80	3.70	3.6	3.5	3.45	3.40	3.30	3.25	3.20
PCS	3.6	4.10	3.95	3.80	3.70	3.6	3.5	3.45	3.40	3.30	3.25	3.20
Van	2.1	2.21	2.19	2.12	2.11	2.1	2.0	2.04	2.01	2.00	1.99	1.95
MB	2.1	2.21	2.19	2.12	2.11	2.1	2.0	2.04	2.01	2.00	1.99	1.95
LB	2.1	2.21	2.19	2.12	2.11	2.1	2.0	2.04	2.01	2.00	1.99	1.95
LGV	3.6	4.10	3.95	3.80	3.70	3.6	3.5	3.45	3.40	3.30	3.25	3.20
MGV	3.6	4.10	3.95	3.80	3.70	3.6	3.5	3.45	3.40	3.30	3.25	3.20
HGV	2.1	2.05	1.93	1.80	1.70	1.6	1.5	2.06	1.32	1.22	1.15	1.11

Table 18 - Predicted traffic volumes

Expressway	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080
E01 expressway	940.95	1159.96	1396.25	1552.77	1808.03	2089.89	2385.81	2768.62	3171.81	3566.70	4061.72	5320.57
E02 expressway	860.31	1061.87	1275.89	1432.38	1671.38	1935.38	2214.39	2572.34	2952.86	3323.21	3789.01	4861.91
E03 expressway	1947.36	2376.60	2886.42	3271.87	3826.40	4439.35	5090.78	5914.63	6811.51	7673.70	8760.93	10999.01

In this study, PCE values were calculated using the method proposed by Chandra (1995) for eight vehicle categories across three Sri Lankan expressways. The study found that PCE values varied depending on traffic flow characteristics at survey locations. Comparisons with previous research underscore the necessity for localized PCE calibration to account for diverse operational and environmental conditions.

Vehicle categories such as vans and LBs exhibited PCE values similar to prior local studies, whereas MBs and MGVs showed notable differences, highlighting variations in traffic conditions. International studies on PCE values revealed significant differences due to variations in vehicle classifications, traffic flow patterns, and regional weather conditions.

To validate the accuracy of calculated and simulated speed values from PTV VISSIM, statistical measures such as percentage bias, MAE, MSE, RMSE, and R-squared were applied. Among these, the R-squared value showed a moderate match with the model.

To enhance model accuracy and the R-squared value, refinement methods such as extending the traffic survey duration, conducting segment-wise analysis, and incorporating weather variables can be applied.

Selected road segments for PCE analysis on E02 and E03 expressways cover over one-third of their total length, ensuring comprehensive traffic representation. For E01 expressway, analysing its full 200.45 km length was impractical, so a smaller but diverse segment was chosen, capturing key features such as curves, gradients, intersections, and a typical vehicle mix. This approach minimizes the impact of weather and road surface variations while ensuring representativeness. Weightages were applied to PCE values to enhance accuracy for future expressway designs in Sri Lanka.

Greenshield model was used to analyse traffic behaviour, assuming a linear speed-density relationship under uninterrupted flow. Despite its homogeneous traffic assumption, it was adapted for heterogeneous conditions by converting vehicle flows into PCUs. Model calibration with local data ensured an accurate representation of free-flow speed and traffic behaviour.

While this study excluded factors like weather and road geometry, updating PCE values is crucial as influencing factors evolve. Future research incorporating larger survey lengths will strengthen traffic behaviour analysis for expressway planning in Sri Lanka.

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