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PASSENGER CAR UNITS FOR DIFFERENT MIDBLOCK SECTIONS IN SRI LANKA UNDER MIXED TRAFFIC CONDITION

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Traffic-related analyses are essential to implementing traffic management approaches to create mobility more convenient. In this context, Passenger Car Unit (PCU) values as a uniform measure of vehicles are instrumental in analysis such as traffic capacity estimation, traffic flow model development, level of service determination, etc. These studies always demand a recently calculated set of PCU values since the traffic conditions in arterials often change. PCU values for expressway and three-lane (one-way) road types have not been calculated in the Sri Lankan context, and the available set of values has become somewhat outdated. Hence, this study used Chandra's method to assess the PCU values of ten vehicle categories for four different mid-block road sections in the Colombo district, Sri Lanka. The data relating to the two main variables of this method, categorical speed, and area of vehicles, were collected from field surveys. The results of four-lane arterials were aggregated and compared with the existing PCU values, intending to propose an updated set for general transportation studies in Sri Lanka.

Keywords: Passenger Car Unit (PCU), heterogeneous traffic, mixed traffic, midblock road sections, chandra's method

1 INTRODUCTION

The National Highway Network in Sri Lanka, with an approximate total length of 12,438 km, is administered by the Road Development Authority (RDA) of the country. Mobility between main cities within the country is primarily facilitated by this network, playing a pivotal role in the transportation needs of the society. As the commercial capital of Sri Lanka, the city of Colombo has become a leading site in this context since it causes to attracts a vast number of trips to fulfill the needs of people. Demand for roads that facilitate these trips has increased with the development, population, and suburban settlements. Therefore, it is time to utilize the existing road network with more appropriate traffic management approaches supported by constructive analyses [1]. Traffic-related studies are quite challenging because of the diverse behaviors of various vehicle types due to different speeds, accelerations, space occupation on roads, and maneuvering capabilities. Utilizing a uniform measure such as the Passenger Car Unit (PCU) assists in minimizing this issue [2].

PCU values express the impact of different vehicle types on traffic variables compared to passenger cars. More importantly, PCU values are highly sensitive to the results of any traffic-related analysis. This concern is even more significant in developing countries such as Sri Lanka, where the vehicle composition of non-car vehicles is considerably higher. In such a case, PCU estimation should be done more precisely, considering all the factors impacting its accuracy. Furthermore, PCU values of a vehicle type depend not only on the vehicle's characteristics but also on factors such as road type, vehicle mix, nature of the traffic, and environmental conditions [3].

PCU values should be different for road section type and road type. In this study, only the road midblock sections were considered for a set of road types. Most road networks in developing countries carry mixed traffic with poor lane discipline which is also referred to as non-homogeneous traffic. While PCU estimation for homogeneous traffic conditions can be performed using a single parameter, multiple parameters are required in non-homogeneous [3]. Parameters such as speed [4], vehicle composition [5], headway [6], and area of the vehicles [7] have been used in studies to develop methods for PCU estimation in non-homogeneous traffic. Mainly five methods were used in previous studies for PCU estimation in urban midblock sections, such as Chandra's method, space occupancy, multiple linear regression, headway, and simulation methods [3]. Chandra's method, which utilizes the vehicles' speeds and area as the main two parameters, was used to estimate the PCU values in this study.

2 LITERATURE REVIEW

Chandra and Kumar [8] introduced a method of PCU estimation utilizing the speed and the projected area of the vehicle interacting with other vehicles in a traffic flow. Many studies in Asian countries have used this method due to its applicability to non-homogeneous traffic conditions [9], [10]. The space occupancy method, which is also based on Chandra's method, utilizes a vehicle's effective area instead of the projected area. Different approaches are used in determining the effective area of a vehicle. Srikanth [2] added average headway to the length and an additional 10% of the width to the original width of the vehicle when obtaining the effective area. Raj et al. [7] considered the impact of neighboring vehicles under a defined set of scenarios in measuring the effective area and defined it as an influence area.

In the multiple linear regression method, the PCUs are estimated by regressing the average stream speed against the independent variables of categorical vehicle flows. Thus, the incremental impact of a given vehicle category on the average stream speed is primarily considered [5]. However, unlike in midblock sections, the saturated green time has been used for PCU estimation at the intersections when using the regression [11], [12]. For midblock sections, the mean time headway of cars and vehicles is used to measure the PCU values based on the headways [6]. Different simulation models have also been used in PCU estimation studies [13]. Giuffre et al. [14] successfully determined the PCU values of heavy vehicles on a freeway utilizing the Aimsum micro-simulator.

The vehicle flow of the selected road sections should not get affected during the data collection for PCU estimation by intersections and facilities such as bus halts, fuel stations, pedestrian crossings, roadside openings, etc. [2], [6]. Furthermore, the data should be collected in clear weather conditions to avoid deviations from standard traffic patterns [15]. The required data collection for most of the studies was carried out through videography, ensuring that the equipment had been placed to avoid any distraction they may cause drivers [7], [10]. Researchers have gone beyond PCU estimation to determine the parameters that could impact the PCU values. Thus, the impact of traffic variables such as traffic speed, volume, composition, and geometric road features such as road width, gradient, and horizontal curvature has been considered [16]. However, the fact that the outcomes of one study contradict the other makes it difficult to accept specific relationships for these parameters with PCUs [3].

3 METHODOLOGY

3.1 Estimating PCU values using Chandra's method

Since the headway method is more suitable for steady traffic conditions with lane discipline, it is not easy to apply in this study. As the Simulation methods require large data sets and extensive research for the development, it is pretty challenging to get adopted. Regressing the space mean speed of vehicles against the flow is ideal for PCU estimation for road sections with unsaturated flow conditions and high-speed variations [5]. Therefore, it is difficult to use multiple linear regression methods at road sections like expressways where the speed variation is minimum. Moreover, there is a risk of losing coefficients when fitting the regression model for vehicle types with fewer observations. Due to these limitations, Chandra's method was selected for this study.

$$PCUi = \frac{(Vc/Vi)}{(Ac/Ai)} \quad (1)$$

Vc = Mean speed of cars

Vi = Mean speed of the vehicle type i

Ac = Projected area of the car

Ai = Projected area of the vehicle type i

Since Chandra's method requires projected area and determined mean speed of vehicles to estimate PCU values, as shown in Equation 1, the required data were obtained by field surveys.

3.2 Categorizing the vehicles

Ten vehicle categories were chosen based on the general vehicle composition in the country for PCU estimation: Car, Van, Three-Wheeler, Motorcycle, Minibus, Large Bus, Light Truck, Medium Truck, Large Truck, and Multi-Axle. However, the Car and Van categories consist of different types of vehicles that may impact determining the projected area for PCU estimation. For instance, the area of a small car largely differs with the sedan cars. In order to mitigate the impact that could occur from this concern, subcategories were assigned to these vehicle categories, as indicated in Table 1.

Table 1. Subcategories of cars and vans

Vehicle category	Subcategories
Car	Mini Car, Mini Van, Sedan Car, Mini Sport Utility Vehicle (SUV), Large SUV, Pickup Truck
Van	Small Van, Large Van

3.3 Selection of midblock road sections for PCU value estimation

Four types of midblock road sections were selected for the PCU estimation as four-lane urban midblock section, four-lane suburban midblock section, three-lane urban (one-way) midblock section, and four-lane expressway midblock section based on the existence within the road network of the country. Five survey locations were used to collect the measures required to calculate the vehicle speed data, consisting of two four-lane urban midblock sections. These locations are depicted in Fig. 1, and details are given in Table 2. As a notable factor, it was ensured that all these selected locations consist of an overhead bridge before the selection to make the survey team not observable to the drivers, avoiding any change in traffic behavior that could impact the PCU estimation.

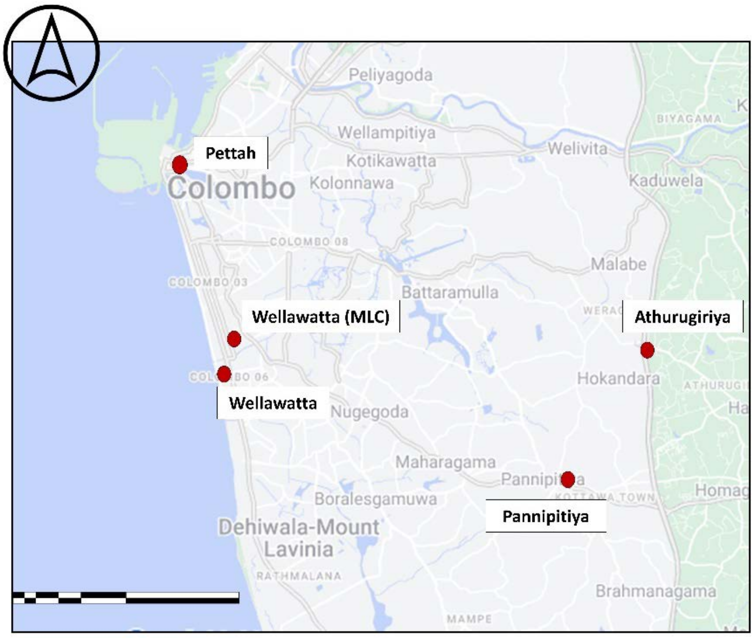

Fig. 1. Locations of selected midblock sections for PCU estimation

Table 2. Details of selected midblock sections for PCU estimation

Location	Road Name	Road Type	Road Class
Athurugiriya	Outer Circular Expressway	4 – Lane (Expressway)	E01
Pannipitiya	High-Level Road	4 – Lane (Suburban)	A004
Pettah	Olcott Road	4 – Lane (Urban)	A001
Wellawatte	Colombo Plan Road	4 – Lane (Urban)	AB12
Wellawatte (Muslim Ladies College (MLC))	Duplication Road	3 – Lane (Urban/one-way)	A002

3.4 Measuring vehicle speeds

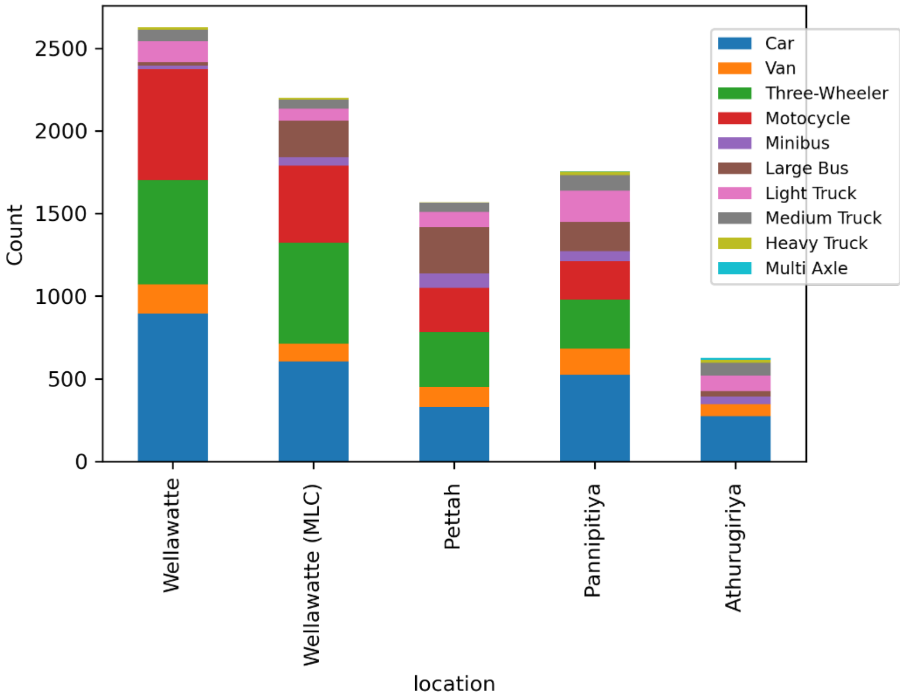

Fig. 2. Distribution of the number of captured speed values over locations

The traffic flow of the selected five locations was videotaped for 12 hours (6:00 AM to 6:00 PM) by locating two cameras at a distance of 100m to obtain timestamps in calculating categorical space mean speeds. These videotaped data were sampled as 5 minutes for every 15 minutes, and the vehicles were captured randomly within that period using a number plate as a unique identifier. The distance between the two cameras was divided by the gap between the timestamps at the two video frames to determine the speed of a vehicle. A total number of 8,766-speed values was captured to use for the study, and it is shown in Fig. 2. The number of observations at Athurugiriya (Expressway) is relatively lower because of the lower vehicle density.

3.5 Measuring areas of vehicles

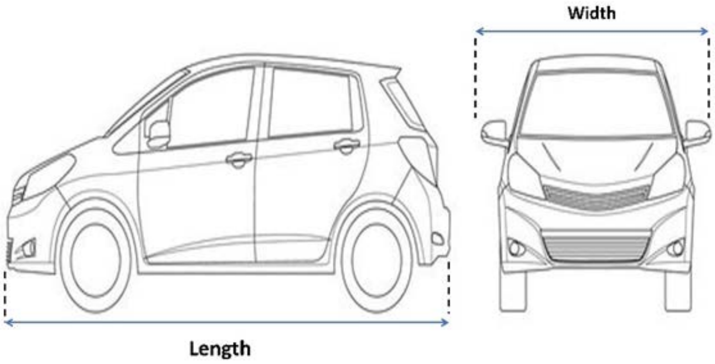

Fig. 3. Defined dimensions for vehicle area calculation

Using the most precise measurements for the area of each vehicle category is imperative to obtain accurate PCU values based on Chandra's method [8]. Although the vehicle areas could be easily obtained using the vehicle blueprints, a field survey was used to obtain more accurate vehicle areas as it impacts largely for the PCU values. A critical advantage is provided by utilizing a field survey over blueprints as it assists in obtaining width with the side mirrors of a vehicle, as shown in Fig. 3. Using vehicle area with the side mirrors is more appropriate for PCU estimation as it provides an actual value of the area a vehicle takes on the road.

Some vehicle categories or defined subcategories consist of a higher number of models while others are not. For instance, Motorcycles generally have a variety of models, but Buses do not have such a variety. Based on this scenario, ten models for vehicle categories or subcategories with a higher number of models and five for the others were taken to acquire the average area. It was required to further average the determined average areas for subcategories in Cars and Vans as only a single PCU value was expected to derive for each of those categories. This was satisfied by assigning a weight for each subcategory based on its traffic composition, and then the final average was taken referring to that weight. Video footage of 15 minutes was taken randomly from each location to determine the traffic composition of each subcategory.

4 RESULTS AND DISCUSSION

4.1 Measured vehicle areas

Fig. 4 and Fig. 5 summarize the achieved vehicle composition in subcategories of Cars and Vans because of the taken random footages, respectively. The weighted areas for cars and vans were calculated using the vehicle composition of each subcategory as mentioned. The calculated weighted areas for both types are presented in Table 3, along with the areas of subcategories. Table 4 presents areas of vehicle types that do not have subcategories, as previously explained. These areas were measured directly using the averages of selected models from each category.

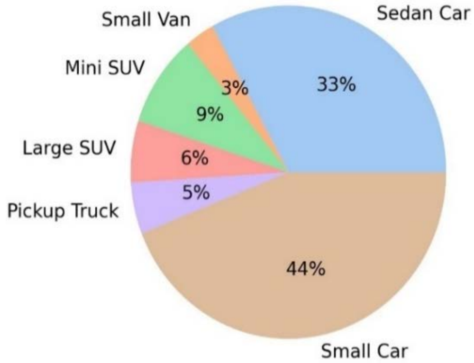

Fig. 4. Achieved vehicle composition for subcategories of cars

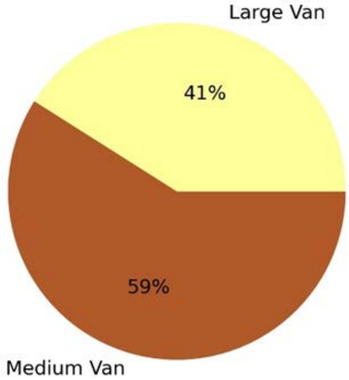

Fig. 5. Achieved vehicle composition for subcategories of vans

Table 3. Calculated average vehicle dimensions of cars and vans

Vehicle Category	Subcategory	Weight	Average Width (m)	Average Length (m)	Average Area (m^2)	Standard Deviation
1. Car	Small Car	0.44	1.94	3.41	6.62	0.89
	Sedan Car	0.33	2.13	4.34	9.24	0.91
	Small SUV	0.09	2.18	4.16	9.06	0.62
	Large SUV	0.06	2.31	4.60	10.61	0.56
	Pickup Truck	0.05	2.16	5.14	11.12	0.63
	Small Van	0.03	1.84	3.31	6.10	0.17
	Weighted average area = 8.15 m^2					
2. Van	Medium Van	0.59	1.84	4.02	7.40	0.21
	Large Van	0.41	2.03	4.90	9.94	1.13
	Weighted average area = 8.44 m^2					

Table 4. Calculated average dimensions for vehicle categories without subcategories

Vehicle category	Average width (m)	Average length (m)	Average area (m^2)	Standard Deviation
3. Three-Wheeler	1.39	1.39	3.57	0.23
4. Motorcycle	0.82	1.84	1.51	0.22
5. Minibus	2.41	6.49	15.71	2.15
6. Large Bus	10.01	2.80	28.04	2.26
7. Light Truck	1.86	3.80	7.07	0.66
8. Medium Truck	2.18	5.31	12.54	2.55
9. Heavy Truck	2.59	8.36	21.67	1.30
10. Multi-Axle	2.94	15.46	45.44	2.39

4.2 Average hourly vehicle speeds

Fig. 6 illustrates the calculated hourly vehicle speed distribution for each considered location. Due to a lack of observations, continuous hourly average speeds for a few vehicle categories, such as Heavy Trucks and Multi-Axles, have been missed.

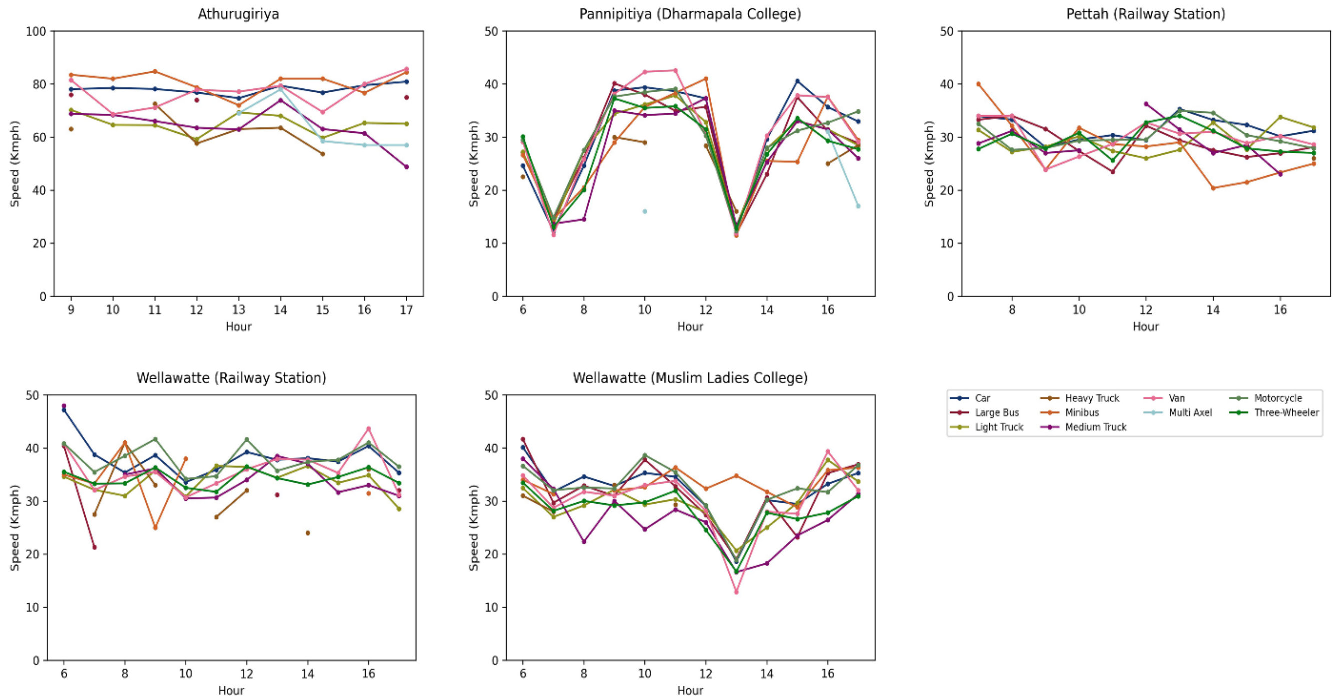

Fig. 6. Distribution of hourly categorical speed values at selected locations

4.3 Estimated PCU values

Table 5 illustrates the PCU values calculated using Chandra's method. In the first instance, the PCUs were calculated based on the hourly average speeds to observe deviations between the hourly values as an accuracy measurement. Then, statistical measures were estimated using the previously calculated hourly PCU values. Because expressway access is limited to a few vehicle types and multi-axle vehicles were not observed at some locations, some empty cells could be seen in Table 5.

Table 5. Summary statistics of estimated hourly PCU values

		Car	Van	Motor-cycle	Three-Wheeler	Large Bus	Small Bus	Light Truck	Medium Truck	Heavy Truck	Multi-Axle
Athurugiriya 4 lane (Expressway)	Min	1.00	1.03	-	-	3.46	1.77	0.93	1.65	2.86	5.67
	Max	1.00	1.25	-	-	3.71	2.00	1.12	2.55	3.80	7.90
	Mean	1.00	1.11	-	-	3.57	1.87	1.04	1.90	3.33	6.94
	SEM	0.00	0.02	-	-	0.05	0.02	0.02	0.08	0.13	0.45
Pannipitiya 4 lane (Sub-Urban)	Min	1.00	0.92	0.15	0.36	2.93	1.62	0.78	1.38	1.98	6.41
	Max	1.00	1.33	0.24	0.54	4.43	3.08	1.06	2.61	3.79	13.71
	Mean	1.00	1.10	0.19	0.48	3.59	2.12	1.91	1.77	3.18	10.30
	SEM	0.00	0.03	0.01	0.02	0.12	0.12	0.03	0.10	0.23	3.12
Pettah 4 lane (Urban)	Min	1.00	0.98	0.18	0.39	3.07	1.63	0.77	1.25	3.19	-
	Max	1.00	1.28	0.22	0.54	4.45	3.13	1.11	2.01	3.19	-
	Mean	1.00	1.16	0.19	0.47	3.77	2.27	0.93	1.70	3.19	-
	SEM	0.00	0.02	0.01	0.01	0.14	0.14	0.03	0.07	0.00	-
Wellawatte 4 lane (Urban)	Min	1.00	1.01	0.17	0.45	3.80	1.66	0.85	1.51	2.29	-
	Max	1.00	1.32	0.22	0.58	6.26	2.98	1.18	1.81	4.22	-
	Mean	1.00	1.17	0.19	0.49	4.72	2.27	0.98	0.98	3.31	-
	SEM	0.00	0.02	0.00	0.01	0.47	0.21	0.03	0.03	0.23	-
Wellawatte (MLC) 3 lane (One-Way)	Min	1.00	0.92	0.17	0.47	3.22	1.03	0.76	1.51	2.64	-
	Max	1.00	1.58	0.20	0.53	4.37	2.27	1.07	2.54	3.44	-
	Mean	1.00	1.19	0.19	0.50	3.54	1.85	0.94	1.90	3.06	-
	SEM	0.00	0.04	0.01	0.01	0.09	0.09	0.03	0.09	0.16	-

Deviation of the hourly PCU values was determined using the Standard Error of the Mean (SEM). SEM is the variability of a sampling distribution of means. Except for the Multi-Axle vehicle category at Pannipitiya, almost all vehicle categories have gained relatively more minor SEM values. As a result, the PCU value for the Multi-Axle vehicle category at Pannipitiya was rejected. Another fact is that, in comparison to the other locations, the PCU values for Large Buses at the Wellawatte location have become somewhat inconsistent. The reason for this deviation is that it is not a regular bus route. Except for the two PCU values mentioned above, all other mean PCU values for each location are shown in Table 6. As per the results, the estimated PCU values depend on the traffic and road conditions at the specific surveyed locations. Furthermore, the results revealed that PCU values for Motorcycles are consistent across all locations, whereas PCU values for Three-Wheelers vary slightly.

Table 6. Estimated PCU values for the selected midblock sections

	Athurugiriya	Pannipitiya	Pettah	Wellawatte	Wellawatte (MLC) Road
	4-lane (Expressway)	4-lane (Sub-Urban)	4-lane (Urban)	4-lane (Urban)	3-lane (One-Way)
Car	1.00	1.00	1.00	1.00	1.00
Van	`1.11	1.10	1.16	1.17	1.19
Motorcycle	-	0.19	0.19	0.19	0.19
Three-Wheeler	-	0.48	0.47	0.49	0.50
Large Bus	3.57	3.59	3.77	-	3.54
Small Bus	1.87	2.12	2.27	2.27	1.85
Light Truck	1.04	0.91	0.93	0.98	0.94
Medium Truck	1.90	1.77	1.70	1.68	1.90
Heavy Truck	3.33	3.18	3.19	3.31	3.06
Multi-Axle	6.94	-	-	-	-

PCU values of large vehicle types (i.e., Small Buses, Large Buses, and Heavy Goods vehicles) show the minimum PCU values at the Wellawatta (MLC). This midblock section facilitates one-way traffic and consists of three lanes. Therefore, the mobility of large vehicles is relatively easy in this road section, indicating the minimum PCU values for large vehicle categories. Furthermore, PCU values of Small and Large buses at Athurugiriya are relatively low. This deviation is because these two vehicle categories have significantly higher speeds on expressways than on regular bus routes. As per the results, the highest PCU values for Small and Large buses could be observed in Pettah. It should be highlighted that Pettah has the highest bus density of all locations because the central bus terminal is located. Having the highest PCU value for buses highlights the impact of Pettah's higher bus density on general traffic.

There is a slight pattern among the four-lane urban and suburban arterials. Pettah values are greater than Pannipitiya values, while Wellawatta values are greater than Pettah values. This observed pattern, however, does not apply to Medium Truck vehicles. One notable feature is that this representation corresponds to the observed traffic conditions at those locations. Although Pannipitiya is a suburban arterial, it had the lowest stream speeds at certain times because it is one of the main corridors for the Colombo city limits. In contrast, the highest stream speeds were recorded at the Wellawatte location, where the Colombo Plan Road was surveyed, because that road serves as an alternate route along the main corridor. When the vehicle flow speed decreases, so do the speed difference between the subject and reference vehicles. According to Chandra's method, this pattern is reasonable because it allows the PCU values to increase as the speed difference between the vehicle category and the car increases. Except for the Athurugiriya and Wellawatta (MLC), an average set of values was taken to obtain a comparative insight with the existing PCU values for the Sri Lankan context and shown in below Fig. 7. The average values were used because it is necessary to have more generalized values than specific ones for each surveyed location.

4.4 Comparison with existing PCU values

Table 7.Comparison of new PCU values with existing values

Study	This study	*Kumarage* [5]	*RDA* [19]	*Jayarathne et al.* [17]
Year	2021	1996	2002	2018
Car	1.00	1.00	1.00	1.00
Van	1.14	1.10	-	1.20
Motorcycle	0.19	0.50	0.50	0.23
Three-Wheeler	0.48	0.75	0.80	0.56
Large Bus	3.68	2.40	1.80	5.36
Small Bus	2.22	1.60	1.60	2.32
Light Truck	0.94	1.50	1.50	1.00
Medium Truck	1.72	2.00	1.70	2.52
Heavy Truck	3.27	3.80	2.80	3.56

It can be seen that the estimated PCU values in this study differ from the existing values and are slightly aligned with the 2018 set. It is a general fact that PCU values change as the vehicle's composition and dimensions change over time. Table 7 indicates that the PCU values obtained in this study for Motorcycles and Three-Wheelers are slightly lower than the existing ones. Dhamaniya & Chandra [18] studied that the increase in volume to capacity (v/c) ratio of smaller vehicles than cars cause a decrease in their PCU values. If one were to put this argument forward, having a higher (v/c) ratio on the selected midblock sections at present compared to the past supports it.

The estimated PCU values in this study reflect the impact caused by the evolution in vehicle dimensions brought into the country over the last two decades. During the previous two decades, the use of Medium Vans has reduced, especially due to the introduction of Mini Vans (subcategory under Cars). On the other hand, the size of Large Vans has increased slightly, and much larger vans (i.e., KDH 222R-LEMDY HIGH ROOF) have also been introduced to the vehicle mix. This change in the composition of Vans on the roads is the reason behind higher PCU values of Vans compared to older values.

The Light Truck vehicle, a rare vehicle category in the past, has become a popular alternative to small freight transport solutions. The introduction of fuel-efficient Light Truck vehicles that are small in size to the country is a primary reason behind that. Since these vehicles are small compared to Cars, having a PCU value of less than one is acceptable. Although different Truck vehicle brands have been introduced to the country's vehicle market, the sizes and capacities of truck bodies seem to remain the same due to the standardization. Therefore, further research is needed to find a possible reason for the deviation in calculated PCU values compared to the previous studies for Medium Truck and Heavy Truck vehicles.

Concerning the Buses, different capacities and sizes can be observed on the roads at present than in the past. Also, the super-luxury buses joined the service during the past period. Therefore, compared to the available models in the past, the dimensions of buses increased. The scenario for the Small Buses is also similar to Large Buses. In that case, having higher PCU values for both Small and Large buses is reasonable.

5 CONCLUSION

PCU values are an essential component in conducting various traffic-related analyses. Also, the accuracy of PCU values significantly impacts the results of those analyses. Using Chandra's Method, this study estimated PCU values for four different types of midblock road sections in the Colombo District. It was observed that the PCU values determined for each type of midblock section varied based on the nature of the traffic flow at the survey locations. In the four-lane urban and suburban road types, an increase in PCU values was observed as flow speed increased at each midblock section. However, Motorcycles and Three-Wheelers with the highest traffic volume did not show a significant difference in PCU values according to road type. PCU values of buses at the expressway were marginally lower due to the higher speed compared to other midblock sections. PCU values of large vehicles at three-lane (one-way) midblock sections were lower since wider roads ease the mobility of large vehicles. Higher bus density at the Pettah has caused to increase in the PCU values of buses.

To summarize, the PCU value for the same vehicle category varied depending on the traffic speed, nature of traffic flow, and nature of the midblock section. Furthermore, the averaged PCU values depicted the impact for PCU values from changes in vehicle sizes used in Sri Lanka over the last two decades. The PCU values estimated in this study can be used as the set of updated PCU values for traffic-related analysis in Sri Lanka hereafter. It is worth noting that there is still room for further studies regarding PCU values in the Sri Lankan context, such as dynamic PCU value estimation based on different flow levels and the impact of vehicle composition on the PCUs.

6 ACKNOWLEDGEMENT

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