Estimation of Passenger Car Unit Values of Vehicles in Urban Arterial Roads Based on the Influence of the Neighboring Vehicles

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Abstract: The Passenger Car Unit (PCU) value is used to convert the heterogeneous traffic streams to hypothetical passenger car streams, and its value varies with factors. This study aims to estimate the PCU values of the different types of vehicles using a speed-based method, considering the influence of the neighboring vehicles in a five-lane urban arterial road in the City of Manila. A video survey was used for data collection, and the Image Processing and Acquisition toolbox of MATLAB was used for data analysis. The analysis of the neighboring vehicles is based on the six scenarios of combinations of the existence and position of neighboring vehicles. The result shows a variation of the PCU values across scenarios. It shows that of all scenarios, bus is consistently the vehicle type with the highest estimated PCU value of 4.69, while two-wheeler is consistently the vehicle type with the lowest estimated PCU value of 0.259.

Keywords: Passenger Car Unit, Estimates, Influence, Manila, Variation, Neighboring Vehicles.

1. INTRODUCTION

1.1 Background of the Study

The increase in the number of road vehicles in the Philippines has become a major problem, contributing to traffic congestion, air pollution, and road crashes. Compounding this problem is the increasing number of different types of vehicles running on the roads, making it more challenging for traffic engineers in the analysis of traffic flow and assessment of traffic impacts. From the measured traffic volume of roads and intersections in vehicles per hour, it is then converted to flow in terms of passenger car units (PCU) per hour and used with the road capacity, which is expressed in passenger car units per hour. A passenger car unit (PCU) is a common unit used to convert traffic streams into hypothetical passenger car streams (Sharma and Biswas, 2020). It is inappropriate to express the traffic capacity of the road under a heterogeneous mixture as a number of vehicles passing a road section per hour. That is why the passenger car unit is introduced to settle the issue (Raj et al., 2017). The PCU is used to assess the traffic flow rate on roads and intersections; however, the accuracy of the PCU value needs to be considered for the traffic flow analysis (Gani et al.,2017).

Current traffic analysis and road design methods in the Philippines are based on developed countries, where the traffic characteristics are different. Traffic on roads and streets in Metro Manila and the Philippines is characterized as mixed traffic with vehicles varying in static and dynamic characteristics. One of the important characteristics of the traffic streams in Metro Manila is the presence of a higher percentage of motorcycles (Sigua et al., 2017), which the developed countries did not consider the effect of the motorcycle on PCU (Espenilla et al., 2010), thus contributing to the lane discipline problem which greatly influence the characteristics of traffic flow in Metro Manila, Philippines.

1.2 Problem Statement

In the Philippines, on February 22, 2013, Department Order (D.O.) No. 22 of the Department of Public Works and Highways (DPWH) presented the Passenger Car Equivalent Factor (PCEF) of the different types of vehicles except motorcycles as the basis for road capacity design.

However, at present, the PCU values used are relatively outdated (Guide for Road Function Improvement Planning,1987). Decades ago, the road and vehicle characteristics in Metro Manila were not as improved as of today (Metro Manila Urban Transportation Integration Study Update and Enhancement Project, 2015, and National Roads Improvement and Management Program, 2017). Therefore, there is a need to update PCU values due to changes in road and vehicle characteristics.

1.3 Objectives of the study

The objectives of this study are the following:

a) to estimate the passenger car unit (PCU) values of vehicle types on an urban arterial road using a speed-based method; and,

b) to investigate the effect of neighboring vehicles on the PCU values of subject vehicles on a five-lane urban road in the City of Manila.

1.4 Significance of the study

The significance of the study is that updated values of PCU can be used by the traffic and road engineers in the analysis of traffic flow and assessment of traffic impact through road capacity design and level of service assessment of urban roads in the Philippines.

1.5 Conceptual Framework

Figure 1 shows the conceptual framework of this study. A speed-based method was used to estimate the PCU values of vehicle types, as shown in Table 1. It shows the definition of this method. In this method, there are two parameters to consider in data gathering. These are the speed of the vehicle expressed in kph and the effective area of the vehicle expressed in sq.m. The parameters of the subject vehicle are influenced by the neighboring vehicles. The adopted approach for the estimation of the PCU values by (Raj *et al*., 2017) of the vehicles is used.

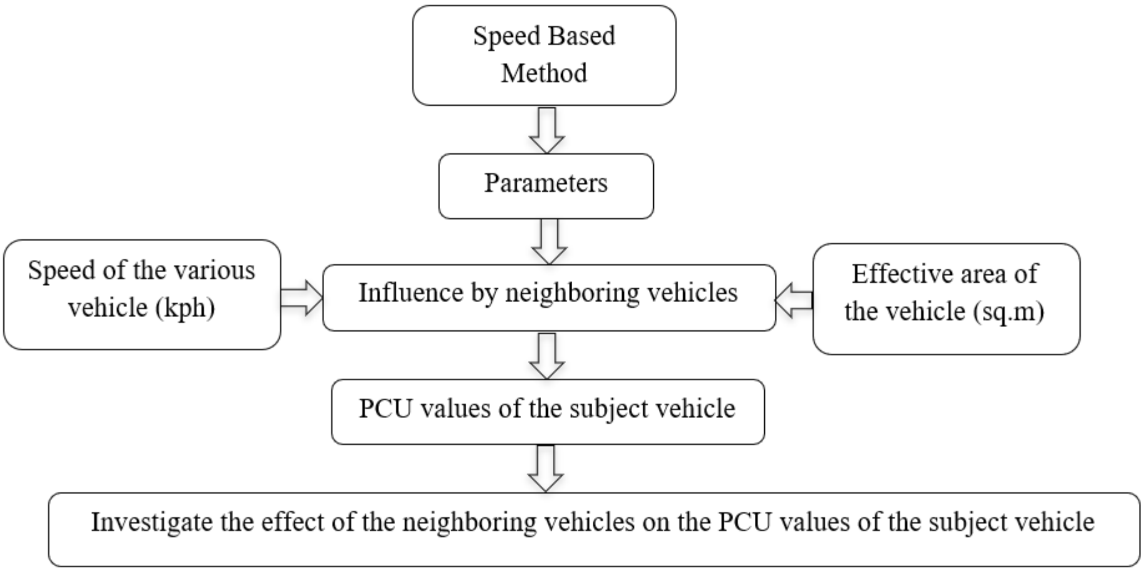

Figure 1. Conceptual Framework

2. REVIEW OF RELATED LITERATURE

2.1 Experience of Estimating Passenger Car Unit (PCU) Values

2.1.1 International PCU Value Estimation

Bangladesh is where the degree of heterogeneity of the traffic stream is significantly high; therefore, a study in determining the passenger car unit values became mandatory for traffic flow studies (Rahman et al., 2020). In India, the traffic scenario is reported to be mixed in conditions without observing any lane discipline on roads, and the flow was said to be highly heterogeneous and difficult to evaluate due to its magnitude and the nature of the traffic stream. There were related studies regarding the estimation of passenger car unit values in India. A study was the analysis of saturation flow at signalized intersections using various PCU estimation methods (Mondal, et al., 2019), Chandra et al. (2015) researched the effect of carriageway on the estimation of the PCU values of vehicle types. A case study using three different approaches were observed such as the static value from IRC 64 (1990), the concept of dynamic PCU values as proposed by Chandra (2004) and the method suggested in Indonesia – HCM (2017) and (Pal et al. 2019) and estimation of passenger car unit values of vehicles based on influence of neighboring vehicles (Raj et al., 2017). One of the important characteristics of the traffic flow in developing countries is the presence of small vehicles, which are motorcycles (Minh et al., 2010). A study from Raj et al. (2017) highlighted the impact of the neighboring vehicles in the traffic stream, which affected the characteristics of traffic flow, and Gani et al. (2017) cited the differences in the traffic conditions between the developing and developed countries. Vergel and Morichi (1995) compared the traffic capacities and road conditions in Manila, Bangkok, Seoul, and Tokyo and estimated the PCU values at urban intersections using the headway-based method.

Espenilla et al. (2010) estimated the PCU value of motorcycles that ranged from 0.26 to 0.30. Sigua et al. (2017) investigated the lane capacities of motorcycles, developed design guidelines for motorcycle lanes at road sections and at intersections for the purpose of intersection traffic signal control settings. The study has shown the relationship between the number of motorcycles that can be stored in a 12-m. length of road at different proposed lane widths of 1.5 m., 2.0 m., 2.5 m., and 3.0 m., as well as the relationship of speed, flow, and density. They also estimated the PCU value of the motorcycle, which resulted in 0.24 under controlled conditions.

2.1.2 Summary of Methods

There are various methods used to estimate the passenger car unit values (Table 1). However, the known method used is headway-based and speed-based. In the Philippines, Sigua et al. (2017) estimated the PCU values of motorcycles using a headway-based method, and Vergel and Morichi (1995) estimated the PCU values of some vehicle types except motorcycles using the headway-based method. Meanwhile, Raymundo et al. (2024) focused on the estimation of the PCU values of tricycles, similar to Espenilla et al. (2010) estimated the PCU values of motorcycles using a speed-based method (as shown in Table 5).
Table 1 presents the different methods for determining and estimating the PCU values of different types of vehicles; however, not all of the methods are applicable for heterogeneous traffic conditions (Gani et al., 2017). Most of the methods are commonly used for homogenous traffic conditions but failed in converting volumes under heterogeneous traffic conditions (Chandra et al.,2015).

Table 1. Common methods used to estimate PCU value

Methods	Advantage	Disadvantage	Characterization
Author/s			
Headway	Best suited in less mixed traffic conditions, low terrain, and a better level of service.	Data collection is difficult due to the identification of the saturation period	Time between two successive vehicles in a traffic stream as they pass a point on a roadway.
(Vergel & Morichi, 1995), (Rao et al., 2017), (Sigua et al., 2017), (Okura & Sthapit, 1995), (Saha et al., 2009), (Obiri-Yeboah et al., 2014), (Satthamnuwong et al., 2018) & (Swetha, 2016)			
Homogeneous Coefficient	The level of data collection is easy.	Does not show variation of interaction due to the consideration of length only.	Ratio of the length and speed of the subject vehicle to the ratio of the length and speed of the passenger car.
(Rahman et al., 2020), (Mounika et al., 2022) & (Swetha, 2016)			
Multiple Linear Regression	Represents mixed traffic conditions and can capture many vehicles.	Sometimes results to an inaccurate estimation of PCUs and gives negative values, and also difficult in field data due to traffic composition of all vehicles cannot be	The average speed of the subject vehicle is based on the classified traffic volumes in the form of multiple linear regression.

		obtained under controlled conditions.	
(Srikanth & Mehar, 2017), (Minh C. et al., 2010) & (Sugiarto et al., 2021)			
Speed Based	Suitable for mixed traffic conditions of any vehicle type and the ability to capture the dynamic nature of PCU.	Intensive work is required to estimate the value.	Directly proportional to the speed ratio and inversely proportional to the projected area ratio with respect to the standard vehicle.
(Raj et al., 2017), (Pal et al., 2019), (Gani et al., 2017), (Krishna et al., 2019), (Chandra et al., 2015), (Khanorkar et al., 2014), (Dhananjaya et al., 2023), (Raymundo et al., 2024) & (Espenilla et al., 2010)			
Density	Data collection is easy and simple	The method is applicable if there is only one vehicle type present.	Based on the traffic flow rate, and considers only the truck and standard car in the traffic stream.
(Tiwari, Fazio, & Pavitravas,2015), (Weerasinghe, 2017) & (Swetha, 2016)			
Simulation	Any type of traffic conditions	Need to validate	Uses a computer model replicating the real-world situation of traffic
(Asaithambi et al., 2016), (Mohan & Chandra, 2017), (Deshmukh & Sultan, 2021), and (Mehar et al., 2014)			

Srikanth and Mehar (2017) attempted to use the different methods and applied them in a developing country for the estimation of the PCU values; however, they concluded that the obtained PCU values were inaccurate and existing methods to estimate PCU values of vehicle types are not found to be realistic under developing country road conditions. However, speed-based or dynamic methods gave the best results among the others.

2.1.3 The Philippine Context

Table 2 presents the PCEF of the different types of vehicles in the Philippines, except for the motorcycle. The PCEF of the three-wheelers and trucks is the same, which is 2.5. Despite being a small vehicle type, the reason is that tricycles a slow-moving vehicle that causes queuing on roads. In an area where the greatest number of vehicle types are three-wheelers, it exhibits a higher volume-capacity ratio (VCR) since one three-wheeler is equivalent to 2.5 passenger cars and therefore, the area is a candidate for road widening or traffic intervention (Raymundo et al., 2024).

Table 2. Passenger Car Equivalent Factor (PCEF) of vehicles as per Department of Public Works and Highways (DPWH) Department Order No.22 Series of 2013

No.	Vehicle Type	PCEF Values
1	Three-Wheelers	2.5
2	Passenger Car	1.0
3-5	Good Utility and Small Bus	1.5
6	Large Bus	2.0
7	Rigid truck, 2 axles	2.0
8	Rigid truck, 3+ axle	2.5
9	Truck Semi – Trailer, 3 and 4 axles	2.5
10	Truck Semi-trailer.5+ axles	2.5
11-12	Truck Trailer, 4 axles or 5+ axles	2.5

2.1.4 Influencing Factors

Table 3 presents the different factors affecting the PCU values of the vehicle types. The PCU values may not be considered as constant and vary with various factors (Krishna et al., 2019).

Table 3. Factors on PCU values as per US Highway Capacity Manual (2000)

No.	Factors	Characteristics
1	Vehicle	physical and mechanical
2	Stream	speed, positioning and trajectories
3	Roadway	location, horizontal alignment, stretch, pavement surface, flow regulation, carriageway width, sight distance and geometrics
4	Environment	surrounding factors, obstruction and terrain condition

In recent studies, additional factors were found. Najid (2018) estimated the PCU value of motorcycles in different locations and concluded that the total population and population density were considered as factors affecting the PCU values. The World Road Association (Guidelines for Road Design,2019) considered time of day, such as morning, afternoon, and evening, as factors affecting the PCU values, and the Transportation Research Board (2020) considered weather and climate, such as temperature, humidity, sun glare, wet road, and frost road condition, as factors affecting the PCU values.

2.1.5 Research Gap

The PCU values in Table 4 were authored by different Filipino researchers with different methods used in estimating from 1995 to 2024. To fill this gap, this author considered other methods of estimating the PCU values of different types of vehicles to update.

Table 4. PCU Values of Vehicle Types Based on Local Research

No.	Vehicle types / Classification	PCU Values	Authors
1	Medium Truck	1.50	(Vergel and Morichi, 1995)
2	Large Truck	2.43	
3	Bus	1.87	
4	Jeepney	1.50	

5	Three-Wheelers	0.535	(Raymundo et al., 2024)
6	Two-Wheeler	0.24/0.26-0.30	(Sigua et al., 2017) & (Espenilla et al., 2010)

2.1.6 Method of Data Collection and Extraction

Raj et al. (2017) used the video graphic technique as a tool in gathering the necessary data for the study. The camera is mounted and sighted adjacent to the selected roads of study. They used Irfanview, an image processing software that converts ordinary images to high graphical image resolution in their study. The software obtained the X-Y coordinates of all points in terms of pixels on the image. The gridlines were plotted in CAD with the obtained image coordinates and then overlaid on the video using video editor software.

3. METHODOLOGY

The speed and effective area are the determining parameters for the estimation of the PCU values, considering the influence of the neighboring vehicles. Figure 2 shows the study flow referring to sub-sections 3.1 to 3.5 for the explanation of the details.

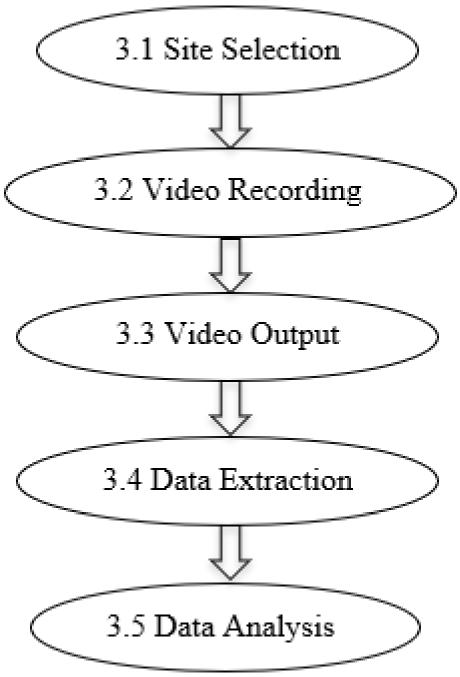

Figure 2. Study Flow

3.1 Site Selection

The first criterion of selecting the site location for the study road section must have heterogeneous traffic streams where different types of vehicles are present. The second criterion is that the road section must be far from the intersection (midblock section). The camera must be mounted adjacent to the selected road at the top of the building, aiming for a top-view image. Figure 3 shows the site location for the study, which is Quezon Boulevard in Quiapo, Manila. It has a length of 1.1 km and has a total of 10 lanes (5 lanes per direction).

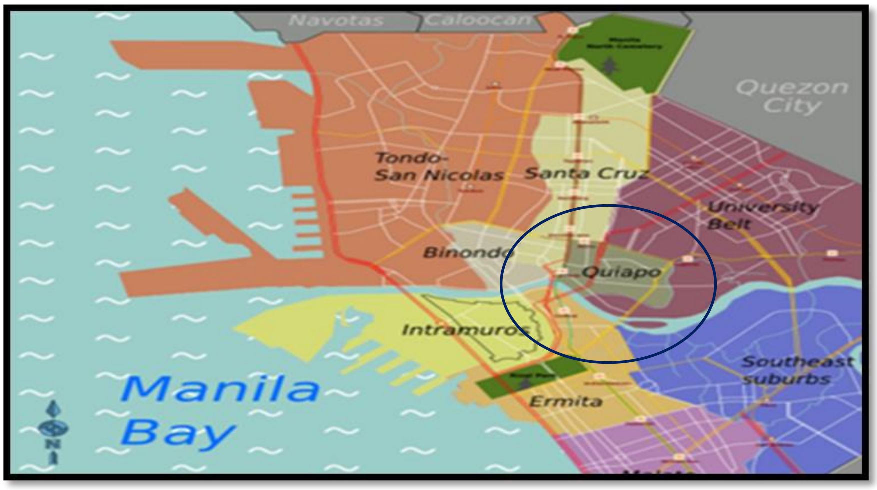

Figure 3. Study Site (Quiapo Boulevard, Manila City),
Source of Image: Travel guide at wikivoyage

3.2 Video Recording

To determine the speed of the vehicle, the video graphic technique was used as a method of processing data from the video stream by using a camera. Figure 4 shows the tools and equipment used in the data gathering, and the camera was set up overhead at the study site.

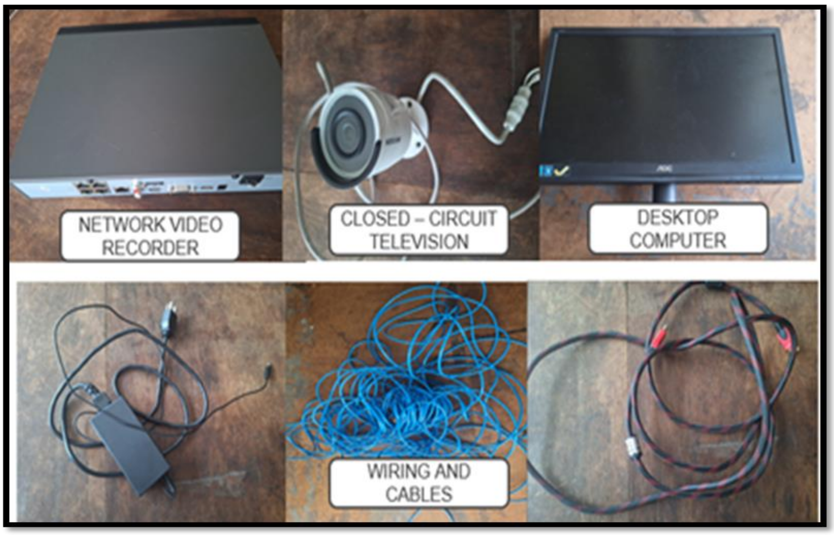

Figure 4. Tools and Equipment used in data gathering

According to Senstarpedia, an article that enriches and expands on physical technologies, NVR (Network Video Recorder) is a specialized computer that records security video surveillance footage in digital format to a hard drive. The video is typically processed and encoded from the CCTV camera. NVR resolution of recording offers 1080P high-definition recording capabilities, incredible image clarity and readily scalable. This served as a video recorder link thru CCTV via wiring and cables then connected to a desktop computer for the viewing of the image.

3.2.1 Video Survey

The video survey was conducted on May 2, 2024, from 6:30 a.m. to 5:30 p.m. under fair weather conditions. Figure 5 shows the position of the camera during the video survey. The camera is mounted at the top of the building to capture a top-view image of the road.

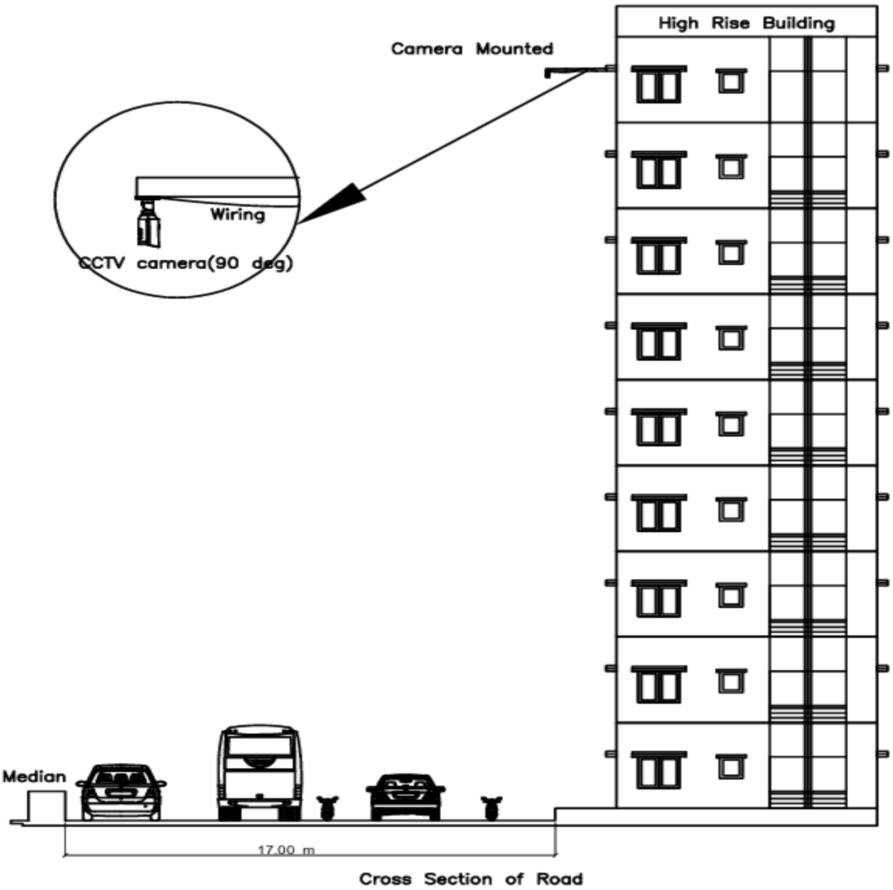

Figure 5. Positioning of the CCTV Camera

3.3 Video Output

The video output was collected from the NVR, then stored on a USB and transferred to a computer for data extraction. A total of 30 videos every 15 minutes was collected for the estimation. Figure 6 shows the top-view image of the video traffic in the desktop computer.

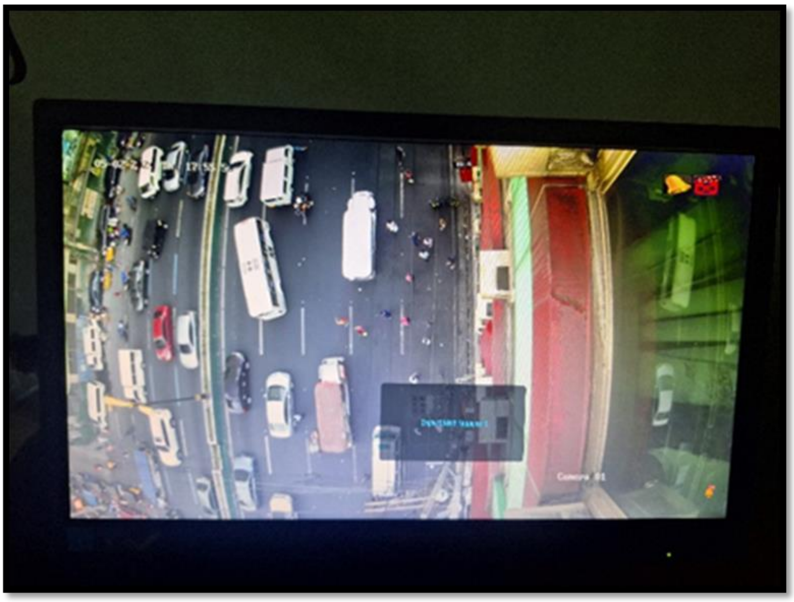

Figure 6. Sample image of the video during the survey

3.4 Data Extraction

Using MATLAB (Image Processing and Acquisition toolbox) as a means of data extraction for this study. The following advantages of this software.
1. Can read trajectory
2. Measure position
3. Easy repetition if needed for verification,
4. Easy Filter and user-friendly

Figure 7 shows the video image when integrated into MATLAB. Since the measurement of the distance from point to point of the vehicle and the XY coordinate is in terms of pixels in MATLAB. On-site surveys were done to scale the distance by using a laser beam measure. One frame per second was the frame rate used during the analysis.

Figure 7. Shows the video image in MATLAB

3.5 Data Analysis

3.5.1 Data Analysis

It is expected that there will be a variation in the speeds of different types of vehicles. Therefore, weighted space mean speed is treated as the mean stream speed. The entry and the exit of the subject vehicle into the segment will be recorded. The speed will be calculated by dividing the known segment length by the recorded time.

3.5.2 Effective Area

The effective area of a subject vehicle is a space requirement occupied by every running vehicle to maintain its speed on a roadway (Raj et al., 2017). It is calculated by the product of the effective length and effective width of a subject vehicle based on the influence of the neighboring vehicles. The value depends on speed, type, position, and neighboring vehicles. There are six scenarios to be considered in computing the effective area of the subject vehicle. The closest vehicles that overlap the position of the subject vehicle size are selected as the neighboring vehicles.

Scenario 1: No surrounding vehicle
Scenario 2: With one adjacent vehicle
Scenario 3: With two adjacent vehicles
Scenario 4: With one leader vehicle
Scenario 5: With one leader vehicle and one adjacent vehicle
Scenario 6: With one leader vehicle and two adjacent vehicles

Table 5 presents the effective area computation per given situation where L is the physical length of the subject vehicle, W is the physical width of the subject vehicle, Dl and Dr are the allowable distances to the left and right, respectively, and Df is the gap distance in front of the subject vehicle.

Table 5. Computation of Effective Area

Scenario No.	Description	Effective Area (EA)
1	No surrounding vehicle	$EA = L \times W$
2	Subject vehicle with one adjacent vehicle either left or right	$EA = L\,(W + D_r)$ / $EA = L\,(W + D_l)$
3	Subject vehicle with two adjacent vehicles	$EA = L\,(W + D_l + D_r)$
4	Subject vehicle with a leader vehicle	$EA = W\,(L + D_f)$
5	Subject vehicle with one adjacent vehicle and one leader vehicle	$EA = (L + D_f)(W + D_l)$ / $EA = (L + D_f)(W + D_r)$
6	Subject vehicle with two adjacent vehicles and one leader vehicle	$EA = (L + D_f)(W + D_l + D_r)$

In Figures 8 to 13 below, there are 6 scenarios presented assuming a passenger car as the subject vehicle with its corresponding neighboring vehicle.

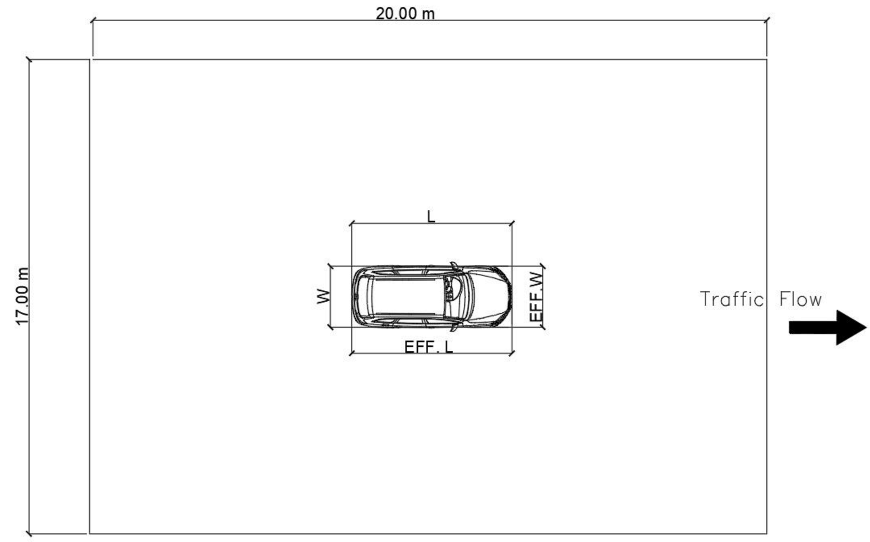

Figure 8. Scenario 1 - No Surrounding Vehicle

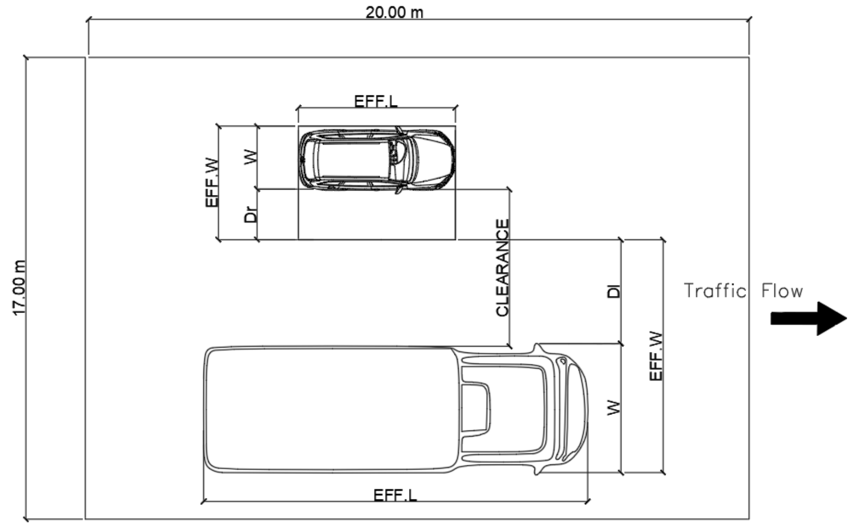

Figure 9. Scenario 2 - Subject Vehicle with One Adjacent Vehicle either Left or Right

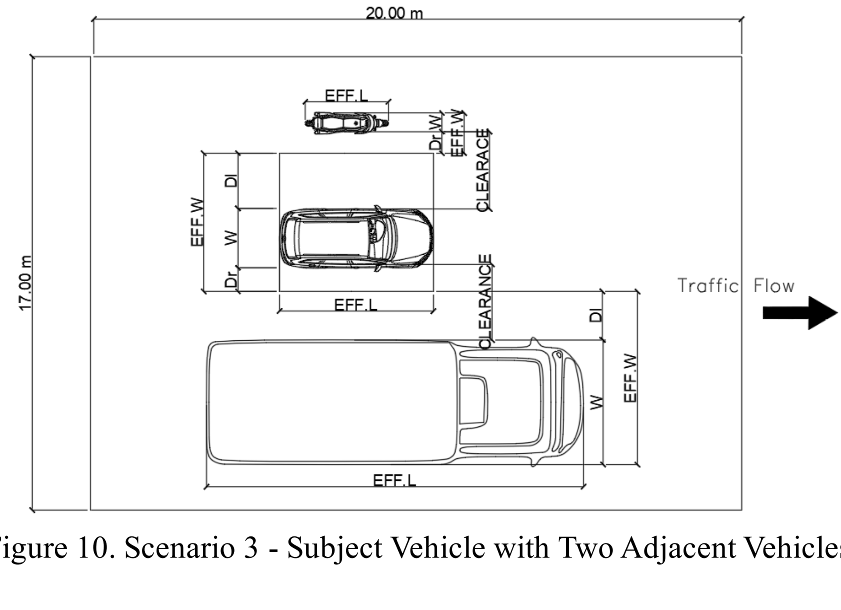

Figure 10. Scenario 3 - Subject Vehicle with Two Adjacent Vehicles

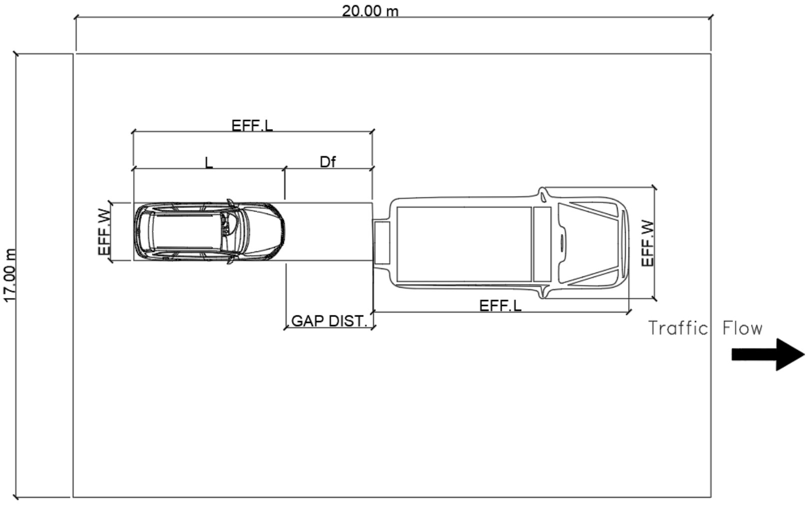

Figure 11. Scenario 4 - Subject Vehicle with a Leader Vehicle

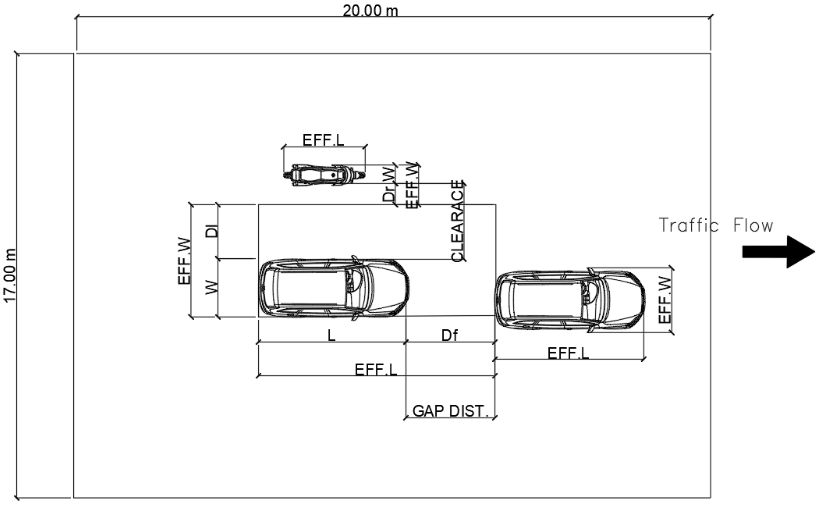

Figure 12. Scenario 5- Subject Vehicle with One Adjacent Vehicle and One Leader Vehicle

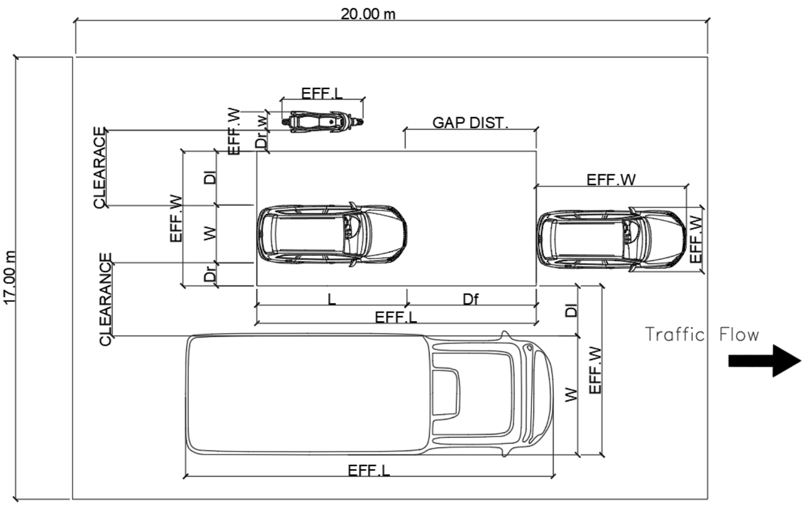

Figure 13. Scenario 6 - Subject Vehicle with Two Adjacent Vehicles and One Leader Vehicle

3.5.3 Estimation of PCU Values

The modified speed-based method is used for the estimation of the passenger car unit values of the different types of vehicles. The PCU is directly proportional to the speed ratio and inversely proportional to the effective area ratio as per given scenarios with respect to the standard vehicle, which is the passenger car, as shown in Equation 1.

$$PCUi = \left(\frac{V_c}{V_i}\right) / \left(\frac{EA_c}{EA_i}\right) \tag{1}$$

where:

Vc and Vi = space mean speeds of passenger car and vehicle i, respectively
EAc and EAi = effective area of the passenger car and effective area of the vehicle

The effective area of the vehicle is the product of the effective length and the effective width. The definitions for the effective length and effective width are the following:

Effective Length = physical length of the subject vehicle + gap distance from the front of the subject vehicle.

Effective Width = physical width of the subject vehicle + allowable distance either from the left or right.

The allowable distance is computed based on the size ratio for the adjacent vehicle, either left or right. The size ratio is the ratio of the physical size of the subject vehicle and the adjacent neighboring vehicles with respect to clearance. Gap distance is the space between the front of the subject vehicle to the tail of the front vehicle.

Figures 8 to 13 illustrate the effective area of the subject vehicle per scenario. The effective area required by the subject vehicle moving at a certain speed is assumed to be a rectangular shape to maintain its speed. This effective area is considered to be dynamic, and it depends on the speed, the size of the subject vehicle, and its neighboring vehicle and driver characteristics. The criteria for selecting the neighboring vehicles are the following:

Adjacent Vehicles – the closest vehicle that longitudinally overlaps with the length of the subject vehicle.

Leader Vehicle – the closest vehicle that overlaps laterally with the width of the subject vehicles within the trap length.

Table 6 shows the average dimensions of the vehicle types considered in this study.

Table 6. Vehicle Type with Corresponding Average Dimensions

Vehicle Type	Average length (m)	Average width(m)	Remarks
Car	4.16	2.09	small car, sedan car, small SUV, large SUV, pick up, and small van

Van	4.46	1.94	medium van and large van, and light commercial Van (LCV)
Three-Wheelers	1.39	1.39	any type
Two-Wheeler	1.84	0.82	any type and engine displacement
Bus	14.50	2.55	Standard
Modern Jeepney	7.00	2.50	existing
Traditional Jeepney	11.00	2.50	existing
Truck	12.50	2.50	light truck (delivery truck)

4. RESULT AND DISCUSSION

There are 2,670 vehicles from the data that are used for the estimation of the PCU values. The breakdown by subject vehicle type is as follows: Car – 782, Van – 220, Three-wheeler – 89, Two-wheeler – 950, Bus – 169, Modern Jeepney – 109, Traditional Jeepney – 244, and Truck – 107. The following is the breakdown per scenario: Scenario 1 – 1,278, Scenario 2 – 374, Scenario 3 – 344, Scenario 4 – 368, Scenario 5 – 203, and Scenario 6 – 103. The PCU values of vehicle types are estimated for each scenario. The following are the sections discussing the frequency of neighboring vehicles on the subject vehicle, the relationship of space mean speed and mean effective area of each vehicle type, and the estimated PCU values per scenario. It also highlights the significance of neighboring vehicles when estimating the PCU value of a subject vehicle. Using ANOVA (single factor) to analyze the variance of the PCU values. Single PCU values were obtained by computing the average of the PCU values of all scenarios with respect to their vehicle type. Figure 14 shows the distribution of vehicles over 11-hr video survey in percent.

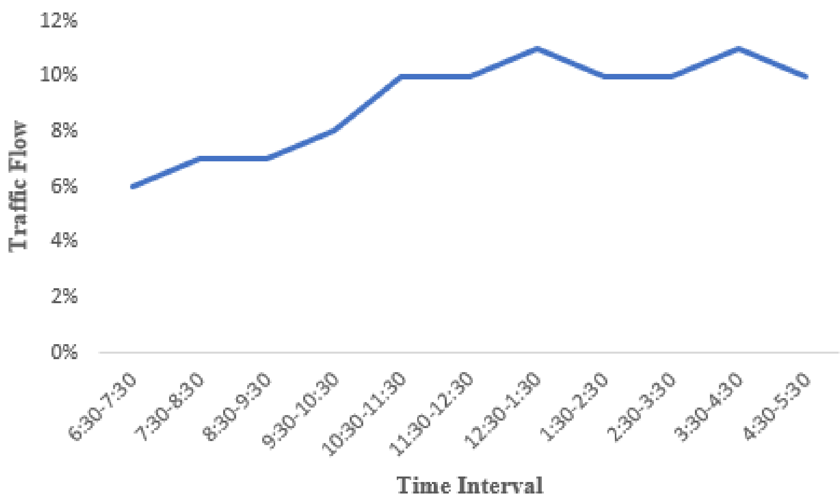

Figure 14. Hourly Distribution of Vehicle

4.1 Space Mean Speed, Mean Effective Area, and PCU

Table 7 shows the space mean speed, mean effective area, and the PCU values of the different types of vehicles in the six scenarios. In this study, space mean speed was used instead of time mean speed. The formula for space mean speed = (n / Σ(1/Vi)) where n is the number of vehicles, and Vi is the speed of the ith vehicle. The space mean speed differs from the time mean speed. The space mean speed is more suitable to use than the time mean speed when estimating the PCU value because it represents the overall traffic flow and speed conditions over a section of road. Table 6 shows the basis of the computation of the effective area of the vehicle type. Figures 8 to 13 illustrate the consideration of the effective area of the vehicle type per scenario. Estimating the PCU value, the ratio of the space mean speed of the passenger car and the vehicle i, and also the ratio of the mean effective area of the passenger car and the vehicle i were computed as shown in Table 7. Comparing the PCU values of each scenario, the bus is consistently the highest estimated PCU value, while the two-wheeler is consistently the lowest estimated PCU value. The ratio of the mean effective area of the car to the mean effective area of the bus is the lowest value which is ranging from 0.235 – 0.640 (from Scenario 1 to Scenario 6) meanwhile the ratio of the mean effective area of the car to the mean effective area of the two-wheeler shows the highest value which is ranging from 5.762 – 1.940 (from Scenario 1 to Scenario 6). It shows an increasing pattern for bigger vehicles than passenger cars and a decreasing pattern for smaller vehicles than passenger cars as the traffic flow increases. Ratio of the space mean speed of the car to vehicle i does not show a pattern. The majority of the highest estimated PCU values of vehicles are in Scenario 1, while the majority of the lowest estimated PCU values of vehicles are in Scenario 6. It can be observed that for all types of vehicles, Scenario 6 has the largest effective area due to when the subject vehicle is surrounded by more neighboring vehicles, the entire effective area has to be considered. Meanwhile, for all types of vehicles, Scenario 1 has the highest space mean speed due to the absence of neighboring vehicles interfering with its movement. It shows every scenario result with different PCU values for the vehicle type. Neighboring vehicles have an impact on the variation of the PCU values of the subject vehicle.

Table 7. Individual Computation of PCU Value of Different Scenarios

Vehicle Type	**Scenario 1**					**Scenario 2**					**Scenario 3**				
	Space Mean Speed (V)	Mean Effective Area (EA)	Vc/Vi	EAc/EAi	**PCU**	Space Mean Speed (V)	Mean Effective Area (EA)	Vc/Vi	EAc/EAi	**PCU**	Space Mean Speed (V)	Mean Effective Area (EA)	Vc/Vi	EAc/EAi	**PCU**
Car	59.99	8.69	1.00	1.000	**1.00**	51.45	15.47	1.00	1.000	**1.00**	47.44	18.28	1.00	1.000	**1.00**

Scenario	Vehicle Type	Car	Truck	Traditional Jeepney	Modern Jeepney	Bus	Two-Wheelers	Three-Wheelers	Van
Scenario 4	Space Mean Speed (V)	36.86	37.91	35.84	47.14	38.73	70.81	37.78	44.60
	Mean Effective Area (EA)	23.47	31.25	27.50	17.50	36.98	1.51	1.93	8.65
	Vc/Vi	1.00	1.58	1.67	1.27	1.55	0.85	1.59	1.34
	EAc/EAi	1.000	0.278	0.316	0.497	0.235	5.762	4.5000	1.005
	PCU	**1.00**	**5.69**	**5.29**	**2.56**	**6.59**	**0.15**	**0.35**	**1.34**
Scenario 5	Space Mean Speed (V)	36.63	36.49	31.84	34.03	28.73	57.33	31.27	35.51
	Mean Effective Area (EA)	34.24	53.49	46.38	27.59	59.29	3.41	3.62	15.16
	Vc/Vi	1.00	1.41	1.62	1.51	1.79	0.89	1.65	1.45
	EAc/EAi	1.000	0.290	0.330	0.560	0.270	4.530	4.280	1.020
	PCU	**1.00**	**4.88**	**4.84**	**2.70**	**6.52**	**0.20**	**0.38**	**1.42**
Scenario 6	Space Mean Speed (V)	36.09	34.73	28.04	37.94	20.21	44.43	18.94	38.72
	Mean Effective Area (EA)	51.66	62.49	55.28	35.23	61.00	4.95	6.31	19.82
	Vc/Vi	1.00	1.67	1.69	1.27	2.35	1.07	2.51	1.23
	EAc/EAi	1.000	0.290	0.330	0.520	0.300	3.690	2.890	0.920
	PCU	**1.00**	**4.67**	**5.12**	**2.44**	**7.83**	**0.29**	**0.87**	**1.33**

Truck	Traditional Jeepney	Modern Jeepney	Bus	Two-Wheelers	Three-Wheelers	Van
34.16	34.44	59.87	27.01	67.49	31.07	50.06
41.07	37.74	26.66	45.62	6.01	11.11	22.53
1.08	1.07	0.62	1.36	0.55	1.19	0.74
0.570	0.620	0.880	0.510	3.910	2.110	1.040
1.89	**1.72**	**0.70**	**2.65**	**0.14**	**0.56**	**0.71**
32.98	39.28	51.52	31.24	42.87	34.58	37.66
76.55	66.66	45.92	63.75	16.90	15.96	26.43
1.11	0.93	0.71	1.17	0.85	1.06	0.97
0.450	0.510	0.750	0.540	2.030	2.140	1.300
2.48	**1.82**	**0.95**	**2.18**	**0.42**	**0.49**	**0.75**
21.16	27.90	33.09	24.09	51044	27.08	25.71
81.13	62.32	53.56	80.98	26.57	31.08	43.99
1.71	1.29	1.09	1.50	0.70	1.33	1.40
0.640	0.830	0.960	0.640	1.940	1.660	1.170
2.68	**1.56**	**1.13**	**2.35**	**0.36**	**0.80**	**1.20**

4.1.1 Analysis of Variance

ANOVA (single factor) test was used to compare the means of scenarios of vehicle types to determine if there is a significant difference between them.

Table 8. Statistical Treatment

Vehicle Types	Count	Sum	Average	Variance
Car	6	6.000	1.000	0.000
Van	6	6.740	1.123	0.098
Three-Wheelers	6	3.460	0.576	0.045
Two-Wheeler	6	1.556	0.259	0.013
Bus	6	28.123	4.687	6.547
Modern Jeepney	6	10.480	1.746	0.830
Traditional Jeepney	6	20.3524	3.392	3.465
Truck	6	19.446	3.241	3.174

Source of Variation	SS	df	MS	F	P-Value	F-Critical
Between Groups	105.521499	7.00	15.0744998	8.5071219	2.3931E-06	2.249024325
Within Groups	70.8794349	40.00	1.77198587			
Total	176.400934	47.00				

Null hypothesis: There is no significant difference in the differing position of the neighboring vehicle combination on the subject vehicle.
Alternative hypothesis: there is a significant difference in the differing position of the neighboring vehicle combination on the subject vehicle.

The implemented p-value is 0.05, and the calculated p-value is 2.3931E-06. Since the calculated value is less than the implemented p-value therefore it indicates rejecting the null hypothesis. There is a significant difference after running the PCU values of different scenarios in an ANOVA (single-factor test) at a 95 % confidence level. Therefore, when estimating the PCU value of a vehicle, one of the factors to consider, aside from Table 3, is its neighboring vehicles.

4.2 Relationship of Space Mean Speed and Mean Effective Area

Considering the space mean speed and the mean effective area of the different scenarios for the relationship of the two variables, where x for the space mean speed and y for the mean effective area of each vehicle. Figures 15 to 22 are essential for developing PCU estimation models. It helps to visualize how different vehicle types occupy road space and behave at various speeds. The R-squared values of all relationships are greater than 0.50. Using a linear regression model at a 95% confidence level to predict the x and y relationship of the different types of vehicles.

4.2.1 Space Mean Speed Vs. Mean Effective Area of the Car

Figure 15 shows the linear regression model of the mean effective area and the space mean speed for cars.

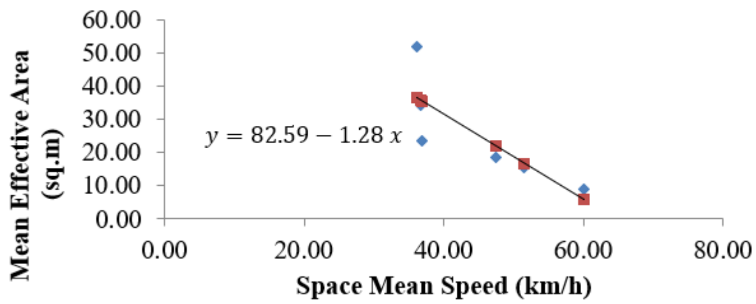

Figure 15. Regression Model of Mean Effective Area and Space Mean Speed – Car

4.2.2 Space Mean Speed Vs. Mean Effective Area of the Vans

Figure 16 shows the linear regression model of the mean effective area and the space mean speed for vans.

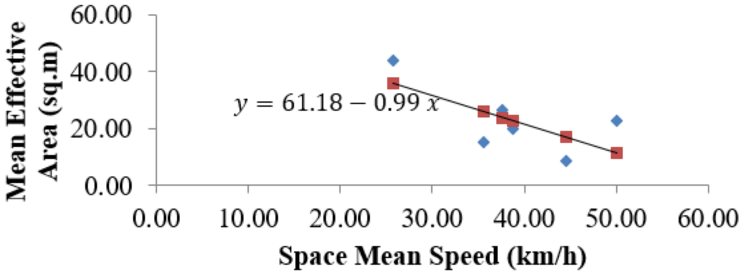

Figure 16. Regression Model of Mean Effective Area and Space Mean Speed – Van

4.2.3 Space Mean Speed Vs. Mean Effective Area of the Three–Wheelers

Figure 17 shows the linear regression model of the mean effective area and the space mean speed for three–wheelers.

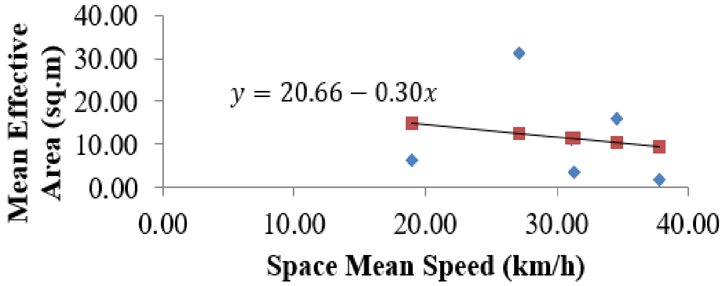

Figure 17. Regression Model of Mean Effective Area and Space Mean Speed – Three-Wheelers

4.2.4 Space Mean Speed Vs. Mean Effective Area of the Two–Wheeler

Figure 18 shows the linear regression model of the mean effective area and the space mean speed for a two-wheeler .

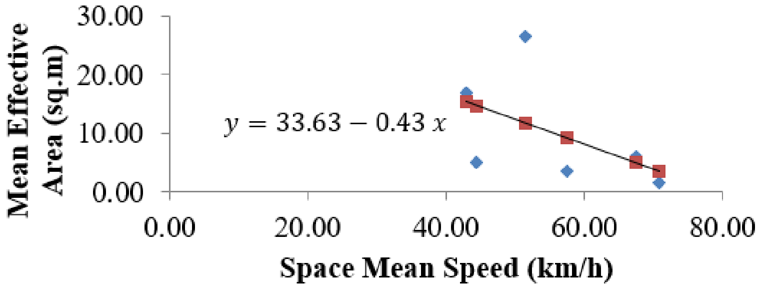

Figure 18. Regression Model of Mean Effective Area and Space Mean Speed – Two-Wheeler

4.2.5 Space Mean Speed Vs. Mean Effective Area of the Bus

Figure 19 shows the linear regression model of the mean effective area and the space mean speed for buses.

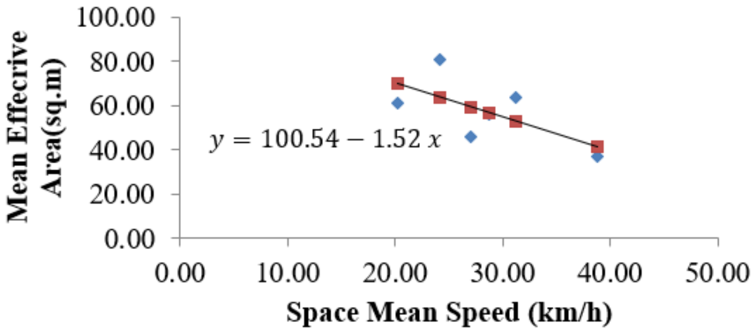

Figure 19. Regression Model of Mean Effective Area and Space Mean Speed – Bus

4.2.6 Space Mean Speed Vs. Mean Effective Area of the Modern Jeepney

Figure 20 shows the linear regression model of the mean effective area and the space mean speed for the modern jeepney.

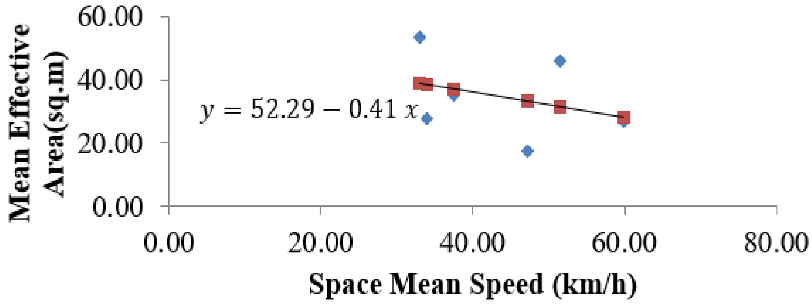

Figure 20. Regression Model of Mean Effective Area and Space Mean Speed – Bus

4.2.7 Space Mean Speed Vs. Mean Effective Area of the Traditional Jeepney

Figure 21 shows the linear regression model of the mean effective area and the space mean speed for the traditional jeepney.

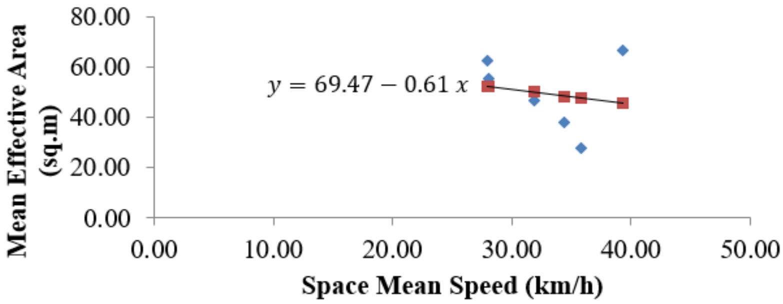

Figure 21. Regression Model of Mean Effective Area and Space Mean Speed – Traditional Jeepney

4.2.8 Space Mean Speed Vs. Mean Effective Area of the Truck

Figure 22 shows the linear regression model of the mean effective area and the space mean speed for trucks.

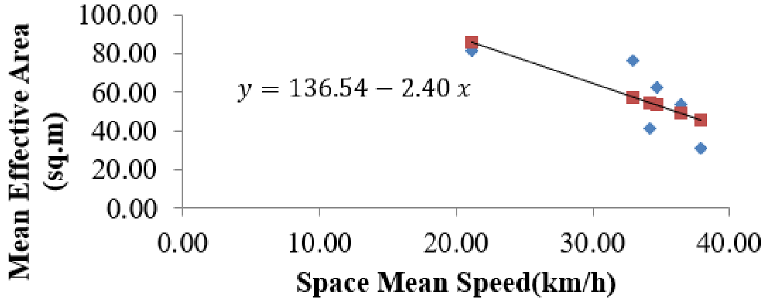

Figure 22. Regression Model of Mean Effective Area and Space Mean Speed – Truck

Figure 15 to Figure 22 above show an inversely proportional relationship between space mean speed and mean effective area of the vehicle. It implies that if there are a greater number of neighboring vehicles, the subject vehicle tends to move slower. The higher the effective area results in lower the space mean speed of the subject vehicle which gives lower PCU value of vehicle type in contrast the lower the effective area results in higher space mean speed of the subject vehicle which gives higher PCU value. It implies that the neighboring vehicle has an effect on the subject vehicle as shown in Table 8 as the PCU value varies by scenario. In the estimation of the PCU, the surrounding factors such as its neighboring vehicles must be a consideration when estimating the PCU value. it is clearly showing, differing position of neighboring vehicle results to different PCU values of the subject vehicle.

4.3 Average PCU Values

Figure 23 shows the estimated single PCU values of vehicles.

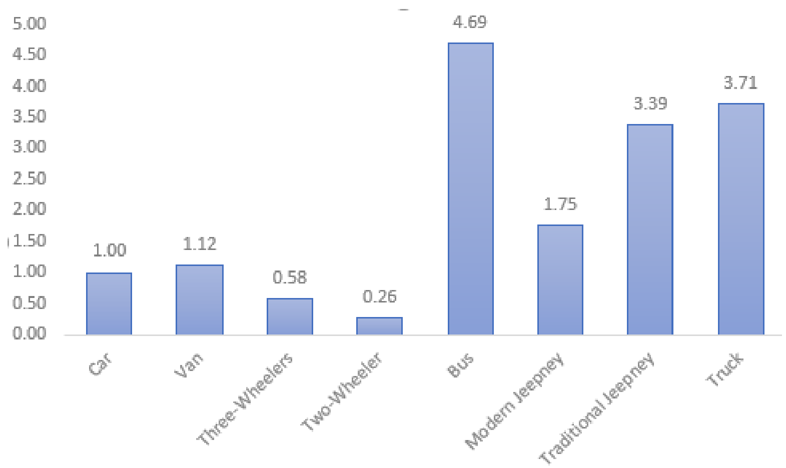

Figure 23. Estimates of Single PCU Values of Vehicle Types

Higher PCU value indicates a vehicle's greater contribution to traffic in a mixed stream condition. Averaging the PCU values of all scenarios results in a single PCU value that represents each type of vehicle. Comparing vehicle types, it can be noted that the bus has the highest PCU value with an average value of 4.69 while the vehicle type with the lowest value of 0.259 is the two-wheeler. In a local study, Raymundo et al. (2024) estimated the PCEF of the three-wheelers using a speed-based method with time mean speed and projected area as the variables in their study, and it is influenced by road width and lane configuration and to obtain its single PCEF of three-wheelers is by averaged the different PCEFs as shown in Table 10 for its result value. Espenilla et al. (2010) determined the PCU values of the motorcycle (two-wheeler) using a speed-based method with space mean speed and dynamic projected area as the variables in their study, and it is represented by different approaches of estimation such as Chandra method, frame method, and turbulence method as shown in Table 10 for its result values. Vergel and Morichi (1995) estimated the PCU values of the bus, truck and jeepney in Metro Manila and found bus has the highest estimated PCU value and the jeepney has the lowest estimated PCU value using the headway-based method, as shown in Table 4 for its result values. Sigua et al. (2017) estimated the PCU values of the two-wheeler using a headway-based method under controlled conditions as shown in Table 4.

Dhananjaya et al. (2023) estimated the PCU values of vehicle types in Sri Lanka roads using speed-based method with time mean speed and projected area as the variables and found bus has the highest estimated PCU values which is 3.68 and two-wheeler has the lowest estimated PCU value which is 0.19 comparing the result with the study of Raj et al. (2017) estimated the PCU values of vehicle types in India roads using speed-based method with space mean speed and effective area as the variables and found bus has the highest estimated PCU values which is 4.57 and two-wheeler has the lowest estimated PCU value which is 0.31. It shows that whatever type of variables the researchers used in a speed-based method, the big vehicle gives higher PCU value and small vehicle gives smaller PCU value however, the result PCU value of the vehicle using space mean speed and mean effective area as the variables is higher compared to the time mean speed. and projected area. In connection to this study, refer to Figure 23, it shows that the big vehicle has the highest PCU value than the small vehicle. In DPWH, small vehicle and big vehicle has same PCU value as shown in Table 2.

4.4 Comparison of PCU Values using Speed–Based Method

Table 9 compares the new estimated PCU values with the existing estimated PCU values of the vehicle types. The PCU values are estimated in different countries with different approaches of estimation using the speed-based method.

Table 9. Comparison of New PCU Values of Vehicle Types with Existing Values

Authors/s	PCU Values of Vehicle Types using Speed-Based Method								Remark	
	Car	Van	Two-Wheeler	Three-Wheelers	Bus	Modern Jeepney	Traditional Jeepney	Truck	Country	Variables

This study	1.00	1.12	0.26	0.58	4.69	1.75	3.39	3.71	Philippines	Space mean speed and mean effective area
	Average of the PCU values obtained by the influence of neighboring vehicles									
(Dhananjaya et al.2023)	1.00	1.19	0.19	0.48	3.68	-	-	0.94	Sri Lanka	Time mean speed and projected area
	Average of the PCU values of five different locations									
(Raymundo et al.2024)	-	-	-	0.535	-	-	-	-	Philippines	Time mean speed and projected area
	Average of the PCU values obtained by the influence of road width and lane configuration									
(Raj et al.2017)	1.00	1.43	0.31	0.90	4.57	-	-	-	India	Space mean speed and mean effective area
	Undivided road and off-peak flow condition									
(Espenilla et al.2010)	-	-	0.26 - 0.30	-	-	-	-	-	Philippines	Space mean speed and dynamic projected area
	Three different approaches of estimation (Chandra, Frame and Turbulence)									
(Pal et al.2019)	1.00	1.54	0.30	1.71	4.60	-	-	3.92	India	Time mean speed and projected area
	Influence by different locations									

(Gani et al.2017)	1.00	1.00	0.40	-	1.30	-	-	1.30	Indonesia	Space mean speed and projected area
	Urban arterial road which vehicles classified into three categories									
(Krishna et al.2019)	1.00	1.90	0.40	0.80	4.60	-	-	3.20	India	Time mean speed and projected area
	Different locations (Jeedemetla road as the PCU values represent this discussion)									
(Chandra et al.2015)	1.00	1.47	0.26	1.26	5.24	-	-	2.77	India	Time mean speed and projected area
	Undivided road at section Mumbai Chennai road as the PCU values represent this discussion									

Table 9 shows that the majority of the researchers when estimating PCU values using speed-based methods, they just considered the projected area of the vehicle which is the area of length and width of the vehicle or the projected dimension of the vehicles itself and neglecting the effect of the neighboring vehicles as represented by the effective area. Time mean speed of various vehicles was also considered in their estimation which is in this study, space mean speed is used simply because it accounts for interaction between vehicles especially in heterogeneous traffic conditions and also it captures better than the time mean speed in terms of traffic flow dynamic and impact of neighboring vehicles on speed. The time mean speed is more influenced by individual vehicle speed only as shown in their study. Dealing with the interaction of the vehicle, it needs to consider the best representation of the traffic conditions. To capture traffic flow characteristics when estimating PCU value as a best representation is by considering the effective area and space mean speed as the variables of the speed-based method instead of time mean speed and projected area.

5. CONCLUSION AND RECOMMENDATION

In most developing countries, mixed traffic conditions on roads are common, where different types of vehicles are present. The study estimated the PCU values of the different types of the vehicles according to six scenarios representing combinations consisting of differing positions of the neighboring vehicle/s with respect to the subject vehicle. The result shows that each scenario gave varying PCU values of considered vehicle types. Using speed-based methods, neighboring vehicles need to be considered because it greatly influences the PCU values of the subject vehicle. Some key points of this study are the following:

a) The effective area ratio is inversely proportional with the space mean speed ratio.

b) Combination of differing positions of the neighboring vehicle with respect to the subject vehicle results to variation of PCU values.
c) For all types of vehicles, Scenario 6 has the largest effective area.
d) For all scenarios, the bus has the highest average PCU values which is 4.69 and a two-wheeler has the lowest average PCU values which is 0.26.
e) Space mean speed and mean effective area as variables in speed-based method are better than time mean speed and projected area as variables in speed-based method as it represents interaction of vehicle in mixed traffic conditions.
f) Neighboring vehicles have impact on the PCU value of the subject vehicle and DPWH considered it as one of the factors when updating the estimation of the PCU value of the vehicle type.

In the Philippines, estimation of the PCU values of vehicle types is necessary for further study. There is a need to explore more such as using other methods in estimating the PCU values, different set up of study such as different types of roads and other situations, such as the factors affecting PCU values of vehicles. A speed-based method with space mean speed and mean effective area as the variables in estimating the PCU value of vehicles in an urban arterial road can be adopted by the DPWH in updating the vehicle's PCU value.

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