Determination of Passenger Car Unit Equivalence for Motorcycles: The Case of Metro Manila

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Abstract: The study primarily focuses on the determination of Passenger-Car-Unit of motorcycles along straight road segments with continuous flow in Metro Manila. To aid in the determination of motorcycle PCU values, a passenger-car unit traffic analysis program (PCU-TAP) was developed that considers the maneuverability of each vehicle. In determining the capacity of the road, obtaining the PCU values was a secondary goal to check whether it would have any significant effect on road capacity. In the study, video surveillance was done on three sites with two to four lane roads. Raw video footage was then edited in order for it to be analyzed by the program. The outputs from PCU-TAP were organized in order to present the characteristics of both the mixed traffic and all-passenger car traffic and the computed PCU values from three PCU determination methods namely Chandra, Frame and Turbulence PCU methods. The outputs were further analyzed using the Greenshield's model in order to determine the speed, density and flow relationships for the observed traffic. It was determined that PCU values attained using the three methods did not vary significantly as these ranged from 0.26-0.30. Capacity was found to increase slightly when the presence of motorcycles in the traffic stream were taken into consideration.

Key words: Passenger Car Unit (PCU), motorcycle PCU, road capacity, traffic analysis program

1. INTRODUCTION

This study aims to determine the PCU equivalence of motorcycles considering their maneuverability based on traffic conditions local to Metro Manila. The obtained PCU values of motorcycles would be integrated in the design of the roads specifically when computing for the capacity, giving consideration to the presence of motorcycles in traffic stream. This PCU has proven to vary at different traffic conditions and as a result, the capacity of the road would vary accordingly. Methods that of which would be utilized in the study to determine the PCU equivalence of the motorcycles would be based on studies conducted in India where motorcycles occupy approximately 60% of the vehicle population and as a result, Indian traffic engineers have also found the need to make use of PCU values of motorcycle in designing their roads.

2. PROBLEM

The current highway design being utilized in Metro Manila is based on Western standards, which neglect the PCU of motorcycles. However, different conditions exist in Western countries compared to developing nations that warranted the omissions of the motorcycles. Vehicular traffic along roads in Metro Manila is heterogeneous in nature with a wide variation in the static and the dynamic characteristics of vehicles. Due, to significant vehicular population of motorcycles, a localized PCU value for Metro Manila must be obtained, and must vary with respect to the traffic condition and behavior present on roadways.

3. HYPOTHESIS

The expected PCU value of motorcycles will be less than 1.0 PCU. Also, considering the passenger-car unit equivalence of motorcycles would increase the traffic volume in the observed traffic stream. Finally, PCU equivalence of motorcycles changing lanes is higher than the PCU equivalence of a motorcycle travelling parallel to the direction of the traffic stream.

4. SCOPE AND LIMITATIONS

The areas of the study are multilane roadways up to four lanes with continuous traffic flows of at least 100 m in length located in Metro Manila. We considered part of the said roads clear of any access roads. The study is primarily concentrated on determining the PCU values of motorcycles in Metro Manila, taking into consideration the number, speed, position and space that the motorcycles utilize on the road. The study would be limited to regular conditions and disregard unique conditions such as traffic accidents which disrupt the flow of traffic.

Other modes of transport was considered when possible in this study which includes passenger-cars, SUVs, trucks, Vans, Jeeps, LCV and buses as it will affect the said parameters of the motorcycles such as speed and positioning on the road.

For this study, PCU values for roads with more than four lanes, intersections and parking spaces were not derived. Data during occasions when weather conditions are not acceptable were disregarded as well as during occasions such as road accidents or other events where the vehicular flow on the road was not under normal conditions.

The number of observation periods that were analyzed should at least be five to six per road section to have been able to be able to plot the behavior of a traffic stream. Each observation period should last from at least thirty minutes to an hour to be able to note the changes that occur in the traffic stream.

5. CONCEPTUAL FRAMEWORK

Given below is the conceptual diagram utilized in the study for determining the PCU equivalence values.

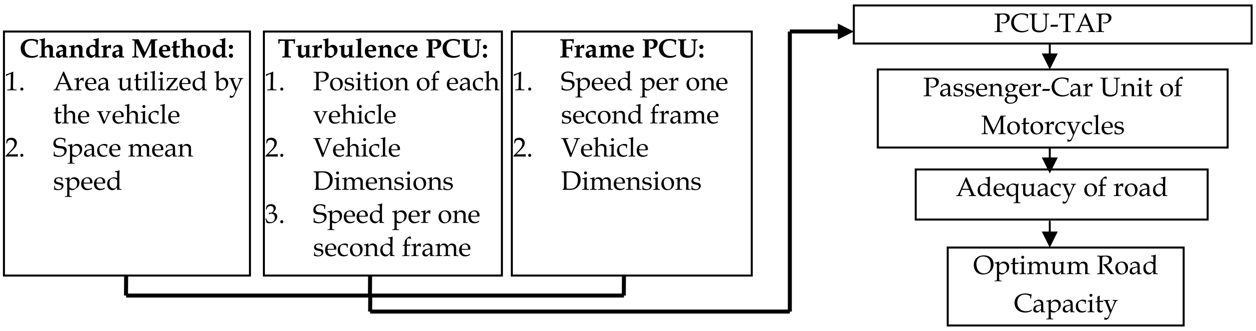

Figure 1. Conceptual Framework Diagram

6. THEORETICAL FRAMEWORK

The study conducted by Chandra et al. (2003) concerning the estimation of Passenger-car Unit values in heterogeneous traffic, showed that the area or space the vehicle occupied on the road was a significant variable as well as speed. The study pointed out that PCU can be determined using operating speed. It was also stated that though lanes were marked for four wheeled vehicles, these could also accommodate at least one small vehicle. As the width of the vehicle is smaller as compared to the lane, then the gap between the lane markings and the vehicle tend to be utilized by smaller vehicles, thus two vehicles can travel adjacent to each other. In heterogeneous traffic conditions, where vehicles lack lane discipline, the occupancy of lanes was better shown by the area and the physical size of the vehicle and not length alone was considered by Chandra in PCU determinations as given by equation (1). Chandra's method of determining PCU however analyzes the traffic stream as whole and does not take into consideration the individual frames of traffic streams with respect to video analysis. The study requires a more specific analysis of the behavior of vehicles in the traffic. With the use of the traffic analysis program for determining PCU (PCU-TAP), it was possible to individually and more thoroughly analyze each 1 second video frame. Chandra formula can be used to determine PCU for every 1 second frame. This PCU is applied to the volume of that specific frame which gave a frame density. Vehicles travel at different speeds. PCU varies for every 1 second frame while the area utilized by each vehicle remains fixed throughout the video. Stream PCU values for each vehicular entity type can be determined by taking the average of the 1 second PCU per frame of each vehicular entity. To dig further into the subject, a third method known as Turbulence PCU was developed which takes into consideration the projected area of the vehicles known as dynamic area. The area utilized varies depending on the orientation of the vehicle with respect to the direction of traffic flow as seen in Figure 2.

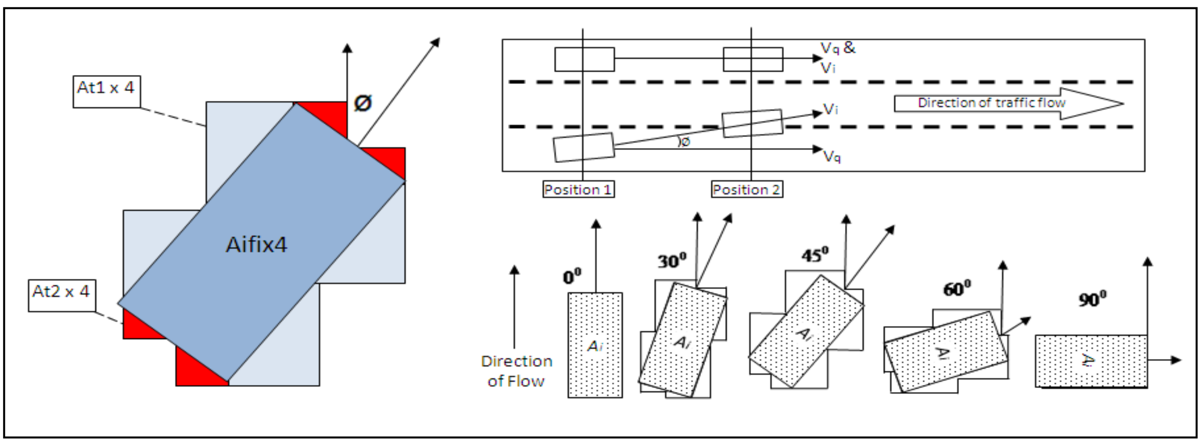

Figure 2. Dynamic Area Projections

Capacity, by standard practice in road design, is given in terms of per individual lane. In order to determine the capacity per lane, the data from the three Sites were converted into single 3 meter lanes and then combined in order to obtain the data given below. By doing this, more data can be utilized in order to give better projections of Greenshield's models having more reference points.

7. ROAD CAPACITY

The capacity of a road is the maximum hourly rate at which vehicles reasonably can be expected to traverse a point or a uniform section of a lane or a roadway during a given time period under prevailing roadway and traffic, and control conditions. Capacity is generally expressed as PCU per hour or PCU/lane/hour and PCUs per kilometer length of lane. For this study, Greenshield's model for density flow relationship was primarily used.

Space mean speed is given by variable *us* and k is used for density. Jam density is denoted *kj*, theoretically the space mean speed at this point should theoretically be zero due to the high density and lack of space for vehicles to maneuver through. *uf* represents free flow speed where in which the traffic stream is theoretically flowing freely at a steady pace.

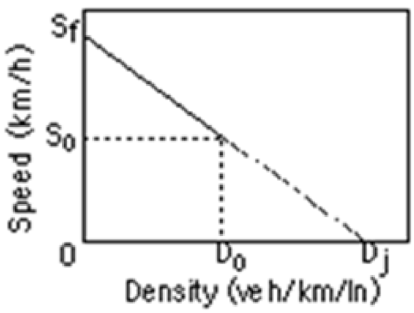

Figure 3. Generalized Relationships between Speed and Density on Uninterrupted-Flow Facilities

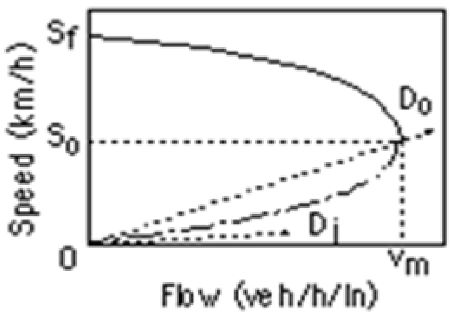

Figure 4. Generalized Relationships between Speed and Flow Rate on Uninterrupted-Flow Facilities

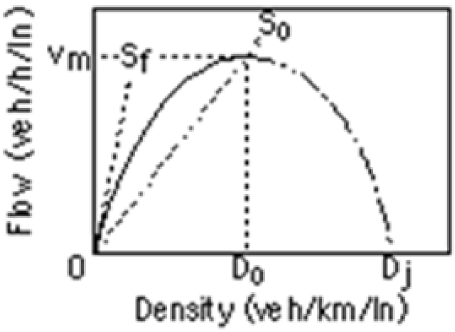

Figure 5. Generalized Relationships between Flow Rate and Density on Uninterrupted-Flow Facilities

In establishing these graphs, it is very rare to be able to complete the graph as to this will require a very large and well distributed sample size. Usually, only a few points on the graphs will be identified and the critical will be based on the three equations for the graphs.

8. RESEARCH FLOW DIAGRAM

Figure 6 below is a representation of the procedures that were conducted in the study.

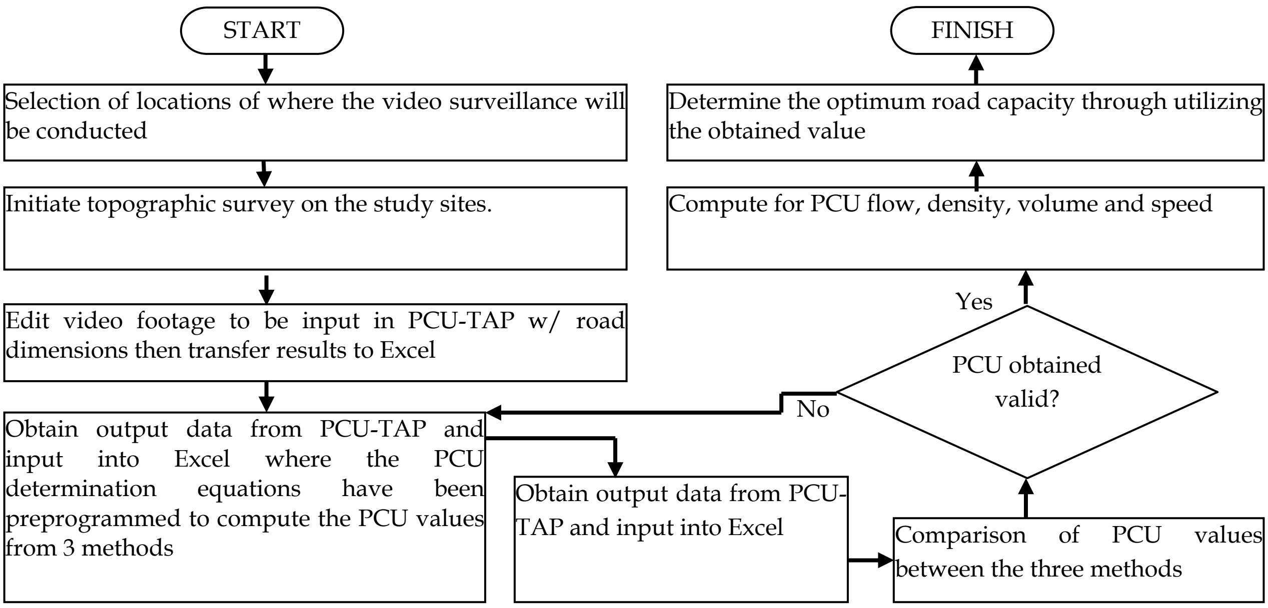

Figure 6. Research Flow Diagram of the Procedure

Statistical Treatment

Validation of PCU values had been done by graphically representing the converted vehicular traffic based on Chandra's PCU determination method since values obtained from this method from other countries have been accepted. If the PCU values obtained from the two other methods are similar for roads with free flowing traffic where lane changing does not occur as much, then the obtained PCU values are assumed to be valid.

Traffic Analysis Program Outputs for the combined Data

Capacity, by standard practice in road design, is given in terms of per individual lane. In order to determine the capacity per lane, the data from the three Sites were converted into single 3 meter lanes and then combined in order to obtain the data given below. By doing this, more data can be utilized in order to give better projections of Greenshield's models having more reference points.

Developed Greenshield's Models

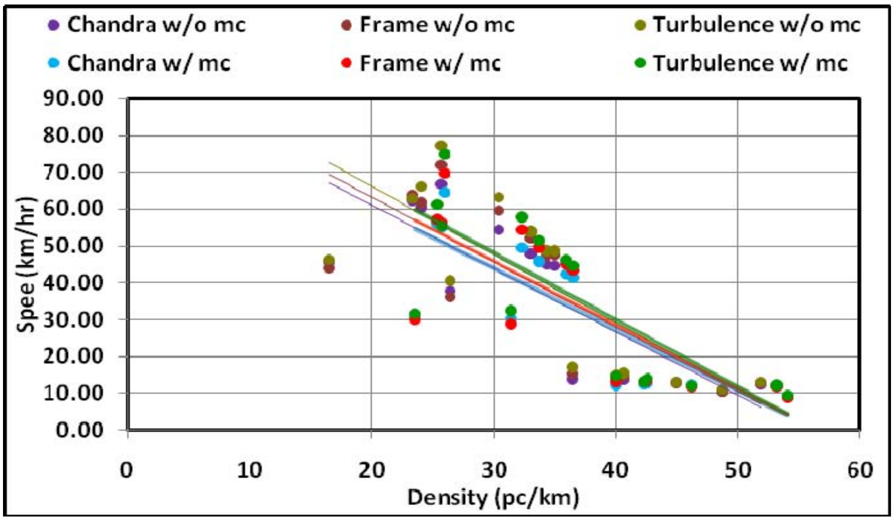

Figure 7. Developed Speed-Density Relationship "Disregarding" Versus "Considering" Motorcycles

Greenshield's linear model for the Speed-Density Relationship for Chandra (1), Frame (2) and Turbulence (3) method for case 1(motorcycles are disregarded) versus case 2 (motorcycles are considered) for Chandra (4), Frame (5) and Turbulence (6) in the traffic stream are given by:

$$\bar{u}_s = 40.24 - 0.306k \quad (1)$$

R-square = .7832 t-stat = 19.89 km/hr

$$\bar{u}_s = 47.32 - 0.346k \quad (2)$$

R-square = .7326 t-stat = 16.52km/hr

$$\bar{u}_s = 47.50 - 0.335k \quad (3)$$

R-square = .7275 t-stat = 16.43 km/hr

$$\bar{u}_s = 49.81 - 0.404 \quad (4)$$

R-square = .7419 t-stat = 18.96 km/hr

$$\bar{u}_s = 49.06 - 0.364k \quad (5)$$

R-square = .6919 t-stat = 16.24 km/hr

$$\bar{u}_s = 49.16 - 0.350k \quad (6)$$

R-square .6924 t-stat = 17.46 km/hr

where: $\hat{u}_s$: Space mean speed of traffic stream (km/hr)
k: Density of the traffic stream (pc/km)

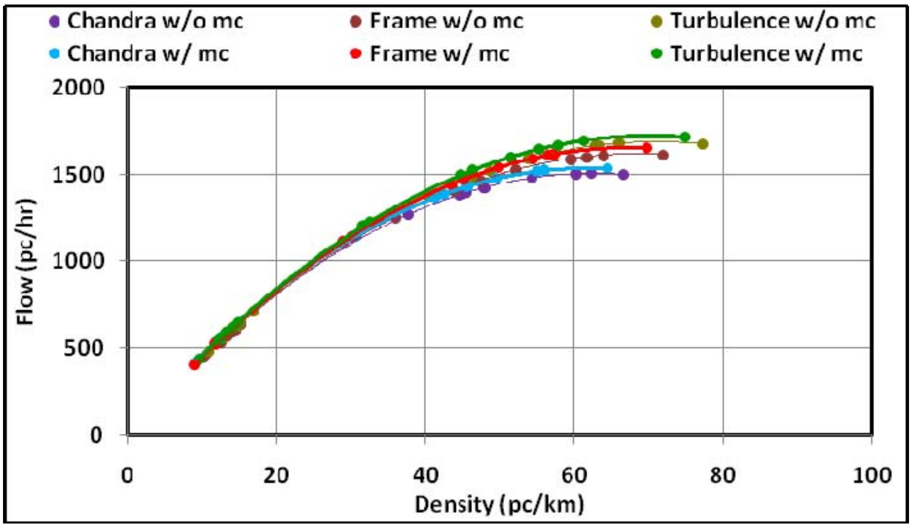

Figure 8. Developed Speed-Density Relationship Considering Motorcycles

Greenshield's model for the Flow-Density Relationship for Chandra (7), Frame (8) and Turbulence (9) method for case 1(motorcycles are disregarded) versus case 2 (motorcycles are considered) for Chandra (10), Frame (11) and Turbulence (12) in the traffic stream are given by:

$$q = 48.24k - 0.386k^2 \quad (7)$$
Max q = 1597

$$q = 47.32k - 0.346k^2 \quad (8)$$
Max q = 1618

$$q = 47.50k - 0.335k^2 \quad (9)$$
Max q = 1685

$$q = 49.81k - 0.404k^2 \quad (10)$$
Max q = 1536

$$q = 49.06k - 0.364k^2 \quad (11)$$
Max q = 1654

$$q = 49.16k - 0.350k^2 \quad (12)$$
Max q = 1725

where: q: Flow of traffic stream (pc/hr)
k: Density of the traffic stream (pc/km)

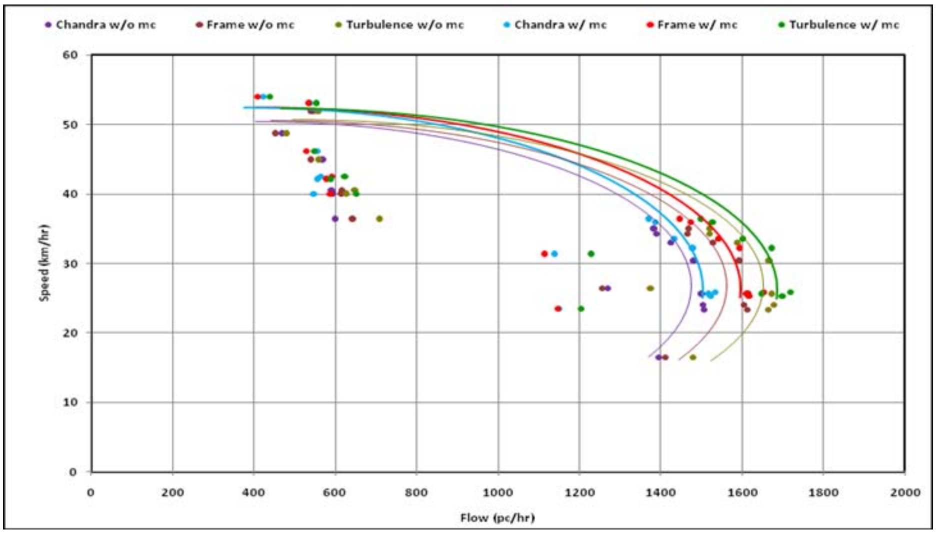

Figure 9. Developed Speed-Flow Relationship Disregarding Motorcycles

Greenshield's model for the Speed-Flow Relationship for Chandra (13), Frame (14) and Turbulence (15) method for case 1 (motorcycles are disregarded) versus case 2 (motorcycles are considered) for Chandra (16), Frame (17) and Turbulence (18) in the traffic stream are given by:

$$\mu_s^2 = 48.24\mu_s - 0.386q \quad (13)$$
Max q = 1597

$$\mu_s^2 = 47.32\mu_s - 0.346q \quad (14)$$
Max q = 1618

$$\mu_s^2 = 47.50\mu_s - 0.335q \quad (15)$$
Max q = 1685

$$\mu_s^2 = 49.81\mu_s - 0.404q \quad (16)$$
Max q = 1536

$$\mu_s^2 = 49.06\mu_s - 0.364q \quad (17)$$
Max q = 1654

$$\mu_s^2 - 49.16\mu_s - 0.350q \quad (18)$$
Max q = 1725

where: q: Flow of traffic stream (pc/hr)
ûs: Space mean speed of traffic stream (km/hr)

9. COMPILATION OF RESULTS

Included in this section is the compilation of all the results from all three sites as well as combined data of the three sites.

Table 1. Compilation of Volume Increase Results

Method		w/o MC	w/ MC	% difference		w/o MC	w/ MC	% difference
Chandra	4 Lanes	3929	4162	**5.60%**	3 Lanes	4996	5097	**1.98%**
Frame		3772	4022	**6.22%**		5437	5547	**1.98%**
Turbulence		4136	4353	**4.99%**		5837	5969	**2.21%**
Chandra	2 Lanes	2861	2951	**3.05%**	Combined	1507	1536	**1.90%**
Frame		2931	3023	**3.04%**		1618	1654	**2.22%**
Turbulence		3015	3104	**2.87%**		1685	1725	**2.32%**

Summarizing the results for the observed four lane road traffic, determined volume capacity for Site 1 when motorcycles are not considered was 3929 (pc/hr), 3772 (pc/hr) and 4136 (pc/hr) for Chandra from, Frame and Turbulence methods respectively. While on the other when motorcycles were considered; capacity was at 4162 (pc/hr), 4022 (pc/hr) and 4353 (pc/hr) respectively. The volume demand was increased by at approximately 5.6% when motorcycles were considered.

The results for the observed three lane road traffic, determined volume capacity for Site 2 when motorcycles are not considered was 4996 (pc/hr), 5437 (pc/hr) and 5837 (pc/hr) for Chandra, Frame and Turbulence methods respectively. While on the other when motorcycles were considered; capacity was at 5097 (pc/hr), 5547 (pc/hr) and 5969 (pc/hr) respectively. The volume demand was increased by roughly 2.06% in all cases when motorcycles were considered.

The results for the observed two lane road traffic, determined volume capacity for Ortigas Flyover when motorcycles are not considered was 2861 (pc/hr), 2931 (pc/hr) and 3015 (pc/hr) for Chandra from, Frame and Turbulence methods respectively. While on the other when motorcycles were considered; capacity was at 2951 (pc/hr), 3023 (pc/hr) and 3104 (pc/hr) respectively. The volume demand was increased by at least 2.99% in all cases when motorcycles were considered.

Table 2. Obtained PCU values from all three sites

Veh Type	Chandra PCU Method				Frame PCU Method				Turbulence PCU Method			
	Site1	Site2	Site3	Mean	Site1	Site2	Site3	mean	Site1	Site2	Site3	mean
Truck	2.77	2.80	2.79	2.79	2.56	2.71	2.69	2.65	2.70	2.82	2.86	2.79
Bus	3.42	3.24	3.22	3.29	3.12	3.14	3.16	3.14	3.28	3.31	3.22	3.27
Car	1.07	1.03	1.04	1.05	0.96	1.00	1.00	0.99	1.05	1.05	1.05	1.05
Van	1.50	1.44	1.44	1.46	1.29	1.40	1.40	1.36	1.42	1.49	1.49	1.47
LCV	1.87	1.87	1.97	1.90	1.71	1.81	1.81	1.78	1.92	1.90	2.06	1.96
SUV	1.64	1.50	1.54	1.56	1.46	1.44	1.44	1.45	1.59	1.51	1.51	1.54
Jeep	2.07	2.07	2.21	2.12	1.89	2.00	2.00	1.96	2.26	2.42	2.25	2.31
MC	0.28	0.26	0.30	0.28	0.23	0.25	0.25	0.24	0.26	0.27	0.29	0.27

One factor that contributes to this effect is that since motorcycles comprise about 17% of the vehicle occupancy in the traffic stream for four lane roads that were observed, these motorcycles greatly influence the overall speed of the flow. The behavior of each motorcycle is also considerable since a motorcycle would generally have a smaller physical projection of utilization area of the road. The lane changing nature of motorcycles would cause motorcycles to become obstructions to other vehicles. The overall projected utilized area of these motorcycles would increase likewise increasing their PCU car values. This increase would result into a higher PCU volume as compared with Chandra method.

Referring to the PCU values of motorcycles, the mean of all of the data per PCU determination method was checked using t-test at 95% confidence level. This was performed so as to determine how much the PCU values varied. The test was done for motorcycle PCU values determined from Chandra versus values attained from Frame PCU determination method. Similar t-tests were also made for Frame versus Turbulence and Chandra versus Turbulence, the results are as follows.

Table 3. t-test results for Chandra versus Frame Motorcycle PCU Values

	Chandra	*Frame*
Mean PCU	0.25794475	0.2499255
Variance	0.00037448	0.00039746
Observations	6	6
Hypothesized Mean Difference	0	
t Stat	0.70700108	
P(T<=t) two-tail	0.49571041	
t Critical two-tail	2.22813884	

Table 4. t-test results for Frame versus Turbulence Motorcycle PCU Values

	Frame	*Turbulence*
Mean PCU	0.2499255	0.26122845
Variance	0.00039746	0.00407169
Observations	6	6
Hypothesized Mean Difference	0	
t Stat	-0.4141478	
P(T<=t) two-tail	0.69316355	
t Critical two-tail	2.44691185	

Table 5. t-test results for Chandra versus Turbulence Motorcycle PCU Values

	Chandra	*Turbulence*
Mean PCU	0.257945	0.26122845
Variance	0.000374	0.00407169
Observations	6	6
Hypothesized Mean Difference	0	
t Stat	-0.12063	
P(T<=t) two-tail	0.907924	
t Critical two-tail	2.446912	

Table 3 compares the mean of the PCU values that were derived from Chandra and Frame PCU determination methods. Since the t-statistic value is lower than the two-tail t-critical value, the null hypothesis value of 0 is acceptable in this case. This implies that using either Chandra or Frame PCU determination method will yield values that do not vary greatly. The same test was done for Frame versus Turbulence and Chandra versus Turbulence as shown in Tables 4 and 5. The outcome was pretty much the same for all three cases.

10. CONCLUSION

The determined average traffic flow demand increase when considering motorcycles in the traffic analysis for four lane roads is 5.6%, 2.1% for three lane, 3.0% for two lane and finally 2.15 for the combined results. PCU of motorcycles ranges from 0.26 to 0.30 for Chandra Method, 0.23 to 0.29 for Frame Method and 0.26 to 0.29 for Turbulence Method. No significant difference was found after running the variables in a t-test under a 95% confidence level. It is possible to account for the maneuverability of vehicles using the developed methods, Frame and Turbulence PCU method. PCU-TAP is an effective traffic analysis program in terms of determining PCU, by considering the changes that occur in a section of road within a one second time frame then averaging these values and as well as analyzing the traffic stream as a whole.

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