ESTIMATING CAPACITY AND VEHICLE EQUIVALENT UNIT BY MOTORCYCLES AT ROAD SEGMENTS IN URBAN ROAD

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ABSTRACT

Heterogeneous traffic with the predominance of motorcycles is very common in many cities in Southeast Asian countries, where motorization has developed speedily in the last few decades. While many developed countries confront troubles relating to vehicle traffic, Southeast Asian countries in general and Vietnam in particular are facing a serious situation in respect to the high volume of motorcycle traffic and congested motorcycle flows. Therefore, passenger car equivalent (PCE) concept becomes hard to be suitable in traffic dominated by motorcycles in these countries. Hence, it would seem to make more sense in such case that the motorcycle is considered as the basic vehicle in this traffic flow. In order to account for other categories of vehicles in the traffic flow, the concept of motorcycle equivalent unit (MCU) value at urban road segment was introduced.

This paper investigates the methodology of MCU at road-segments in motorcycle dependent city. A methodology based on PCE approach previously developed by Chandra *et al*. (2003) is presented in this research. This methodology illustrates a more accurate method of MCU in mixed traffic flow by considering the characteristics of moving vehicles such as velocity and an effective space. In which, the effective space of each kind of vehicle is computed under considering influences of velocity, physical size of the subject vehicle and the surrounding motorcycles.

The proposed methodology was applied to field data collected at twelve road-segments located in Hanoi city, Vietnam. The field data indicated that the effective space of each vehicle varies by the speed of moving vehicle, and MCU value increases slightly corresponding with the lane number of each urban road during the peak hour. Also, it was found that the MCU is a function of the mean speed, a mean effective space of each vehicle. The field data indicates that the MCU values of car, bus, minibus, and bicycle are 3.43, 10.48, 8.34 and 1.38, respectively at road-segments in urban road.

On the other hand the field data of vehicle flow and speed passing through road segments were conducted in three groups of divided road with raised median within the city centre. The fundamental diagrams of vehicle speed-flow-density relationships ranging from the stable traffic flow to unstable conditions were plotted in this paper. Regression analysis was employed to estimate the capacity of each kind of urban roads. The value of capacity, maximum motorcycle flow, a critical mean stream speed and a critical density of traffic flow were computed. Results indicated that the capacity of urban road increases with the number of road lane or total width of urban roads.

1. INTRODUCTION

Heterogeneous traffic with the predominance of motorcycles is very common in many cities in southeast Asia, where motorization has developed speedily in the last few decades. In these areas, the term "motorcycle dependent city "has been used to indicate a city with low income, high density land use and motorcycles' domination in traffic flow. While many developed countries confront troubles relating to vehicle traffic, southeast Asian coutries in general and Vietnam in particular are facing a serious situation in respect to the high volume of motorcycle traffic and congested motorcycle flows. Besides, the ownership of motorcycles is increasing significantly in many other southeast Asian coutries due to their high mobility and affordable price. Furthermore, motorcycle traffic, which has very distinguishable characteristics, significantly affects the traffic condition. Motorcycles may reduce the speed of other modes and make the traffic more congested due to their slim shapes, small size and maneuver behaviour. In addition, motorcycles tend to make use of every space on the carriageway in front and both sides of their locations when in motion.

The term passenger car equivalent (PCE) was introduced in the 1965 Highway Capacity Manual. Since 1965, considerable research effort has been directed toward the estimation of PCE value for various roadway types and the passenger car has been used as the basic vehicles for converting other vehicle into passenger car equivalent (PCE) in the traditional approach. However, PCE concept becomes hard to be suitable in traffic dominated by motorcycles in southeast Asian countries, including Vietnam. Hence, it would seem to make more sense in such case that the motorcycle is considered as the basic vehicle in this traffic flow. In order to account for other categories of vehicles in the traffic flow, the concept of motorcycle equivalent unit (MCU) value at urban mid block sections was introduced in this paper.

The objective of this study is to develop a methodology that accurately estimates the value of MCU for the other vehicles under considering the characteristics of moving vehicles in the traffic stream. These characteristics are the speed of the other vehicles with the surrounding motorcycles, the occupied space between motorcycles taken and a subject vehicle. In addition, this study illustrates and validates how the methodology accurately determines MCU values at mid block sections in urban street. In the other hand, the fundamental diagrams of vehicle speed-flow-density relationships ranging from the stable traffic flow to unstable conditions were plotted in this paper. Regression analysis was employed to estimate the capacity of each kind of urban roads.

2. LITERATURE REVIEW

There is the existence of many methods for determining passenger car units (PCUs) such as the homogenization coefficient method, the semi-empirical method, the Walker's method, the headway method, the multiple linear regression method and the simulation method. PCU is also known as passenger car equivalent (PCE).

For motorcycle analysis, Lan *et al* (2003) analyzed the motorcyclist behaviors in a mixed traffic flow with passenger cars on 2.5(m) and 3.75 (m) lanes. They developed traffic volume-density relationships and speed-density relationships under different percentage of motorcycles. They concluded that under pure motorcycle condition, the maximum flow rates for 2.5 (m) and 3.75 (m) lane widths are 5,600 and 8,300 (Vph), respectively. The motorcycle equivalent unit (MCU) range from 2.63 (speed 14m/sec) to 5.27 (speed 4m/sec) for 10% ~ 100% of passenger cars. Some analyses have been done by Nakatsuji *et al.* (2001) so as to scrutinize the impact of motorcycles on capacity at signalized intersections in Hanoi and Bangkok. Such authors made a classification of some patterns, which were different relative positions of motorcycle to passenger car, then carried out regression analysis in order to estimate how different among these patterns were in terms of headway and start-up lost time. Similarity, Hai (1999) also evaluated effects of motorcycle on saturation flow rate in Hanoi. He estimated motorcycle's influence to car start-up lost time by separating two cases: position and number of motorcycles in front of first car in queue. Furthermore, Minh *et al* (2003) estimated then compared the PCU for motorcycles at some signalized intersections in Hanoi and Bangkok by using multiple linear regression analysis technique. The authors also estimated the saturation flow rates, and the changing of motorcycles and cars in the saturation flow rate. Chandra *et al.* (2003) considered speed to be a prime variable to determine the relative effect of individual vehicles on traffic stream in respect PCU described as follows:

$$PCU_i = \frac{V_c / V_i}{A_c / A_i} \tag{1}$$

Where

V_c , V_i = mean speed for cars and type *i* vehicles, respectively;

A_c , A_i = the respective projected rectangular area (length × width) of roads;

The physical size of a vehicle is an indicator of space occupancy, which is crucial in operational characteristics of traffic stream (Chandra *et al.*, 2003). Nevertheless, the value of the physical size of a vehicle is constant. It is unrealistic that the space occupancy on the road of a vehicle in reality is a function of many attributes, such as speed, surrounding traffic environment, etc. Minh (2005) addressed a comprehensive analysis of motorcycle behavior and operation through videotaping a few roads that have significant motorcycle proportion. Speed – flow relationships were developed for all locations, in which the adjustment factors for the present of vehicles other than motorcycles were based on motorcycle equivalent unit. In addition, a basic understanding of characteristics of motorcycle traffic was provided from the research. However, the calculating formula of motorcycle equivalent unit in Minh (2005) has the same limitations with that of Chandra *et al*. (2003). The concept of motorcycle unit (MCU) values was introduced by Hien *et al* (2007) at signalized junction in Hanoi, Vietnam. He investigated the variability of saturation flow and MCU values in traffic condition dominated by motorcycles. Besides, the MCU value of cars was also found to be constant and it was calculated as equivalent to 3.67 in his research.

In addition, Leong (1968) measured speeds and capacity at 31 sites on rural highways in New South Wales. The sites had varying lane and shoulder widths and all sites had gravel shoulders. The data were analyzed using multiple regression and it was suggested that speed increased with increasing shoulder width. In particular, it was reported that the capacity of a two – lane road can drop by 28% when the lane width changed from 3.7 to 2.75 m. Farouki and Nixon (1976) studied the effect of the carriageway width on speeds of cars in the special case of free-flow conditions in sub-urban roads in Belfast. It was found that the mean-free speed of cars in a suburban area increases linearly with the carriageway width over a certain range of width from 5.2 to 11.3 m.

As described above, the debate of previous research focuses on the concept of PCU and MCU value at signalized intersection or signalized junction. However, very little research has been conducted regarding the motorcycle equivalent unit under mixed traffic flow at road-segments to estimating the capacity in urban road. Therefore, this paper is continuous to developing and validating the methodology of MCU to estimating capacity at road-segments under the traffic condition dominated by motorcycles.

3. PROPOSED MCU METHODOLOGY

Motorcycle equivalent unit (MCU) is defined as the number of motorcycles that can be displaced for one vehicle of specified type running at the speed of that vehicle. MCU for each type of vehicle is developed by taking the consideration of dynamic characteristics of moving vehicles in this study. Such factors show the correlation of speed and occupied space between surrounding motorcycles taken and a subject vehicle. The modified formula that is applied for MCU conversion is depicted as follows:

$$MCU_k = \frac{\overline{V}_{mc}}{\overline{V}_k} \times \frac{\overline{S}_k}{\overline{S}_{mc}} \tag{2}$$

Where

MCU_k = motorcycle equivalent unit of type *k* vehicle;

$\overline{V}_{mc}$, $\overline{V}_k$ = the mean speed of motorcycles and type *k* vehicle, respectively (m/s);

$\overline{S}_{mc}$, $\overline{S}_k$ = the mean effective space for motorcycles and type *k* vehicle, respectively (m^2);

In traffic with lane discipline, the occupancy is under control by the length of a vehicle (See Chandra *et al.*, 2003). However, under the conditions of mixed traffic where vehicles do not follow lanes strictly, the required space is better reflected by area. Therefore, total physical size of the vehicle and the required space has been considered in equation (2).

In order to calculate mean speeds of different types of vehicles ($\overline{V}_k$), the spot speed technique was applied. The speeds of traffic entities were determined by the time required for traveling a known distance (trap length). In this study, the trap length was measured as the distance between two consecutive electric poles. The time required to travel a given distance was captured by recording the entry and exit time of that length. The speed then obtained from the division between the trap length and the travel time for each vehicle.

Since it is assumed that each vehicle has a mean effective space ($\overline{S}_k$) for driving and this space might vary according to speed, traffic condition, driver characteristics (such as age, income or gender) or weather conditions. Therefore, to reduce the influence of these factors on the mean effective space, the weather condition is dry weather and the traffic condition is considered in peak time in this research. In addition, it is impossible to determine the driver characteristics because the data is collected from each video camera that is set on the high building. Therefore, the influence of driver characteristics is not considered in the scope of this paper. It is hypothesized that the mean effective space values might vary by the speed of vehicle in road segments. If this is so, the relation between the mean effective space and mean speed for type k vehicle could be written in the nonlinear function as below:

$$\overline{S}_k = a \times \overline{V}^2_k + b \times \overline{V}_k + c \tag{3}$$

Where

$\overline{V}_k$ = the mean speed of type *k* vehicle (m/s);

$\overline{S}_k$ = the mean effective space for type *k* vehicle (m^2);

a, b, c = parameters of nonlinear function;

The effective space for a vehicle is defined as the necessary space needed by a vehicle to maintain its desired speed. In other words, it is the boundary around the subject vehicle, which is necessary for its maneuver regarding its speed. Therefore, this variable depends on vehicle speed, mode and other adjacent vehicles. The effective space of a subject vehicle is illustrated in Figure 1 and expressed as follows.

$$S_k = L_k \times W_k \tag{4}$$

Where

S_k = effective space for vehicle type k (m^2);

L_k = effective longitudinal distance of running vehicle inclusive of vehicle length (m);

W_k = effective lateral distance of running vehicle inclusive of vehicle width (m);

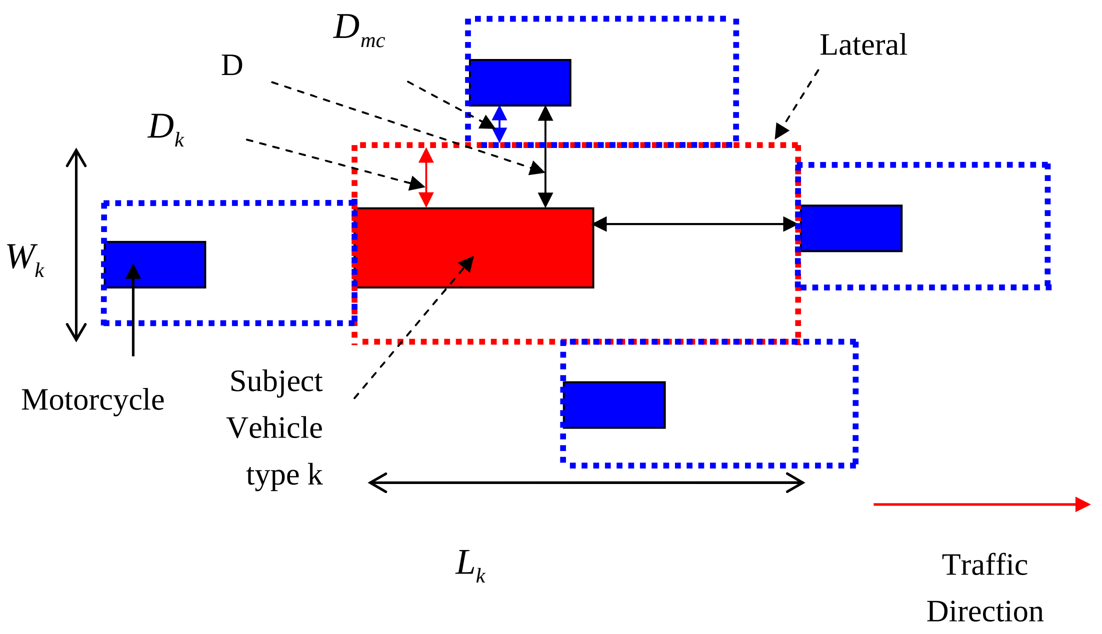

Figure 1 The Effective Space of Subject Vehicle and the Surrounding Motorcycles

The values of the effective space of each sample are calculated at section A and section B in the first 20 meters and the second 20 meters of road segments, respectively. These sections are illustrated in the Figure 2 and the mean effective space value of vehicle is measured based on the values of effective space at two these sections. In addition, it is straightforward to measure the effective longitudinal distance (L_k) value in the formula (4). However, the problem is how to determine the lateral boundary line of the effective lateral distance (W_k) for each running vehicle. In fact, the occupied space of vehicle is affected by the size of the subject vehicle and the surrounding motorcycles. Therefore, it is assumed that the lateral width of the subject vehicle is a function of the lateral width of motorcycles, the total physical size of subject vehicle and motorcycles. The lateral width of subject vehicle may be computed as follows:

$$D_k = \frac{Z_k}{Z_{mc}} \times D_{mc} \tag{5}$$

Where

D_k = the effective space's lateral width of vehicle type k (m);

D_{mc} = the effective space's lateral width of motorcycles (m);

Z_k = the total physical size of vehicle type k (m^2);

Z_{mc} = the total physical size of motorcycles (m^2);

The total physical size's values of vehicle type k and motorcycles are adopted from Chandra et al. (2003). These total physical size's values are chosen because the reason is the data used for Chandra's method also come from the developing countries, where the traffic condition is similar to Hanoi, Vietnam. The tabulation of vehicle categories, along with average dimensions, is illustrated in Table 1.

Table 1 Vehicle Categories and Their Sizes

Vehicles Type	Vehicles included	Length (m)	Width (m)	Rectangular Area (m^2)
Cycle	Bicycles	1.90	0.45	0.86
Motorcycles	Scooter, Motorbike Mopeds	1.87	0.64	1.2
Cars	Car, Jeep, Van	3.72	1.44	5.36
Minibus	Mini bus, mini truck	6.10	2.10	12.81
Buses	Buses	10.1	2.43	24.54

Adopted from Chandra *et al.* (2003)

4. PRELIMINARY FIELD DATA COLLECTION

Twelve approaches that belong to Kim lien Street (KL), Giai phong - A Street (GP-A), Giai phong - B Street(GP-B), Cau giay Street (CG), Hang bong Street (HB), Tran khat chan Street (TKC), Nguyen trai Street (NT), Tay son – A Street (TS-A), Tay son – B Street (TS-B), Nguyen van cu Street (NVC), Thai ha Street (TH), Hoang quoc viet Street (HQV), were selected for data collection in Hanoi, Vietnam. Geometrically, these streets can be divided into three groups such as four-lane road, six-lane road and eight-lane road in both two traffic directions. All these roads are divided road with raised median within the city centre. The geometry and traffic properties of these approaches are shown in Figure 2 and Table 3, respectively. The traffic data were collected in dry weather and at peak time, from 6:00am to 8:00am and 4:00pm to 6:00pm in every weekday. The traffic flow was composed of passenger car, minibus, bus, motorcycle and bicycle; however, motorcycles make up the majority in the traffic stream in all locations. Parameters measured at each road segments were reduced into the following format:

+ The speed of each individual vehicle at 3 sec interval (measured by SEV software),
+ Space mean stream speeds was measured based on the speed on each individual vehicles from vehicle categories,
+ Vehicle volumes at 1 minute interval (counted in number of vehicles),
+ Traffic volumes at 1 minute interval (counted in number of motorcycles based on the equivalent unit as MCU for each kind of vehicle),
+ Total widths of the road segments (measured in meters),
+ Total lengths of the road segments (measured in meters).

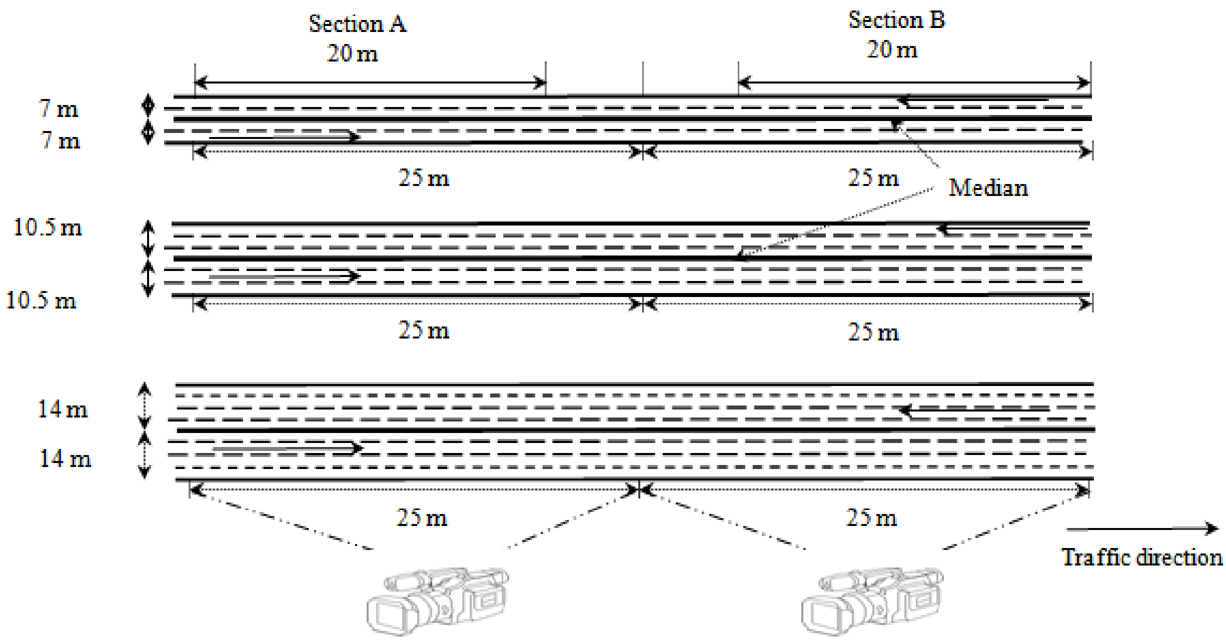

Figure 2 Layouts of Three Kinds of Road-Segments

Table 2 Traffic Composition at Twelve Selected Road-Segments

Location	Lane/ each traffic direction	Time period/ Time interval	Number of Bicycles/ (%)	Number of Motorcycles/ (%)	Number of Cars/ (%)	Number of Buses/ (%)	Number of Mini Buses/ (%)
NT (Nguyen Trai Street)	4	4 hour/ 15 min	2040 (4.91)	36348 (87.54)	2712 (6.52)	300 (0.72)	132 (0.31)
TKC (Tran Khat Chan Street)	4	4 hour/ 15 min	1976 (5.87)	29640 (88.06)	1896 (5.63)	96 (0.28)	48 (0.14)
GP-A (Giai Phong – A Street)	4	4 hour/ 15 min	2064 (3.18)	57276 (88.45)	4488 (6.93)	636 (0.98)	288 (0.44)
GP-B (Giai Phong – B Street)	4	4 hour/ 15 min	1404 (2.23)	57048 (90.77)	3756 (5.97)	432 (0.68)	204 (0.32)
CG (Cau Giay Street)	3	4 hour/ 15 min	4320 (7.05)	53208 (86.9)	3300 (5.39)	336 (0.54)	60 (0.09)
HQV (Hoang Quoc Viet Street)	3	4 hour/ 15 min	1140 (4.85)	19260 (82.05)	2784 (11.86)	156 (0.66)	132 (0.56)
KL (Kim Lien Street)	3	4 hour/ 15 min	540 (1.38)	36072 (92.69)	2172 (5.58)	132 (0.34)	0 (0)
NVC (Nguyen Van Cu Street)	3	4 hour/ 15 min	168 (0.62)	22332 (82.52)	4152 (15.34)	324 (1.19)	84 (0.31)
HB (Hang Bong Street)	2	4 hour/ 15 min	2208 (6.04)	32064 (87.77)	1932 (5.28)	132 (0.36)	192 (0.52)
TS-A (Tay Son – A Street)	2	4 hour/ 15 min	1032 (3.62)	24096 (84.61)	3204 (11.25)	120 (0.42)	24 (0.08)
TS – B (Tay Son – B Street)	2	4 hour/ 15 min	1476 (3.65)	36048 (89.37)	2652 (6.57)	156 (0.38)	0 (0)
TH (Thai Ha Street)	2	4 hour/ 15 min	888 (3.31)	23712 (88.53)	2076 (7.75)	84 (0.31)	24 (0.08)

The traffic flow data was gathered by using two video cameras that were set on the high building. The system consisted of two portable video cameras, two tripods, videodiscs, a measuring roller, and manual counters. Then, vehicle's positions were identified from image video files in laboratory. These positions regarding time events were calculated according to screen co-ordinates then converted into roadway co-ordinates by using Speed Estimation from Video data (SEV) software (Minh, et al. 2005). The screen of SEV is illustrated in Figure 3.

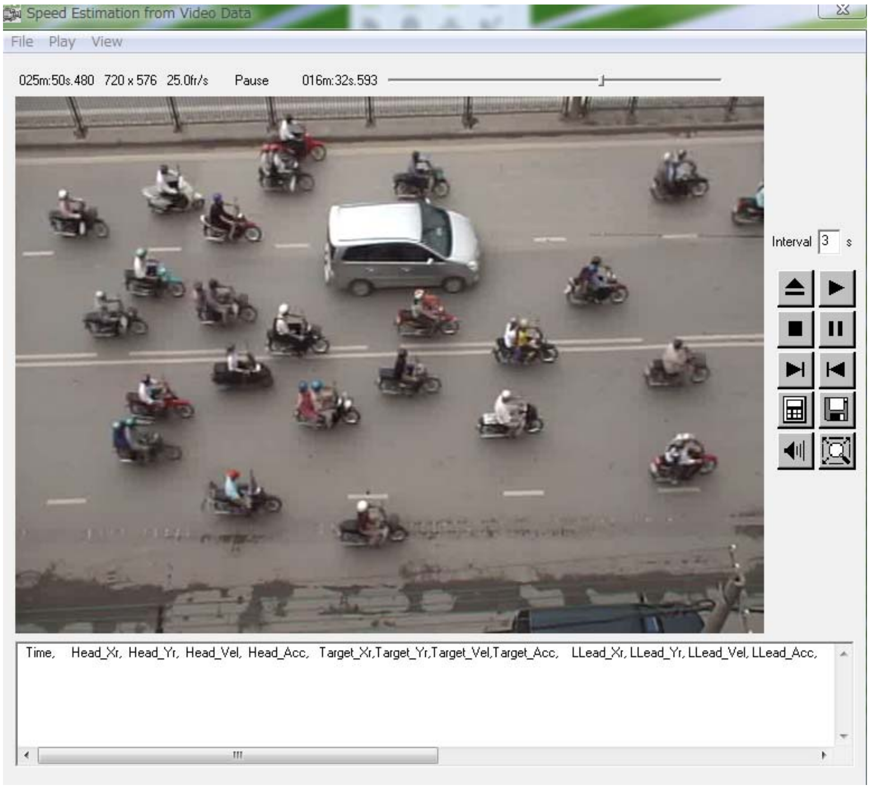

Figure 3 Software Screen of Speed Estimation from Video Data

Therefore, all data of the effective space and speed for each sample was analyzed by author with two laptops corresponding to two sections A and B at each road-segment. From field data it was found that the variation of the speed of subject vehicle and the surrounding motorcycles was little at each section (20 meters). Besides, the value of effective space also was the same for each vehicle at each section. Therefore, it was assumed that the value of speed and the effective space of subject vehicle and the surrounding motorcycles were constant at each section. However, the speed and the effective space of each vehicle changed a lot between two sections in road-segments. Hence, these values were computed at two sections A and B to estimate the correlation relationship between the effective space and speed of each subject vehicle in road-segments.

To estimating capacity of urban road, each sample is the traffic volume that collected in 1 minute and was converted to an equivalent rate of flow in motorcycles per hour. In addition, to fulfill the requirements of dimensional analysis in the computation, the speed in meter per sec was converted into kilometer per hour.

5. RESULTS OF THE PROPOSED MCU METHODOLOGY

5.1 The Relationship between Speed and Effective Space for Each Type of Vehicle

The values of the speed and the effective space of each type of vehicle were calculated at three groups of road segments such as four-lanes, three-lanes and two-lanes per each traffic direction based on twelve selected road-segments. Then, the relationships between the effective space and speed of motorcycles, buses and cars were representative and illustrated in Figure 4. In addition, this relationship of bicycles and minibuses also were computed at each road-segment in this research.

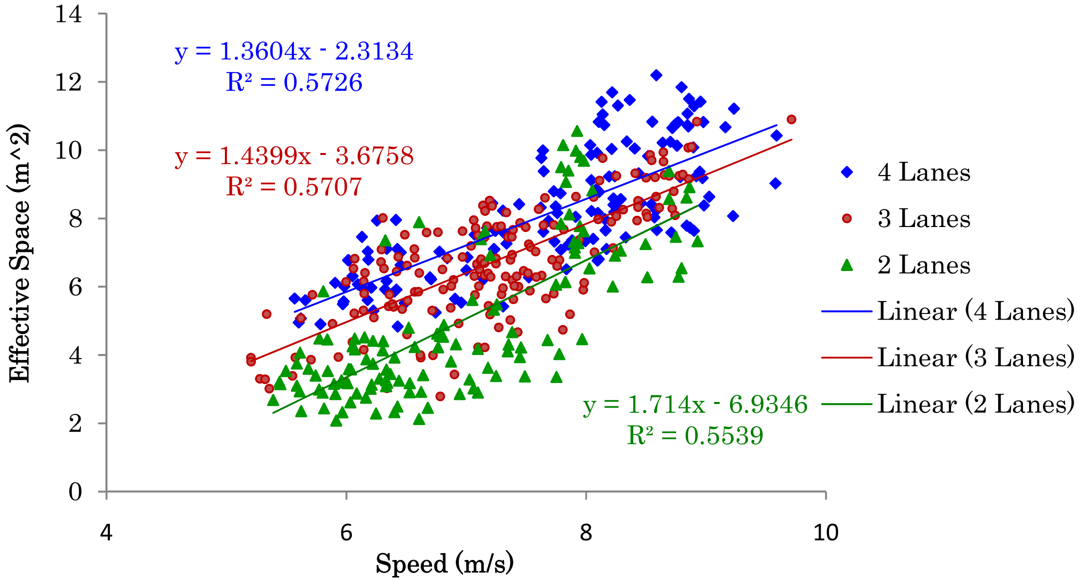

Figure 4a The Relationship between Speed and Effective Space of Motorcycles

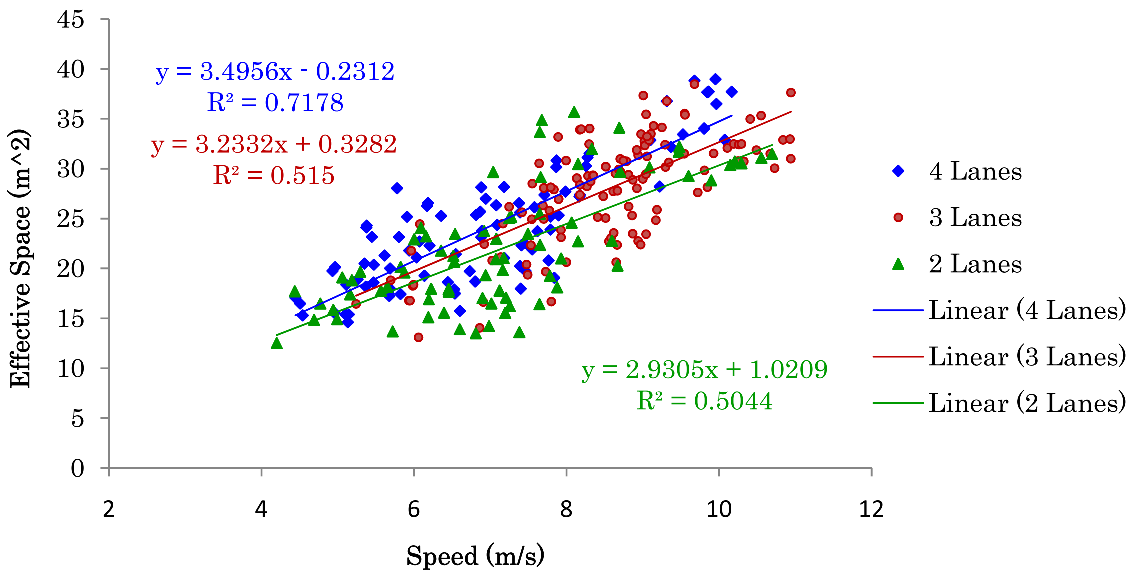

Figure 4b The Relationship between Speed and Effective Space of Cars

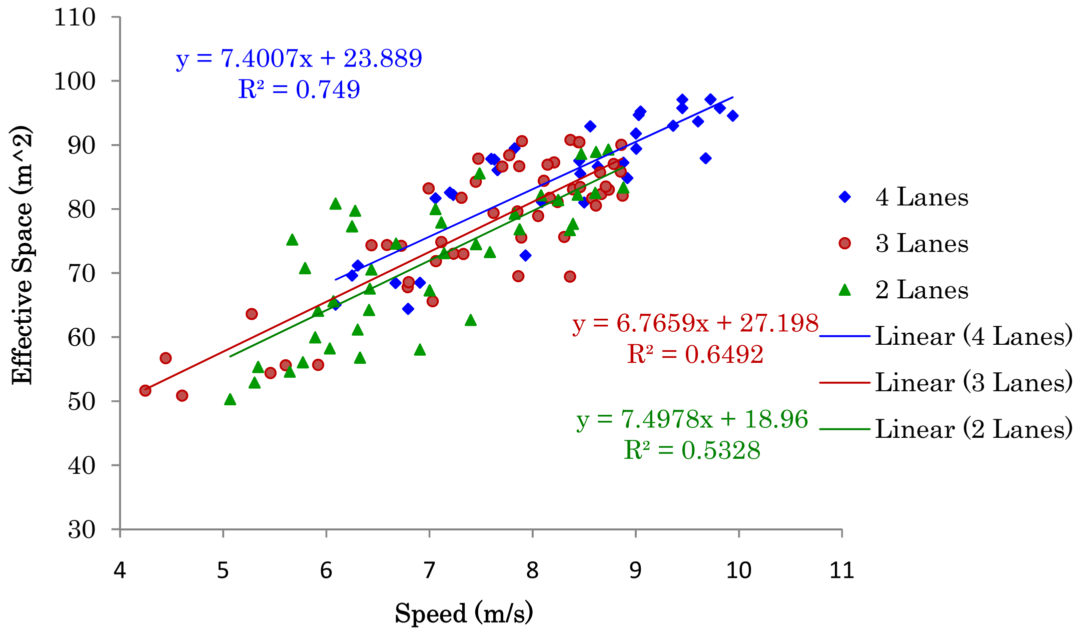

Figure 4c The Relationship between Speed and Effective Space of Buses

From figure 4, it is straightforward to see the correlation relationship between speed and the effective space is high at all selected road-segments. This means that speed of subject vehicle is one of the most important factors which can create the strong influence on the effective space of that vehicle. The area of the effective space of vehicle is larger when the speed of subject vehicle increases in road-segment. In contrast, this area is smaller corresponding to the lower speed of subject vehicle. The results of this correlation relationship prove that the assumption of formula (3) is correct and appropriate in the traffic flow dominated by motorcycles.

In fact, the area of the effective space of subject vehicle is affected by the speed of a head motorcycle. Therefore, to test the influence of the speed of a head motorcycle on the effective space of subject vehicle, the correlation relationship between the speed of a head motorcycle and effective space also was computed at three groups and illustrated in Figure 5. The values of the correlation coefficient are 0.2315, 0.1548 and 0.1224 in three groups, respectively. Therefore, the influence of the speed of a head motorcycle on the area of effective space of subject vehicle is low. Hence, this is the main reason that makes the speed of a head motorcycle is not available in formula (3).

The traffic flow condition is considered as well as the saturation flow at road-segments in this research. From figure 4a, 4b, and 4c, the average speed of motorcycles in the 4 lanes, 3 lanes, 2 lanes per each traffic direction of road segments are 7.69, 7.23, 6.91 (m/sec), respectively. Besides, the average speed of cars is 7.05, 8.53, 7.18 (m/sec) in figure 4b. The average speed of buses also is 8.25, 7.52, 6.96 (m/sec), respectively in figure 4c. In addition, the values of average speed of bicycles are 4.72, 4.65, 4.14 (m/sec) in each kind of road-segment. This value of minibuses is 8.27, 7.85 and 7.41 (m/sec) in the 4 lanes, 3 lanes, 2 lanes per each traffic direction of road segments, respectively. The figures of the relationship between speed and the effective space for bicycles and minibus are not shown in this paper.

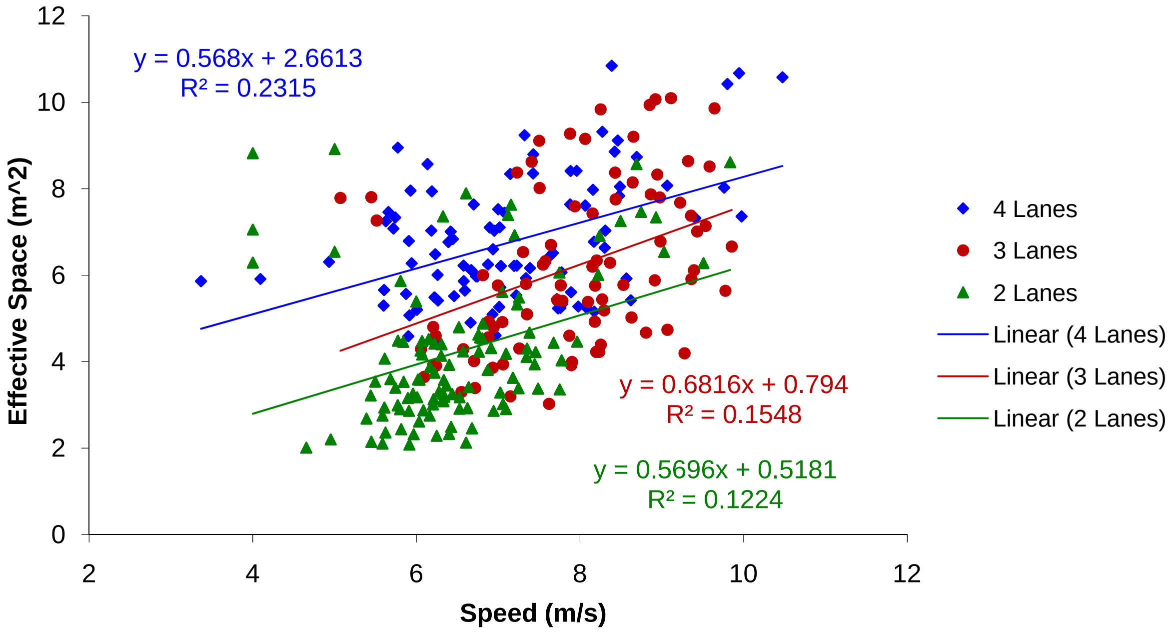

Figure 5 The Relationship between Effective Space of Subject Vehicle and Speed of a Head Motorcycle

Even though, there is the different of geometry among road-segments and this is the main reason that makes the value of speed, the effective space of subject vehicle is a little different among road-segments. However, to determine the value of the mean effective space ($\overline{S}_k$) that is appropriate for many road-segments in urban road. All the results of average effective space, mean speed for each sample at four road-segments can be considered as the input data for estimating the function (3) of the mean effective space ($\overline{S}_k$) by regression technique.

5.2 Calibration of nonlinear regression model and MEU value for each kind of vehicle

To calibrate equation (3), the mean effective space of subject vehicles for heterogeneous traffic is evaluated by using the nonlinear regression analysis. The output of mean effective space by the nonlinear regression analysis is presented in Table 3.

The results show that the influence of mean speed on the mean effective space of bicycles is lowest in traffic flow. This is easy to understand because all bicyclists prefer to run on the lane that nears pavement. Therefore, the influence of motorcycles on the effective space of bicycles is very weak and the area of the mean effective space of bicycles is normally large than the required space of mean speed. In contrast, this influence of buses and minibuses is very high in the mixed traffic flow.

Table 3 Output of Mean Effective Space by Nonlinear Regression Analysis

Subject Vehicle	*Number of observation*	*Adjusted R square*	*Variable in formula (3)*	*Coefficients*	*Std Error*	*95% Confidence interval* Lower Bound	Upper Bound
Motorcycle	*469*	*0.53*					
			$\overline{V}_{mc}$	0.66	0.86	- 1.03	2.35
			$\overline{V^2}_{mc}$	0.07	0.06	- 0.04	0.19
			(Constant)	- 1.72	3.12	- 7.86	4.41
Car	*311*	*0.54*					
			$\overline{V}_{Car}$	1.22	1.45	- 1.64	4.1
			$\overline{V^2}_{Car}$	0.13	0.09	- 0.05	0.32
			(Constant)	7.29	5.41	- 3.35	17.92
Bus	*128*	*0.68*					
			$\overline{V}_{Bus}$	5.12	4.84	- 4.47	14.71
			$\overline{V^2}_{Bus}$	0.19	0.33	- 0.46	0.85
			(Constant)	27.68	17.43	- 6.83	62.19
Minibus	*41*	*0.66*					
			$\overline{V}_{MiniBus}$	- 9.21	6.22	- 21.67	3.25
			$\overline{V^2}_{MiniBus}$	1.34	0.42	0.51	2.17
			(Constant)	49.71	23.24	3.13	96.29
Bicycle	*102*	*0.32*					
			$\overline{V}_{Bicycle}$	-1.61	2.52	- 6.62	3.39
			$\overline{V^2}_{Bicycle}$	0.37	0.27	- 0.17	0.92
			(Constant)	5.35	5.70	- 5.96	16.67

From the Table 3, the final nonlinear function predicting the mean effective space of each kind of vehicle at road-segments in mixed traffic flow dominated by motorcycles in urban road could be written as:

$$\overline{S}_{mc} = 0.07\overline{V}^2_{mc} + 0.66\overline{V}_{mc} - 1.72 \quad (6)$$

$$\overline{S}_{Car} = 0.13\overline{V}^2_{Car} + 1.22\overline{V}_{Car} + 7.29 \quad (7)$$

$$\overline{S}_{Bus} = 0.19\overline{V}^2_{Bus} + 5.12\overline{V}_{Bus} + 27.68 \quad (8)$$

$$\overline{S}_{MiniBus} = 1.34\overline{V}^2_{MiniBus} - 9.21\overline{V}_{MiniBus} + 49.71 \quad (9)$$

$$\overline{S}_{Bicycle} = 0.37\overline{V}^2_{Bicycle} - 1.61\overline{V}_{Bicycle} + 5.35 \quad (10)$$

Where

$\overline{S}_{mc}, \overline{S}_{Car}, \overline{S}_{Bus}, \overline{S}_{MiniBus}, \overline{S}_{Bicycle}$ = mean effective spaces of motorcycles, cars, buses, minibuses and bicycles, respectively;

$\overline{V}_{mc}, \overline{V}_{Car}, \overline{V}_{Bus}, \overline{V}_{MiniBus}, \overline{V}_{Bicycle}$ = mean speeds of motorcycles, cars, buses, minibuses and bicycles, respectively;

The MCU values of vehicle type *k* are achieved after computing the mean effective space and mean speed of each type of vehicles in traffic stream. Table 4 expresses the values of MCU for different types of vehicles computed at the kind of lane group. It is straightforward to see that there is a small difference in the value of MCU of each vehicle type among three kind of selected road-segments. This difference could be explained by the different road width that becomes largely. From table 4, the value of MCU of buses and cars increases slightly when the lane number of each approach increases. In addition, the values of MCU of bicycle are reasonable within the real situation of traffic flow condition in the selected road-segments. In reality, bicyclists prefer to ride on the lane that is near by the roads' pavement; hence, the influence of motorcycles on the mean effective space of bicycles is weak. Therefore, the area of this mean effective space of bicycles is normally larger than that of the required space for riding at these road-segments. However, the value of MCU of bicycles will be more accurate with the saturation flow condition of mixed traffic flow that dominated by motorcycles.

Table 4 The Result of MCU of Vehicles from Proposal Model

	Location	**4 Lanes/ traffic direction**	**3 Lanes/ traffic direction**	**2 Lanes/ traffic direction**
Subject vehicle				
Motorcycles	$\overline{V}_{mc}\ (m/\sec)$	7.13	7.14	6.71
	$\overline{S}_{mc}\ (m^2)$	6.63	6.64	5.93
	MCU_{mc}	***1***	***1***	***1***
	Observation number	*89*	*84*	*110*
Cars	$\overline{V}_{Car}\ (m/\sec)$	6.63	8.45	7.19
	$\overline{S}_{Car}\ (m^2)$	21.16	27	22.86
	MCU_{Car}	***3.43***	***3.42***	***3.59***
	Observation number	*85*	*96*	*72*
Buses	$\overline{V}_{Bus}\ (m/\sec)$	7.72	7.35	6.96
	$\overline{S}_{Bus}\ (m^2)$	78.67	75.7	72.63
	MCU_{Bus}	***10.96***	***11.07***	***11.8***
	Observation number	*23*	*34*	*38*
Minibuses	$\overline{V}_{Minibus}\ (m/\sec)$	8.27	7.85	7.41
	$\overline{S}_{Minibus}\ (m^2)$	65.27	60.05	55.1
	$MCU_{Minibus}$	***8.48***	***8.22***	***8.4***
	Observation number	8	17	16
Bicycles	$\overline{V}_{Bicycle}\ (m/\sec)$	4.72	4.65	4.14
	$\overline{S}_{Bicycle}\ (m^2)$	6.07	5.94	5.08
	$MCU_{Bicycle}$	***1.38***	***1.37***	***1.4***
	Observation number	*30*	*35*	*37*

The selected road-segments were representative for the road-segments that belong to the four-lanes, three-lanes and two-lanes per each traffic direction of street in urban road. Therefore, the weighted mean method was used in this research to calculate the unique value of MCU that was acceptable for each kind of vehicle at road-segments. From table 4, MCU value of cars, buses, minibuses and bicycles are 3.43, 10.48, 8.34 and 1.38, respectively.

6. ESTIMATING CAPACITY OF URBAN ROAD BASED ON THE PROPOSED MCU.

Scatter plot diagrams were obtained for three relationships; i.e. Flow – Speed, Flow – Density, and Speed – Density. The initial calibrations focused on the Speed-Density relationships because Speed-Density curves are monotonically decreasing and involve simpler mathematical forms than the other two curves. In addition, Speed - Density curves represent the most basic interaction of drivers and vehicles on the road. Drivers adjust their speed according to the perceived proximity of other vehicles (density). Flow does not influence behavior, but is a product of speed and density. Since Flow = Speed x Density, the calibration of Speed - Density relationship leads to the derivation of the other two relationships. Various forms have been postulated for the shape of the Speed - Density relationship. The shapes ranged from linear interpretations, discontinuities, logarithmic and exponential descriptions.

6.1 The Relationships between Traffic Flow, Traffic Density and Mean Stream Speed of the Road Segment that have 4 Lanes per each Traffic Direction.

Overall, this research found that the traffic speed – flow – density relationship after converting into the MCU for three groups of road segments such as four-lanes, three-lanes and two-lanes per each traffic direction based on twelve selected road-segments are analogous to vehicular traffic streams. Similar to the vehicular traffic streams, the relation between motorcycle speed and motorcycle indicated that as motorcycle density increases, motorcycle speed decreases.

The logarithmic description of traffic speed – density adopted from Greenberg's hypothesis took into account in this research.

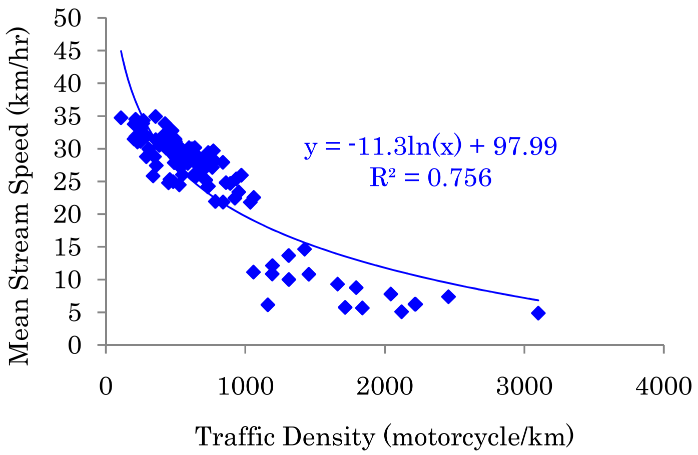

Figure 6a Relationship between Traffic Density and Mean Stream Speed

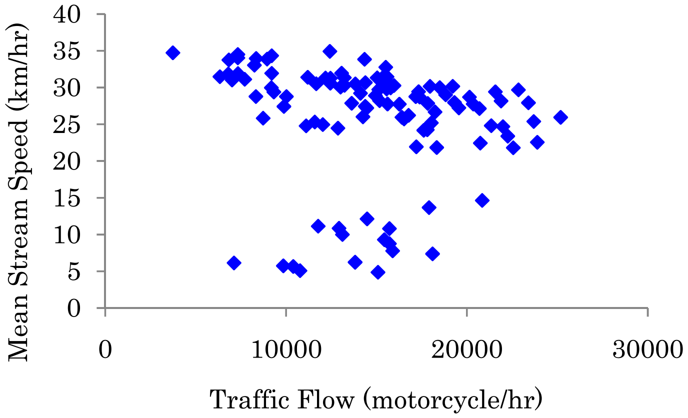

Figure 6b Relationship between Traffic Flow and Mean Stream Speed

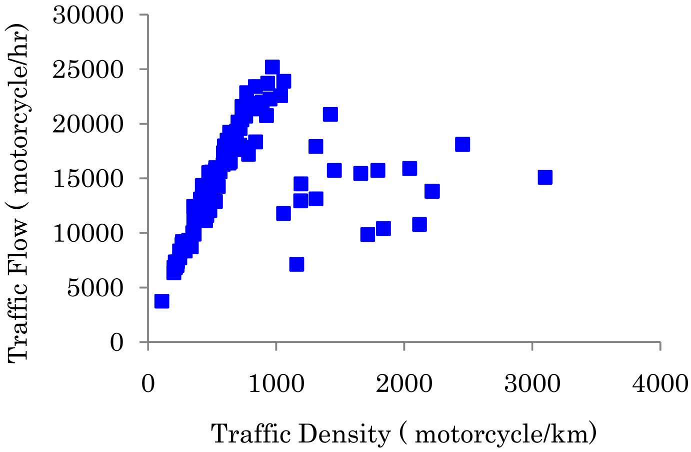

Figure 6c Relationship between Traffic Density and Traffic Flow

6.2 The Relationships between Traffic Flow, Traffic Density and Mean Stream Speed of the Road Segment that have three Lanes per each Traffic Direction.

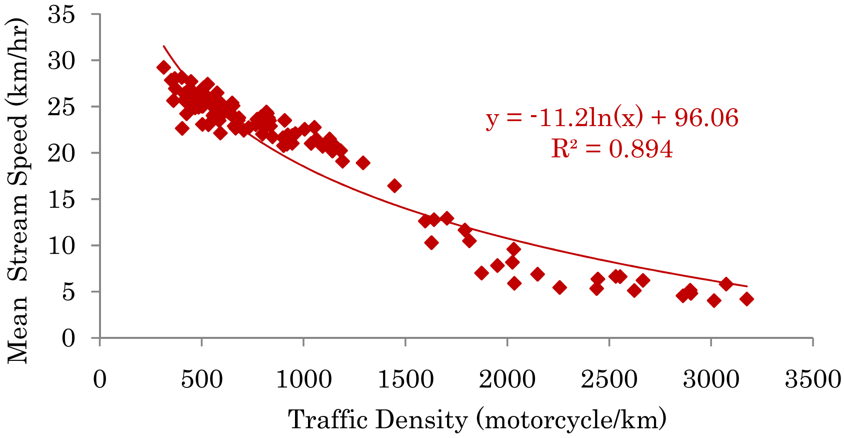

Figure 7a Relationship between Traffic Density and Mean Stream Speed

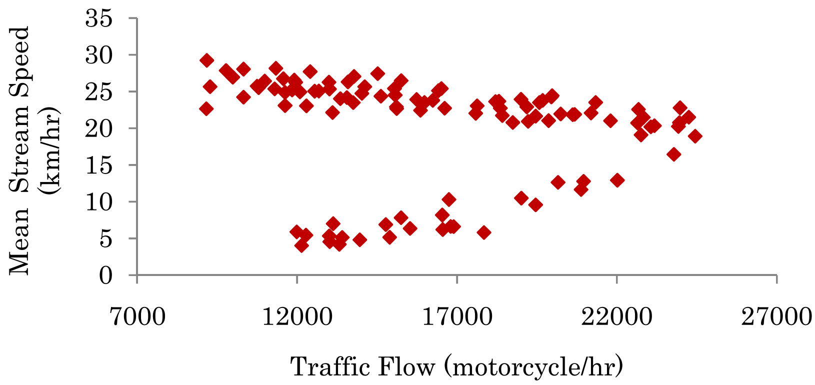

Figure 7b Relationship between Traffic Flow and Mean Stream Speed

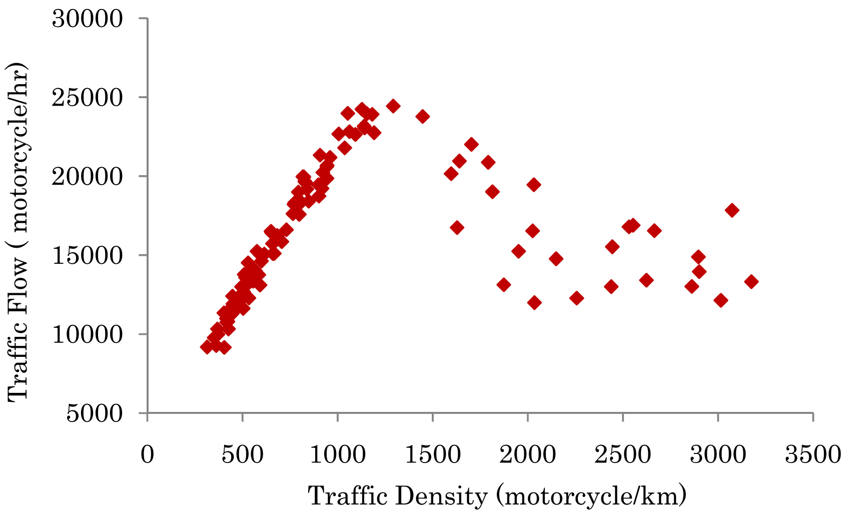

Figure 7c Relationship between Traffic Density and Traffic Flow

6.3 The Relationships between Traffic Flow, Traffic Density and Mean Stream Speed of the Road Segment that have two Lanes per each Traffic Direction.

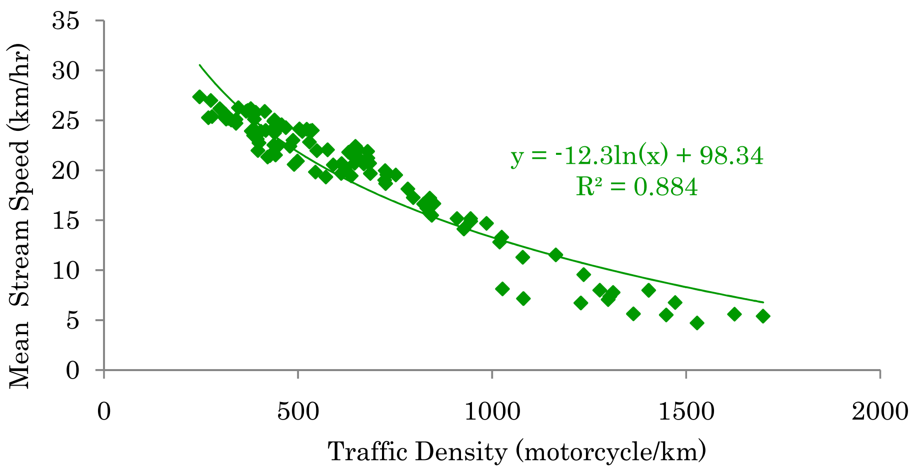

Figure 8a Relationship between Traffic Density and Mean Stream Speed

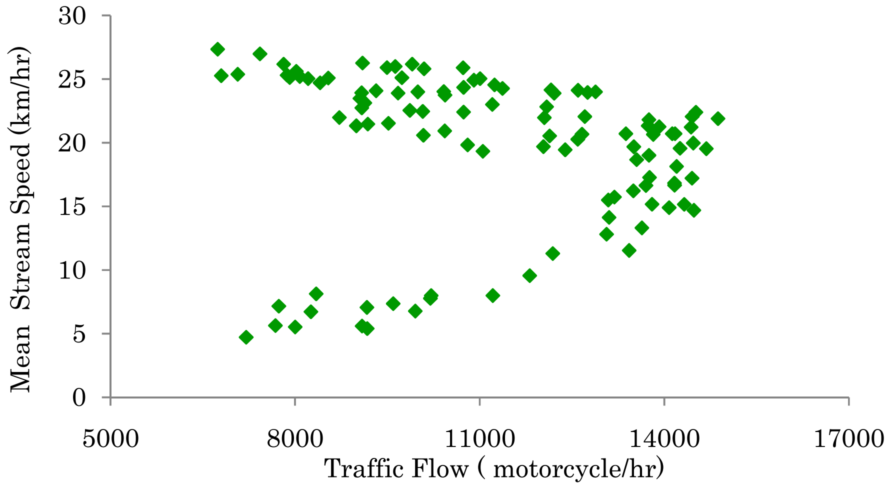

Figure 8b Relationship between Traffic Flow and Mean Stream Speed

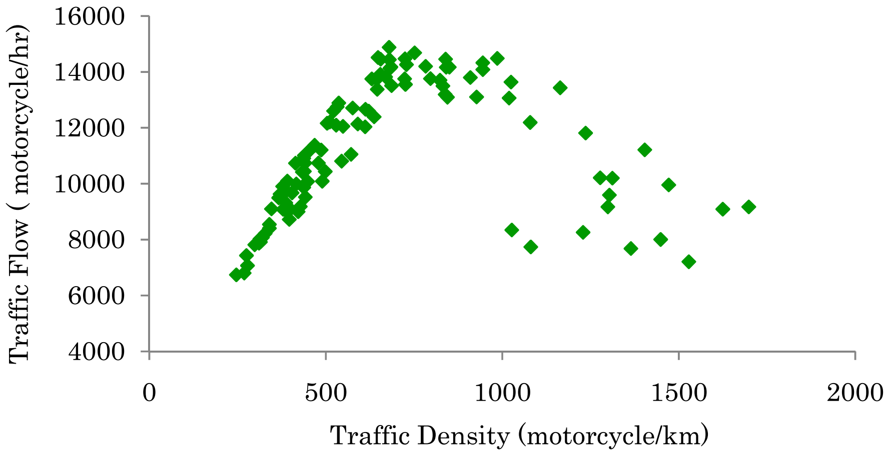

Figure 8c Relationship between Traffic Density and Traffic Flow

6.4 The Results of Estimating Capacity

From the linear regression analysis, mean stream speed and traffic density relationship may be described in a linear form as:

$$S = a + b \ln(D) \quad (11)$$

Where
a,b = unknown parameters
S = Mean Stream Speed (km/hr)
D = Traffic Density (motorcycle /km)

Based on Greenberg's logarithmic model which may be expressed in linear form as:

$$S = \text{Critical Speed} \, [\, \ln(\text{Jam Density}) - \ln(\text{Traffic Density})] \quad (12)$$

The model building process for the S-D relationship incorporated scientific knowledge of Greenberg's logarithmic model in the model selection. Linear regression analysis was employed for the model fitting and model validation process by using the Statistical Package for Social Sciences software. Hence, the fundamental speed – flow – density relationships may be expressed as follows:

Table 4 The Results of Estimating Capacity based on the MCU's Values of Vehicles

	4 lane/ each traffic direction	***3 lanes/ each traffic direction***	***2 lanes/ each traffic direction***
	Mean Stream Speed and Traffic Density		
Figure	6a	7a	8a
Formula	S = 97.99-11.3 ln(D)	S = 96.06-11.2 ln(D)	S = 98.34-12.3 ln(D)
	Traffic Flow and Mean Stream Speed		
Figure	6b	7b	8b
Formula	F = 5852 S exp (-S/ 11.3)	F = 5271 S exp (-S/11.2)	F = 2951 S exp (-S/12.3)
	Traffic Flow and Traffic Density		
Figure	6c	7c	8c
Formula	F = 11.3 D ln(5852/D)	F = 11.2 D ln(5271/D)	F = 12.3 D ln(2951/D)
Jam density *(motorcycle/km)*	5852	5271	2951
Critical speed *(km/hr)*	11.3	11.2	12.3
Critical density *(motorcycle/km)*	2143	1939	1085
Maximum flow *(motorcycle/hr)*	24335	21725	13358
Number of samples	108	108	108
CAPACITY *(motorcycle/hr)*	24335	21725	13358

Figure 6a, 7a, 8a indicated that capacity of each kind of road segment is reached at a critical traffic density of 2143 motorcycles/ km, 1939 motorcycles/km and 1085 motorcycles/km corresponding to a maximum traffic flow of 24335 motorcycles/hr, 21725 motorcycles/hr and 13358 motorcycles/hr, respectively. The results in the Table 4 also identified the effect of land width (or total carriageway width of the road segment as the lane concept is not strictly followed in the mixed traffic flow and vehicles tend to move abreast. The term carriageway width is used for the total width of paved surface of a road segment excluding its pavements) on the capacity of each type of road segments. This study found that the capacity of each kind of road segment increases with increasing carriageway width or increasing of number of lane in each traffic direction in urban street.

7. MODEL VALIDATION

The proposed model was validated with the data that collected from twelve selected road segments. The concept of validation was carried out based on the speed-flow curve that if the mean stream speeds at different time intervals are the same, the volume of mixed traffic flow (after converting into the MCU) must be the same with the volume of traffic flow that has only motorcycles. Therefore, after calculating the mean stream speeds at the different time intervals, we divided the mixed traffic flow into two kind of flow. The first flow was composed by more than 90% of motorcycle and the other flow was composed by less than 90% motorcycles. If two mean stream speeds are similar, the volumes at those intervals are converted into the MCU. If the volume after converting into the MCU is the same, the research methodology for calculating the MCU is correct. The traffic volume of each point is the traffic volume average value of all samples that have the same mean stream speed in each speed interval (there are ten intervals from 0 m/sec to 10 m/sec).

From Figures 9, it is straightforward to see that at the same mean stream speed interval, the traffic volume of the proposal model is acceptable because it is the same with the traffic volume of mixed traffic flow that includes more than 90% motorcycles.

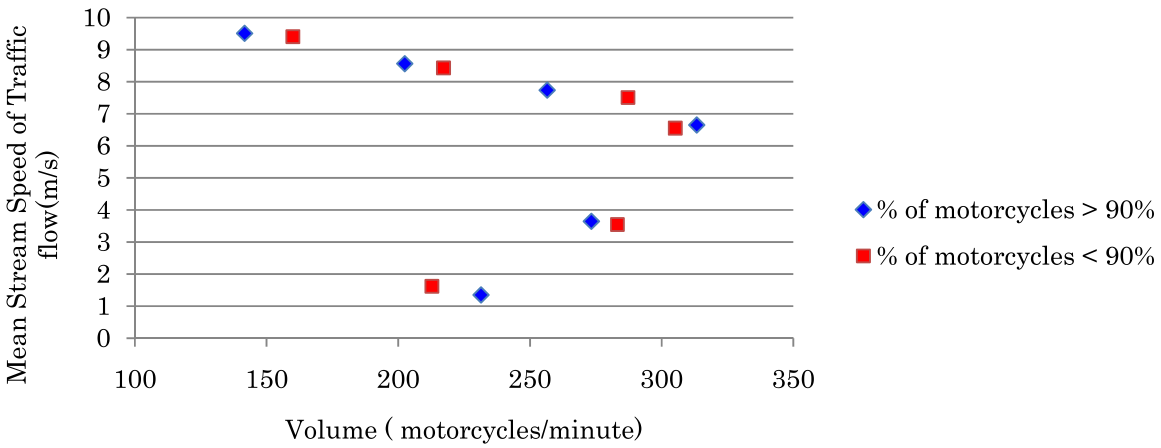

Figure 9 The Relationship between Mean Stream Speed and Volume in Urban Street

8. CONCLUSION

The passenger car unit (PCU) of different type of vehicle under mixed traffic conditions was developed to estimate MCU of various type of vehicle at road-segments in urban road. Field data from twelve selected road-segments in Hanoi, Vietnam were used to illustrate the proposed methodology. The field data showed that the correlation relationships between speed and the effective space of all vehicles were high at all selected approaches in urban road. The variation of the effective space mainly depends on the speed of subject vehicle at road-segments.

The proposed methodology was used to estimate the mean speed, the mean effective space and MCU of the other vehicles under mixed traffic condition that dominated by motorcycles in urban roads. The estimated MCU showed that a single car, a single bus, a single minibus and a single bicycle at road-segments replaces 3.43, 10.48, 8.34 and 1.38, motorcycle equivalent unit, respectively. This methodology makes more sense in a mixed traffic flow in motorcycle dependent cities such as Hanoi, Vietnam in particular and the other cities in Asia in general. There might also be some other factors contributing to the variation of the effective space of subject vehicle but not included in the models such as the age, income or gender of drivers, traffic conditions. Thus, the models can be improved with bigger data size, larger range of variation and more predictor variables to be considered.

This research found that the values of capacity of each kind of road segment are 24335 motorcycles/hr, 21725 motorcycles/hr and 13358 motorcycles/hr in three groups of road segments such as four-lanes, three-lanes and two-lanes per each traffic direction based on twelve selected road-segments, respectively. Results indicated that the capacity of urban road increases with the number of road lane or total width of urban roads.

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