Speed-Density Relationships of Motorcycle and Passenger Car under the Motorcycle-Dominated Traffic: A Case Study of a Road Segment in Phnom Penh

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Abstract: Motorcycle has been used as an outnumbered travel mode in developing countries. Under the motorcycle-dominanted traffic, speed-density relationships of motorcycle and passenger car are investigated considering explicitly the interactions between the two modes. Understanding the explicit modal-interaction relationships leads to better mixed traffic planning and controls which are required particularly for developing countries. A road segment in Phnom Penh was selected as a studied location. Then using video technique, speed and density data were obtained and analyzed. As a result, there is a close form of speed-density relationship corresponding to each mode eventhough the traffic is separated into two.

Key Words : *Speed-density relationship, motorcycle-dominated traffic, mixed-traffic analysis, video technique, explicit modal-interaction relationship, mixed link performance function*

1. INTRODUCTION

Using motorcycle as a travel mode has outnumbered other modes in developing countries which leads to a motorcycle-dominated traffic. In Phnom Penh, Cambodia, motorcycle has shared not less than 70% of traffic composition[1)] and more than 80% was reported in Hanoi and Hochiminh, Vietman[2)]. A second highest percentage of traffic composition is from passenger car. Over 15% was observed in Phnom Penh.

Under the motorcycle-dominated traffic, both modes have shared the same urban streets which create an interesting interaction. Motorcycle and Car do not respect lane markings. They are driving every possible spaces in order to go ahead faster. However, the interactions under this mixed-traffic condition cause severe congestion (see **Fig.1**), noise and air pollutions as well as casualities, disabilities, and asset damages in accidents[1)]. Furthermore, this kind of traffic condition is currently out of control since there is a lack of theories or models dealing with. Therefore, there are many research devoted to mixed-traffic analysis.

Fig.1 Traffic congestion in Phnom Penh, 2011

Minh et al[3] studied the motorcycle traffic characteristics under the mixed traffic situations in Hanoi. They investigated the relationship between the mean stream speed and traffic flow based on the motorcycle equivalent unit (MCU). Furthermore they developed a method to estimate the MCU considering the dynamic characteristics of moving vehicles for motorcycle-dominated traffic[4].

Kov and Yai[1] investigated, considering the effect of light vehicle (car, pick-up, van), the traffic performance of motorcycle-dominated urban street.

Tuan[5] was interested in analyzing the interactions of vehicle-groups behaviors specifically the left-turn and straight-go groups at intersections under the condition of mixed traffic flows.

Radin and Hirobata[6] studied not an analysis but a mixed-traffic assignment by proposing a path-based algorithm based on a nonlinear complementarity problem to solve static mixed-traffic assignemt. Yet, their algorithm still required mixed link-performance functions as inputs in the assignment which currently have not been available.

Although there have been many studies related to mixed-traffic analysis as stated above, none of them considered explicitly the modal-interaction relationships particularly the fundamental relationships of traffic flow based on empirical data. Hence, this paper takes a first step to an empirical study on the speed-density relationships of motorcycle and passenger car considering explicitly their interactions. By investigating these explicit modal interactions, it will lead both to formulate possibly the mixed link performance functions necessary for mixed-traffic assignment as mentioned above and to a better mixed-traffic controls as required particularly in developing countries. In addition, developing mixed link performance functions is the final purpose of this study.

The next sections are organized as follows: Section 2 describes data collection. Speed-density relationship is in Section 3 where model and calibration method are presented. Section 4 concludes this paper.

2. DATA COLLECTION

To get empirical data, a 4-lane road in Phnom Penh was, at first, selected as a study site. The road is separated by steel handrail along the middle way of the road width. This allows two lanes for each traffic direction. Therefore, this study site allows us not to consider the effects of opposite-direction vehicles on the studied direction. Traffic flow data, then, are determined based on a road segment as a studied location. The location was chosen at a distance

Fig.2 Studied location (Phnom Penh, 2011)

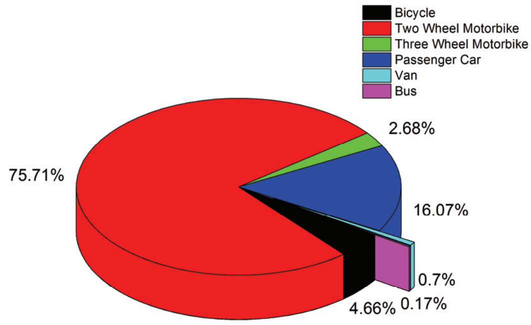

Fig.3 Mixed-traffic composition

Table 1 Statistics of travel speed of vehicles

Vehicle	*Traffic volume*	*Observed speed (km/h)*			
		Mean	Max	Min	Std. dev
Bicycle	79	13.78	20.82	8.6	2.61
2W. bike	1300	25.51	57.86	8.38	7.41
3W. bike	46	20.98	35.53	6.74	6.55
Pass. car	276	24.42	45.09	6.23	8.21
Van	12	25.26	32.69	10.55	7.04
Bus	3	21.30	34.41	13.91	11.39

behind a signalized intersection where a complete traffic data can be obtained; that is data under free flow traffic and congested traffic (see **Fig.2**). There is a disconnection of the steel handrail where vehicles are allowed to either go out from or go into the desired traffic direction. Yet, due to a relative small number and frequency of going-out and going-in vehicles, let us assume there is not much effect on the studied vehicles.

Using videotaping technique, traffic flows and average speeds of each vehicle are obtained. The traffic flow corresponding to each mode was determined as a number of vehicles passing the targeted point (Point No.2 in **Fig.2**) for a desired time interval. A starting time of counting vehicles is the time where the first vehicle passed the Point No.2. The average speed of each vehicle is calculated as an assumption as a ratio of the distance between Point No. 1 and Point No. 2 (60.60m) and the difference in travel time from Point No.1 to Point No.2. Using Fuji software allows us to calculate from the video data the differences in travel time of each vehicle between Point No. 1 and Point No. 2.

Fig.3 above shows the mixed-traffic composition at the studied site during 22-minutes recorded time.

As can be seen in **Fig.3**, two-wheel motorbike shared a highest percentage (76%) of traffic composition meanwhile it happened a highest speed as well (see **Table 1**). Although passenger car which shared a second highest compositioin drove with a highest speed but still lower than that of motorcycle, their mean speeds are not so different. Each driver drove with different speeds as a result of higher standard deviations. Moreover, the mean speeds of motorbike and passenger obtained here were quite comparable to those in Kov[1)]. **Fig.3** also shows that other modes's composition shared less than 3% for each except bicycle shared around 5%, but all of them (bicyclists) always rode near sidewalk which leaded us not to consider its effects on our studied traffic. In addition, we included 3-wheel motorbike and van data in those of 2-wheel motorbike and passenger cars respectively as their relative small amount and similar speeds in next study. In next section, we use the word 'motorcycle' instead of '2-wheel or 3-wheel motorbike'.

3. SPEED AND DENSITY RELATIONSHIP

(1) Speed and density distribution

For each 20s time interval, traffic flows corresponding to motorcycle and passenger car were counted and then their densities were calculated as the ratio between a traffic flow and a space mean speed of each vehicle corresponding to each interval.

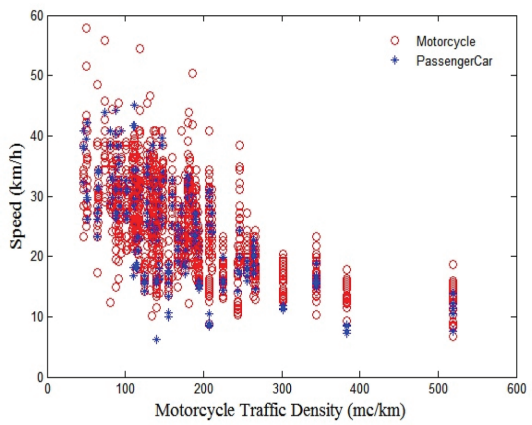

Fig.4 Speed distribution of motorcycle and passenger car vs motorcycle traffic density

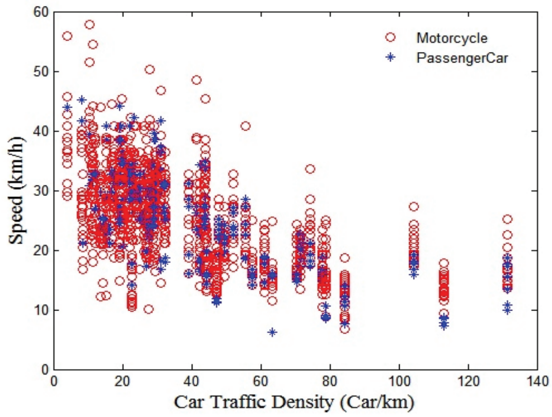

Fig.5 Speed distribution of motorcycle and passenger car vs passenger car traffic density

As a result, we have 66 intervals.

Fig.4 and **Fig.5** showed distributions of an individual speed of vehicles corresponding to each interval versu densities of motorcycle and passenger car, respectively. It has been seen clearly that motorcycle' speeds is higher than those of passenger car for all time intervals. It is because in any traffic condition some motorcyclists are more confident than car to drive in a narrow space wherever is possible particularly near the handrail which can be supported by Kov[1)].

(2) Space mean speed and density model

Since so far, there have not any research separately focusing on relationships between speed and density corresponding to each mode considering explicitly interations under motorcycle-dominated traffic, this section started by investigating individually the space mean speed of both mode versu each density as shown in **Fig.6** and **Fig.7**. Interestly, eventhough the traffic has been separately considered into two modes, the speed distribution still tends to decrease as the both density increases for both cases. This leads to consider an unique model for the relationship between speed and density corresponding to each mode as the followings:

For motocycle:

$$v_m = v_m^{\max} \exp\left\{-\left(\frac{k_m}{k_m^{\max}} + \alpha \cdot \frac{k_c}{k_m^{\max}}\right)\right\} \tag{3a}$$

For passenger car

$$v_c = v_c^{\max} \exp\left\{-\gamma \cdot \left(\frac{k_m}{k_m^{\max}} + \alpha \cdot \frac{k_c}{k_m^{\max}}\right)\right\} \tag{3b}$$

where k_m : is a density of motorcycle

$k_m^{\max}$: is a mximum density of motorcycle

k_c : is a traffic density of car

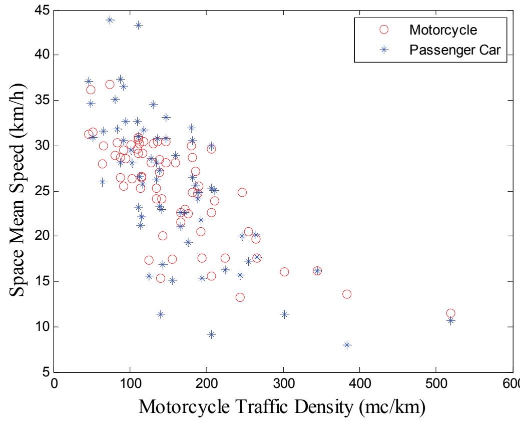

Fig.6 Space mean speed vs motorcycle traffic density

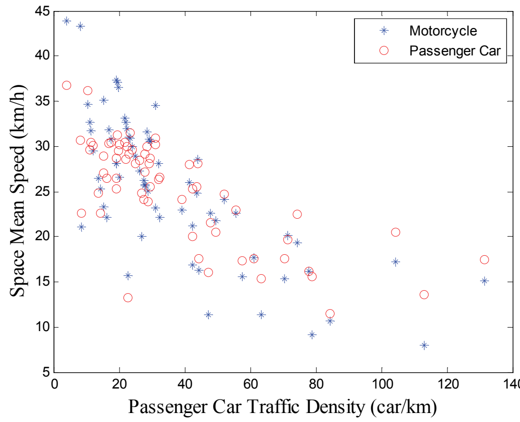

Fig.7 Space mean speed vs passenger car traffic density.

α : is an equilivalent factor of Car to motorcycle
v_m : is an average speed of motorcycle traffic
$v_m^{\max}$: is the maximum speed of motorcycle traffic
v_c : is an average speed of Car traffic
$v_c^{\max}$: is the maximum speed of Car traffic
γ : is a calibrated factor
$\exp(\cdot)$: is used in stead of $e^{(\cdot)}$ as an exponential form

(3) Calibration method

Since the proposed model of the relationship between travel speed and traffic density as the nonlinear exponential function (equation 3a and 3b), it is advantageous to use the Least-Square method by converting the nonlinear forms into a linear form as the following:

For motorcycle

$$\log v_m = \log v_m^{\max} - \frac{k_m}{k_{\max}^m} - \alpha \frac{k_c}{k_{\max}^m} \quad (3c)$$

Suppose $y = \log v_m, x_1 = k_m, x_2 = k_c, \beta_0 = \log v_m^{\max}$, $\beta_1 = -\frac{1}{k_m^{\max}}, \beta_2 = -\frac{\alpha}{k_m^{\max}}$, then the equation (3c) is modeled as the linear form below:

$$y = \beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 \quad (3d)$$

For passenger car:

$$\log v_c = \log v_c^{\max} - \gamma\left(\frac{k_m}{k_{\max}^m} + \alpha \frac{k_c}{k_{\max}^m}\right) \quad (3e)$$

Similarly, suppose $y = \log v_c, x = \left(\frac{k_m}{k_{\max}^m} + \alpha \frac{k_c}{k_{\max}^m}\right)$, $\beta_0 = \log v_c^{\max}, \beta_1 = -\gamma$, then the equation (3e) becomes

$$y = \beta_0 + \beta_1 \cdot x \quad (3f)$$

It should be noticed that the equation (3d) is a multiple linear regression while the equation (3f) is a simple linear regression. It is because some paramters in equation (3f) are reduced as a result of the calibration of the equation (3d). However, for either case; simple or multiple, paramters in equation (3d) and (3f) can be calibrated using the Least-Square minization problem as its general form

$$\min L = \sum_{i=1}^{n}\left(y - \beta_0 - \sum_{j=1}^{k} \beta_j x_{ij}\right)^2 \quad (3g)$$

where n is a number of observed values and k is a number of independent variables. For equation (3d) k=2 and k=1 in equation (3f).

Perhape, it is not new for some of readers, the Least-Square minization problem (3g) is solved by a matrix approach as below:

$$\hat{\boldsymbol{\beta}} = (\boldsymbol{X}' \cdot \boldsymbol{X})^{-1} \boldsymbol{X}' \cdot \boldsymbol{y} \quad (3h)$$

where

$$\boldsymbol{y} = \begin{Bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{Bmatrix}, \boldsymbol{X} = \begin{bmatrix} 1 & x_{11} & x_{12} & \cdots & x_{1k} \\ 1 & x_{21} & x_{22} & \cdots & x_{2k} \\ \vdots & \vdots & \vdots & & \vdots \\ 1 & x_{n1} & x_{n2} & \cdots & x_{nk} \end{bmatrix}, \hat{\boldsymbol{\beta}} = \begin{Bmatrix} \hat{\beta}_0 \\ \hat{\beta}_1 \\ \vdots \\ \hat{\beta}_k \end{Bmatrix}$$

The equation (3h) can be found in many statistical text books i.e [7].

(Note: $\boldsymbol{X}'$ is a matrix transformation of $\boldsymbol{X}$ and $(\cdot)^{-1}$ is an matrix inversion)

(4) Parameter estimation results

The results of the estimation were summarized in the table 2 below. The obtained values R^2 suggested a good correlationship between the proposed models and the observed data. In addition, the value γ (see in **Table 2**) of is 1.39 (this value is not available in PCU or MCU approach), it implies that Car traffic is not so efficient under the motorcycle-dominated traffic. As can be seen in Fig. 8, speeds of Car is

Table 2 Parameter estimation results

	Motorcycle	Passenger car
	$v_m = v_m^{\max} e^{-\left(\frac{k_m}{k_m^{\max}} + \alpha \frac{k_c}{k_m^{\max}}\right)}$	$v_c = v_c^{\max} e^{-\gamma \cdot \left(\frac{k_m}{k_m^{\max}} + \alpha \frac{k_c}{k_m^{\max}}\right)}$
n	66	66
$v_m^{\max}$	36.78 (km/h)	-
$v_c^{\max}$	-	42.23 (km/h)
$k_m^{\max}$	615.38 (mc/km)	615.38 (mc/km)
α	2.52	2.52
γ	-	1.39
R^2	0.71	0.68
Least-square estimation		
β_0	3.6054 (t=95.71)	3.7430 (t=67.18)
β_1	-0.0016(t =-6.24)	-1.3855 (t=-11.44)
β_2	-0.0041(t=-5.03)	-

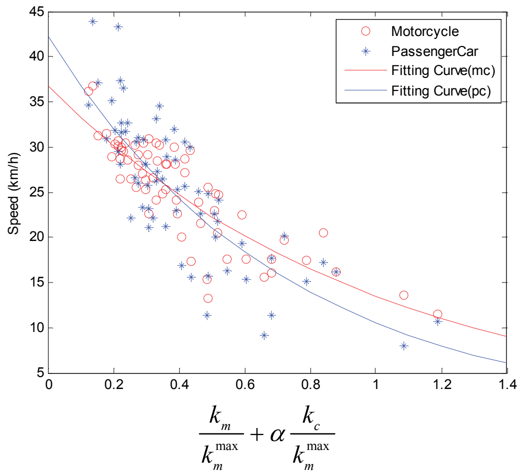

Fig.8 Speed distribution and fitting curve vs relative combined-density.

decreasing lower than those of motorcycle as the traffic starts to be congested.

4. CONCLUSION

It is a starting point to explicitly consider the relationship of mixed-traffic characteristics by avoiding using PCU or MCU for better traffic planning and controls. Though this research considered only two modes, it meant as a basic concept for other modes. Moreover, enlargement of data scale will generalize the calibrated parameters for example the equivalent factor (α) or (γ). This study, finally, will lead to developing mixed link performance functions.

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