ANALYSIS OF MOTORCYCLE EFFECTS TO SATURATION FLOW RATE AT SIGNALIZED INTERSECTION IN DEVELOPING COUNTRIES

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Abstract: In the developing countries, motorcycle is a major transportation mode but very little attention has been paid to their effects on the traffic flow. This paper is to investigate and to analyze the effects of motorcycle at signalized intersections in Hanoi and Bangkok, two capitals of developing countries in South East Asia. The analysis is separated into two parts: effect on saturation flow rate and effect on passenger car. The influential factors associated with these delays, such as the percentage of motorcycles in traffic flow, and the number of motorcycle stopped in front of the lead car, were also investigated. Linear and nonlinear regression models for adjusting the influence of these factors were constructed. Motorcycle impacts on traffic flow of these cities were analyzed independently with the same suppositions and processes. The results of the research indicated that motorcycle strongly affects to traffic flow and it should be taken into account in geometric design and operation of signalized intersection.

Key words: Motorcycle, Saturation Flow Rate, Heterogeneous Traffic Flow.

1. INTRODUCTION

Signalized intersections play a critical role in the smooth operation of both arterial and urban streets, where traffic movement in different directions meet together. The number of vehicle and pedestrian traffic handled by an intersection depends on i) physical and operating characteristics of the roadway, ii) traffic control system, iii) various driver behaviors and iv) environmental conditions affecting to drivers. Because these characteristics influence interrupt traffic movement, intersection is usually the bottleneck of the network, the main sources of traffic accidents and traffic congestions. Study in signalized intersection is one of most effective measure to improve the capacity of road network and relieve traffic congestion.

In South East Asia, where the motorization has developed rapidly in the last few decades, motorcycle is a major transportation mode and effects to traffic flow, especially to signalized intersections. Especially in Hanoi, where two-wheelers are more than 80% of total transportation means, motorcycle reduces the speed of other modes and makes the traffic more congested due to its shapes and its behaviors. It is capable of zigzag maneuvers, creeps up slowly to the front of the queue when the signals are red, and impedes traffic flow by disturbing the start of other vehicles behind. The necessary to obtain a better understanding of the motorcycle influences originates from the requirement to consider all transportation modes in the decision making process. If the better understanding of motorcycle impacts on traffic flow is achieved, the more accurate models can be derived and the better of motorcycle behavior is interpretive in the overall traffic modeling. The objective of this paper is to investigate and to analyze the effects of motorcycle on both heterogeneous traffic and passenger car at signalized intersection in some cities of developing countries in South East Asia.

2. METHODOLOGY

Study on traffic characteristics at intersection is not a new topic. Many researches have been studied on saturation flow rate and start-up lost time to improve traffic condition at an enclosed intersection or entire network. However, in most of these studies, passenger car is considered as the main mode and used for all calculation and analysis, which are incorrect in where two-wheeler overwhelms in traffic flow. Very few researches have been conducted to the effects of motorcycle on the capacity of signalized intersections except concentrated on traffic accident viewpoint. Nakatsuji *et al* (2001) analyzed the effect of motorcycles on capacity of some signalized intersections in two capitals Hanoi and Bangkok. That paper evaluated the effect of motorcycles on saturation flow rate of passenger car based on their relative positions. The authors classified some patterns, which were different relative positions of motorcycle to passenger car, then used regression analysis to estimate how different among these patterns were in terms of headway and start-up lost time. However, that method is quite difficult from practical use. The passenger car equivalent of motorcycle was found as 0.60 and 0.63 for Hanoi and Bangkok respectively, those values are very high and should be re-estimated. Similarity, Hai (1999) also evaluated effects of motorcycle on saturation flow rate on two intersections in Hanoi - Vietnam. The author estimated start-up lost time by separating two cases: position and number of motorcycles in front of first car in queue. Nevertheless, both correlations between start-up lost time and motorcycle for all cases are very low (R^2 = 0.14 and 0.15) and composition of traffic flow is only passenger car and motorcycle modes. In these researches, the effects of motorcycle were presented through their effects on passenger car, which is not a major means. Therefore, the results are only significant in case that motorcycle rate is low. In the study areas, motorcycle presents a key role in traffic composition so that it should be considered as a main mode.

In this paper, in order to overcome the problem, heterogeneous traffic flow is conducted for all calculations and analysis, the effects of motorcycle are analyzed in saturation flow rate, average headway, and start-up lost time. The influential factors associated with these delays are investigated. A regression model for adjusting the influence of these factors is constructed. Average headway and motorcycle capacity data from these cities are calculated and analyzed independently with the same assumptions and procedures.

2.1 Data Collection

In order to determine the effects of motorcycle on saturation flow rate, detail on site observations regarding to traffic flow, delay, split and cycle signalized control time are taken in Hanoi and Bangkok. Due to the great fluctuation in traffic flow, the signalized intersections based on the scope of work are selected in which, i) advantage location for conducting survey, ii) large motorcycle volume and iii) little interference from other factors such as pedestrians, left and right turning, parked vehicles and bus stops, etc. The data used in this study includes topology and geometries of each link, traffic flows passing the approaches for each mode, and traffic signal control. These data are collected from surveying by using video method, manual counting, and measurement.

2.1.1 Data in Bangkok

The observation is taken from Thonglo, Payathai, and Siam Square intersections. They are all four-leg signalized intersections located in the central area of Bangkok in Thailand. The intersections are attractive to many traffic users and very high motorcycle volume. Trucks and heavy vehicles are prohibited, therefore, traffic composition includes of passenger cars, motorcycles and buses. When the traffic is low, signalized control system is operated as pre-time control, otherwise polices are controlled the traffic by themselves. Data collection was carried out during peak periods from 11am to 1pm and from 4pm to 6pm in September and October 2002. The traffic flow at inner and middle lanes, which is mixed traffic of passenger car, bus, and motorcycle, is taken into consideration. The lane widths are varied from 3.2 m to 5 m depending on each approach. At that time, motorcycle shared average 20% of total traffic flow at these lanes. The other lanes were overwhelmed by passenger car. Figure 1a shows the typical traffic situation at Siam Square intersection.

Figure 1a. Siam Square Intersection, Bangkok, Thailand

Figure 1b. TaySon – ChuaBoc Intersection, Hanoi, Vietnam

2.1.2 Data in Hanoi

Four intersections observed in December 2002 include Daewoo, Tayson– Chuaboc, Thaiha – Langha, Ochodua intersections. All study intersections are located on CBD of Hanoi. Trucks and heavy vehicles are prohibited at that time. The time for observation is at peak periods in the morning (from 7am to 9am) and in the afternoon (from 4pm to 6pm). During these periods, the data in 100 cycle times is collected for each study intersection. The video cameras are hung on high buildings to capture the traffic flow at traffic signal, especially concentrating on activity at the stop lines. The study approaches are similar characteristics. They are all pre-time signalized control and have different lane width, 3.5 m to 5 m. The motorcycle contributes average 90% of all transportation modes. Other lanes are fully occupied by motorcycle. Figure 1b presents the typical traffic at TaySon – ChuaBoc intersection in Hanoi.

2.1.3 Measurement of Saturation Flow Rate

The data collection for saturation flow rate is conducted at approaches in several cycle times. Five persons stand on the footpath near the stop line. One person observes the duration of the green time, other three counted the number of classified vehicles crossing the stop line and the last one writes down on the form sheet. Simultaneously, video camera records the traffic movement and the signalized control system. From the video films, vehicle types and passing time are captured later by interpreting in the traffic laboratory. For the traffic survey, the different types of vehicles in the traffic stream are classified into three groups as follows:

1. Motorcycles, mopeds, scooters
2. Passenger cars, vans, taxis
3. Buses

These observations with varying saturated green times (5 – 45 sec) are recorded to estimate PCU of motorcycle, average headway, saturation flow rate. The method for conducting these values is depicted later. More than fifty of such observations are taken at each approach.

2.1.4 Measurement of Start-up Lost Time

Start-up lost time is the time lost due to driver reactions and vehicle acceleration. The start-up lost time is estimated by the summation of the difference between the observed headway of each vehicle and saturated headway.

$$\textbf{Start-up lost time} = \sum(\text{Observed headway} - \text{Saturated headway}) \quad (1)$$

The number of motorcycle stand in front of first car in queue in red light is counted, then the headway for each passenger car is observed until that value is stabilized. The stabilized condition is achieved when the consecutive car's headway is consistent. Usually, the stabilized headway is measured about 2(s) in case of no motorcycle effects.

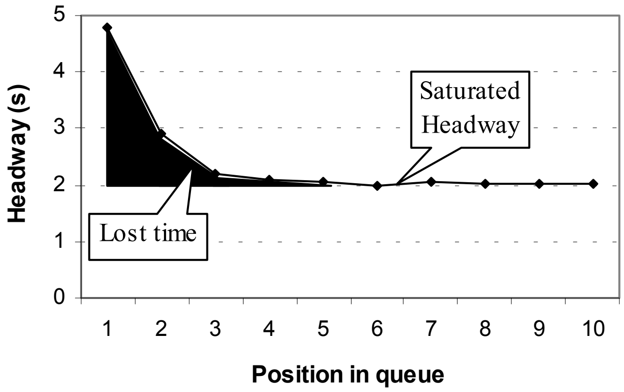

Figure 2. Saturated Headway and Lost Time Measurement.

2.2 Estimation of Saturation Flow Rate

Up to now, there are many methods to compute the saturation flow rate. Most of them were assumed that the saturation flow rate was fixed during the saturated green signal. (i) *Headway method:* Greenshields et al. (1947) and TRB (1997) estimated the average time headway between sequence vehicles discharging from queue as they pass the stop line. Then, the saturation flow rate is calculated as reciprocal of the mean headway. (ii) *TRL method:* TRRL (1963) measured the saturation flow rate in vehicle units without considering the composition of traffic. The saturation flow rate is measured as the number of vehicles in the middle saturated green interval divided by the length of this interval. (iii) *Regression method:* Branston et al. (1978), Kimber et al. (1985) and Stoke et al. (1987) developed an equation involving saturated green time, number of vehicles in different modes in heterogeneous traffic. A regression analysis is the effective method to yield the saturation flow, average headway, and passenger car equivalents for other modes than passenger car. In this research, saturation flow rate is estimated based on heterogeneous traffic condition so that regression method is the most effective one. The saturation flow rate is computed by counting number of vehicle in each group passing through that approach during saturated green time. The lane width of saturation flow rate study is chosen as 5m for all considered intersections in Hanoi and Bangkok.

2.2.1 Regression Analysis for the Saturation Flow Rate

The saturation flow rate for heterogeneous traffic is evaluated using the multiple linear regression analysis, in which the saturated green time is a function of vehicles passing the stop line during that green time. Assuming that the relationship between dependent and independent variables is linear, the regression formula, therefore obtains, for all study intersections.

$$t = a_1n_1 + a_2n_2 + a_3n_3 \qquad (2)$$

where

t : saturated green time (s) is defined as at this time, traffic flow is saturated;
a_1, a_2, a_3 : coefficients of motorcycle, passenger car, bus group respectively;
n_1, n_2, n_3 : number of vehicles in each group crossing the approach during the time t.

In order to determine when the traffic is saturated in heterogeneous traffic, the common unit is used. Therefore, all vehicle passing the stop line at each five-second interval are converted into passenger car equivalent briefly by using Table 1. This table is used for determining saturated flow condition and saturated green time only, it is not results for PCE estimation in this paper. Then, in every five seconds in green time, if more than three PCUs passing through the stop line, that time is considered as saturated green time and the traffic is saturated.

Table 1. Passenger Car Equivalent (PCE) for Other Vehicles

Vehicle	PCE
Motorcycle, moped, scooter	0.25
Passenger car, van, taxi	1.00
Bus	2.00

Source: Mathetharan, 1997

From regression analysis, the PCE values of motorcycle and bus group are obtained lately when the coefficient of motorcycle and bus are divided by the coefficient of passenger car respectively. The saturated green time is divided by the total of the number of different vehicular groups, converted into passenger car units, to the average headway. The formula is shown as bellow:

$$H = \frac{t}{n_1 p_1 + n_2 p_2 + n_3 p_3} \quad (s) \tag{3}$$

where

t : saturated green time (s);
p_1, p_2, p_3 : the PCE value of motorcycle, passenger car, bus group respectively;
n_1, n_2, n_3 : number of vehicles in each group crossing the approach during the time t.

The saturation flow is then obtained as: $\frac{3600}{H}$ *(PCU/egh)* (4)

The numerical analysis for several cycle times in different intersections in Hanoi is described:

$$t = 0.207n_1 + 0.85n_2 + 1.918n_3 \qquad \text{with } R^2 = 0.99 \tag{5}$$

Table 2. The Results of Statistical Significant Test of Hanoi Data.

	Coefficient		t	Sig.
	B	Std. Error		
MC	.207	.002	120.360	.000
PC	.850	.027	31.385	.000
B	1.918	.103	18.548	.000

The numerical analysis for many cycle times in several Bangkok intersections:

$$t = 0.281n_1 + 1.603n_2 + 3.487n_3 \qquad \text{with } R^2 = 0.99 \tag{6}$$

Table 3. The Results of Statistical Significant Test of Bangkok Data

	Coefficient		t	Sig.
	B	Std. Error		
MC	.281	.021	13.282	.000
PC	1.603	.052	30.977	.000
B	3.487	.605	5.761	.000

The PCU, thus obtains and shown in Table 4.

Table 4. Passenger Car Equivalent (PCE) for Other Vehicles

City	Motorcycle	Car, van, taxi	Bus
Hanoi	0.24	1.00	2.26
Bangkok	0.18	1.00	2.18

The lower value of PCU for motorcycle in Bangkok compared to Hanoi can be explained by the difference of motorcycle ratio in traffic flow. In case of high ratio, motorcycle tends to gather in front of the stop line during red line, and then discharge as groups at the beginning of green time. The average headways and saturation flow rates are obtained as bellow:

Table 5. Comparison of Estimated Saturation Flow Rate

City	Average Headway Statistics		Saturation Flow Rate (PCU/egh)
	Mean (s)	Standard deviation (s)	
Hanoi	0.88	0.11	4,092
Bangkok	1.60	0.12	2,253

2.2.2 Analysis of Motorcycle Impacts on Saturation Flow Rate

The result on Table 3 shows that the saturation flow rate (PCU/egh) in Hanoi is nearly twice times as much as in Bangkok although physical characteristics are almost the same. It can be explained by the difference of motorcycle ratio in traffic composition in those cities, 20% for Bangkok and more than 90% for Hanoi. When considering saturation flow rate in Hanoi, the gap between and beside two consecutive passenger cars is fully occupied by motorcycle but in Bangkok, that gap is not. When motorcycle ratio is high, motorcycles make groups and those groups move among and alongside passenger cars. Nevertheless, in case of motorcycle ratio is low, motorcycle is considered as individuals and then usually, it runs at the side, not behind or in front, of passenger car. Consequently, when calculating saturation flow rate, the result in Bangkok shows that passenger cars pass over the stop line one by one but nearly two passenger car overtake simultaneously in case of Hanoi's result. The behavior explains the average headways for heterogeneous are different from Bangkok to Hanoi, from low to high percentage of motorcycle. Furthermore, it also explains the passenger car equivalent of motorcycle in both cities is different. It makes conclusion that motorcycle effects strongly in saturation flow rate. In Bangkok, although the lane width is wide, the passenger car passes one by one through the stop line and other spaces are unused. Therefore, the saturation flow in Bangkok is saturated in case of passenger car but not in case of motorcycle. Difference from that situation, in Hanoi the unused spaces are almost possessed by motorcycle. Figure 3 presents the relationship between saturation flow rate and motorcycle based on the data at intersections in both cities.

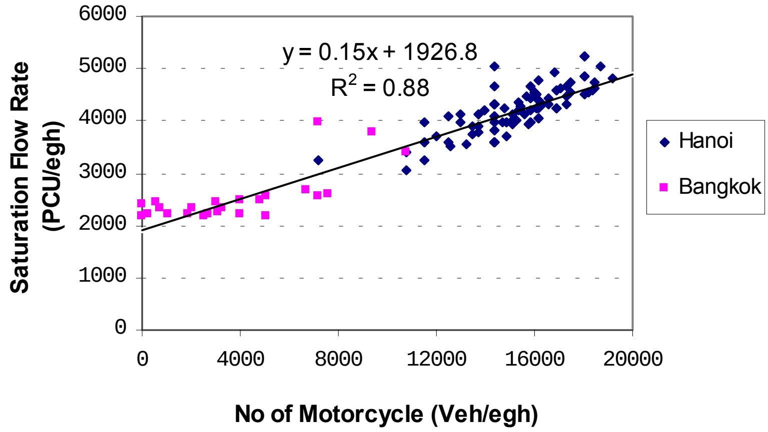

Figure 3. The Effect of Number of Motorcycle on Saturation Flow.

Both data in Hanoi and Bangkok are put together in the same Figure 3. When number of motorcycle or motorcycle ratio increases, the saturation flow rate will increase as well. Figure 3, which is very high R^2, implies that motorcycle strongly effects to saturation flow rate regardless of the different driver characteristics in either city. In the figure, the low saturation flow rates, about 2200 (*PCU/egh*) correlative of low motorcycle percentage, are in Bangkok and the others in Hanoi.

In the saturation flow analysis, there are two types of factors affected saturation flow rate. The first type is an event that interrupts a vehicle stream including parking vehicles, stopped buses, pedestrians for right turns. The second type affects spacing between moving vehicles including different type of vehicles, lane width, horizontal grade, type of maneuver, etc. When considering motorcycle impacts, due to their behavior, their shape, and their size, motorcycles easily maneuver along the roadside and impede other modes. Therefore, the lane width is one of main agents effecting on the number of motorcycle passing the approach and saturation flow rate so far. It is necessary to estimate the saturation flow rate based on number of motorcycle and lane width. The regression model checks statistical fitness of two factors on saturation flow rate *S* (*PCU/egh*) using the field data collected on several intersections in both cities, which are different lane width *w* (*meter*) and number of motorcycle passing the stop line in one hour *mc (Veh/egh)*:

$$S = 1965 + 105 \times (w - 3.5) + 0.12 \times mc \qquad \text{with } R^2 = 0.79 \tag{7}$$

where

S : saturation flow rate *S* (*PCU/egh*);
w : lane width (*m*);
mc : number of motorcycle passing the stop line in one hour *(Veh/egh)*.

The value of t statistic is 8.70, 2.16, and 16.89 for a constant, *w*, and *mc* respectively. The effectiveness of the model is evaluated in Figure 4. This figure shows the correlation between estimated saturation flow and observed saturation flow. It implies that saturation flow rate is strong relationship to number of motorcycle passing the stop line and lane width. The errors can be from the other factors, which are not included in the model, such as: type of maneuver, turning radius, lane location on the approach, etc.

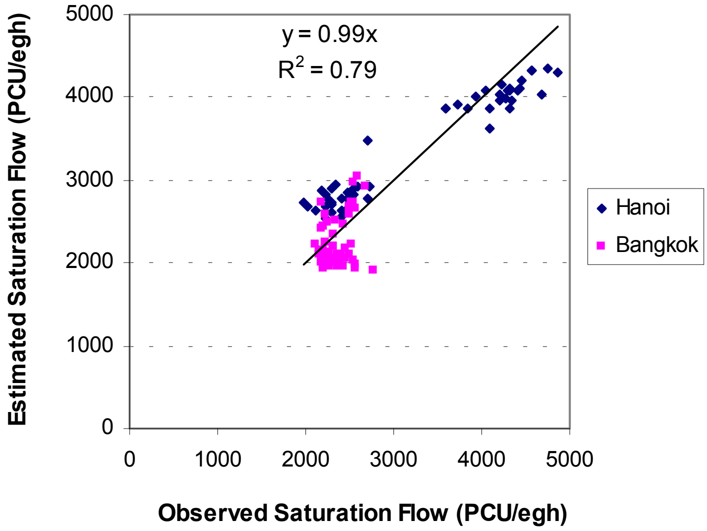

Figure 4. The Correlation between Estimated Saturation Flow and Observed Saturation Flow.

2.3 Effects of Motorcycle to Passenger Car

In the developing countries, when approaching or passing to the stop line of signalized intersection, motorcycle can be mixed with other modes, especially passenger car, with high density. In this situation, the reciprocal influence between motorcycle and passenger car is very sensitive. Therefore, it is necessary to estimate the effects of motorcycle on other modes, particularly on passenger car.

2.3.1 The Changing of Passenger Car and Motorcycle in Saturation Flow Rate

This analysis is taken in case of saturated traffic flow. At that time, the number of motorcycle and the number of passenger car passing the stop line are inversely proportional. If the number of motorcycle is very high, the number of passenger car is low and vice versa. Figure 5 shows how the largest passage number of passenger car is reduced by motorcycles in saturation flow.

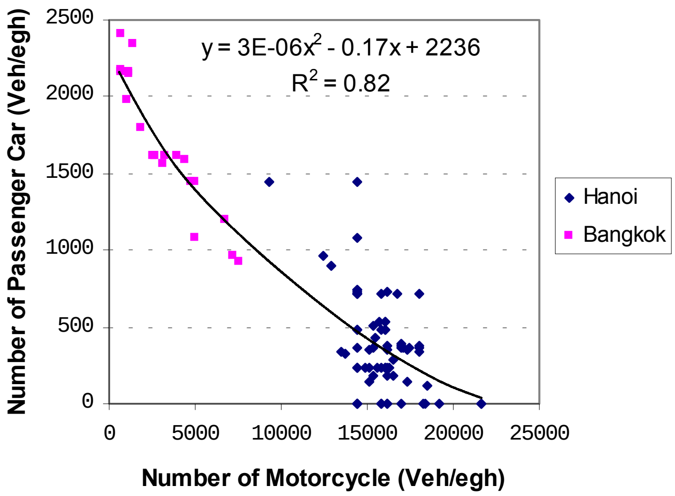

Figure 5. The Changing of Passenger Car and Motorcycle in Saturation Flow Rate.

The figure presents very high correlation between number of motorcycle and number of passenger car. In the extreme case, when number of passenger car is zero, the number of motorcycle is about 20,000 vehicles passing the stop line. This data is at Hanoi intersections. On the contrary, when number of motorcycle is zero, the number of passenger car passing the stop line is about 2300 vehicles. This data is at Bangkok intersections. It depicts that if only passenger car passing the approach, traffic is saturated just in passenger car mode and not saturated in motorcycle mode. The reason is that, despite passenger cars moving continuously, it still has many unused spaces. Differently, if only motorcycles passing the approach, due to their shapes and their sizes, the traffic lane is fully occupied by motorcycles. Therefore, the second case is "more saturated" than the first case in term of passenger car unit. In order to well understand the relationship between both variables, the nonlinear regression analysis is necessary to check statistical fitness between the number of passenger car (*Veh/egh*) and number of motorcycle passing the approach *mc (Veh/egh)* and the lane width *(meter)*. From the figure 5, it shows the best fit correlation between number of passenger car and motorcycle is a second-order polynomial. Consequently, in this regression model, it is also chosen a second-order function of motorcycle variable and a first-order function for lane width variable. The detail of the nonlinear regression model and the value of each parameter are staged as follow:

$$pc = 1985 + 8.08 \times 10^{-6} \times mc^2 - 0.26 \times mc + 203 \times (w - 3.5) \text{ with } R^2 = 0.83 \qquad (8)$$

where

pc : Number of passenger car passing the stop line in one hour (*Veh/egh)*
mc: Number of motorcycle passing the stop line in one hour (*Veh/egh)*
w : Lane width *(m)*

Figure 6 presents the very high correlation ($R^2 = 0.83$) between observed and estimated car number of equation (8). In the figure, the value of Hanoi data is on the left and lower than that of Bangkok because the number of passenger car in Hanoi is less than in Bangkok.

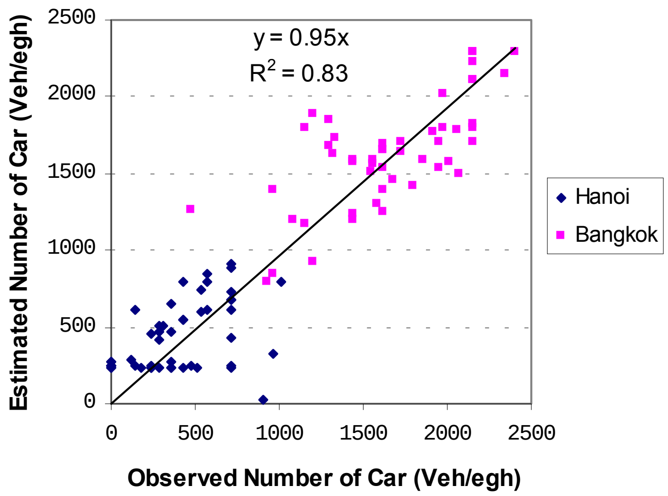

Figure 6. The Correlation between Estimated and Observed Car Number.

2.3.2 The Effect of Motorcycle to Passenger Car Headway

The number of motorcycle moving between successive passenger cars influences on the saturated headway of passenger car. Figure 7a and 7b depict the effects of the number of motorcycle between consecutive passenger cars to car headway. They express that in both cities, the headway is slightly different and increases when number of motorcycle increases. The fluctuations of the data come from the different relative positions of motorcycles among themselves and among them and passenger cars.

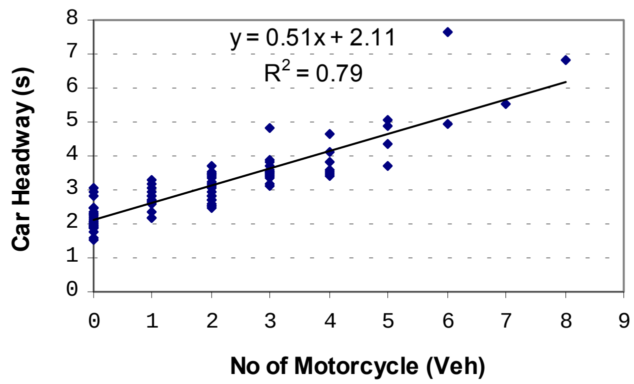

Figure 7a. Correlation between Car Headway and Number of Motorcycle in Hanoi.

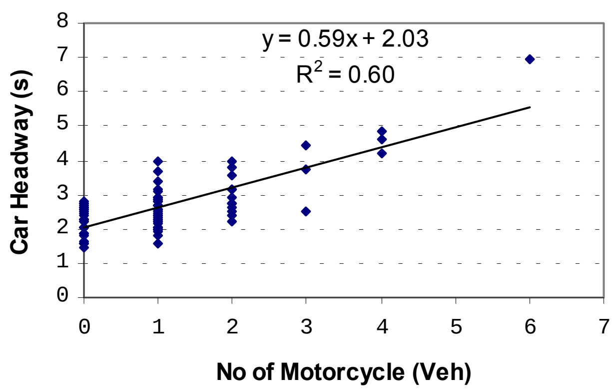

Figure 7b.Correlation between Car Headway and Number of Motorcycle in Bangkok.

2.3.3 The Effect of Motorcycle to Start-up Lost Time

Number of motorcycle in front of first car in the queue has a specific effect to start-up lost time of passenger car. In the study, observation data is collected in both cities and varies from no motorcycle to six motorcycles standing in front of first passenger car. Figure 8a and 8b present the correlation of start-up lost time and number of motorcycle in front of first car in queue. In this study, when there is no motorcycle standing in front of the first car, start-up lost time is similar to one or two motorcycles standing. It can be explained that due to motorcycle behavior, they usually try to stand in front of the stop line during red time, then discharge at all-red time period. This phenomenon leads car drivers have earlier perception – reaction time to accelerate their vehicles.

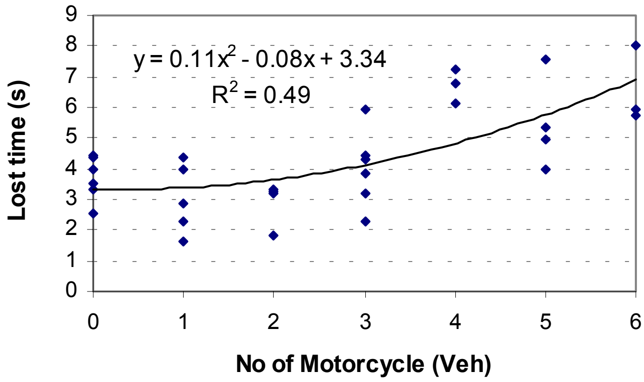

Figure 8a. The Effect of Number of Motorcycle on Start-up Lost Time in Hanoi.

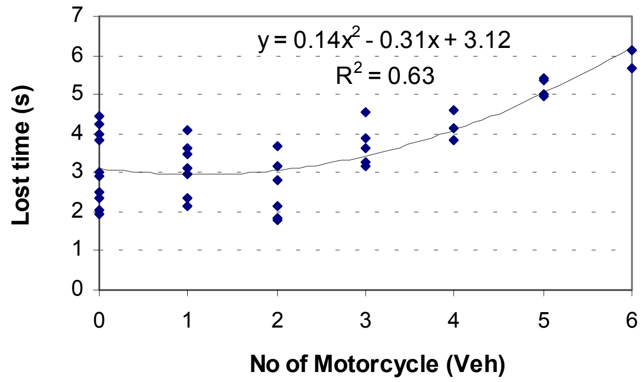

Figure 8b. The Effect of Number of Motorcycle on Start-up Lost Time in Bangkok.

3. CONCLUSIONS

In Hanoi and Bangkok cities, motorcycle is a major mode of transportation. The saturation flow rate of intersection approaches is affected strongly by the presence of motorcycle. The traffic flows are different when percentage of motorcycle and when interaction between motorcycle and passenger car are different. In this paper, the heterogeneous traffic flow is conducted for all calculations and analysis. In order to quantify the effects of motorcycle, two main aspects about saturation flow rate and passenger car impacted are analyzed in Hanoi and Bangkok cities independently with the same processes.

Effect of motorcycle on saturation flow rate is investigated based on regression analysis. The regression model is formulated with very high coefficient of determination ($R^2 = 0.99$ for both Hanoi and Bangkok). This model is used to (i) estimate the passenger car equivalent (PCE) for motorcycle (0.24 in Hanoi and 0.18 in Bangkok); (ii) determine saturation flow rate (4,092 *PCU/egh* ≈ 17050 *mc/egh* in Hanoi and 2253 *PCU/egh* in Bangkok).

Motorcycle impeding passenger car is examined on (i) how the largest passage number of passenger car is reduced by motorcycles in saturation flow (R^2 = 0.82), (ii) passenger car headway (R^2 = 0.79 in Hanoi and R^2 = 0.60 in Bangkok) based on the number of motorcycle between successive passenger cars, and start-up lost time (R^2 = 0.49 in Hanoi and R^2 = 0.63 in Bangkok) based on the number of motorcycle in front of the first car in queue during red time of traffic signal. The result shows that there is little difference between Hanoi and Bangkok data in this analysis although the difference of motorcycle percentage in both cities is significant.

Moreover, two models are constructed to express the relationship between motorcycle and saturation flow rate, passenger car. The first model (R^2 = 0.79) represents the relationship between saturation flow rate and lane width, number of motorcycle. The second model (R^2 = 0.83) depicts the relationship between passenger car and lane width, motorcycle. Both of them are examined and work well in all study intersections.

These results present that motorcycle strongly affects to traffic capacity, especially when motorcycle ratio is high, and impedes other transportation mode. Therefore, it should be taken into account in geometric design and operation of signalized intersection.

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