EFFECTS OF MOTORCYCLE ON CAPACITY OF SIGNALIZED INTERSECTIONS *

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1. Introduction

Motorcycles are a major means of transport in the cities of South East Asia, where motorization has evolved rapidly in the last decade. They make up a large percent of the traffic stream: in Bangkok, chronic traffic congestion attracts motorcycle use. In particular, motorcycle taxis, capable of zigzagging among congested vehicles, are very popular due to their agility and cheap fares. There were nearly 1.6 million motorcycles registered in 1999, more than 25 % of all motor vehicles. In Hanoi, the motorcycle is the most important means of transport because of the country's developing economy and still expensive four-wheel vehicles. Approximately 0.7 millions were registered in 1995, constituting 82% of transportation demands when coupled with bicycles (*1*). Recently, Hanoi has also suffered from a rapid increase in traffic demands, particularly in the number of motorcycle trips. Thus, although motorcycles take up a major share in the transportation system in these countries, they are considered little in the design and operation of intersections.

The saturation flow rate is the most important factor in the geometric design and operation of signalized intersections. So far, many studies have been conducted on the effects of road and traffic conditions on the saturation flow rate. They are summarized as the HCM (Highway Capacity Manual) in many countries (*2,3,4*). However, except for a few studies (*5,6*), little attention has been paid to the effect of motorcycles since they make up only a small percentage of transportation modes in Western countries. They have been investigated merely from a traffic safety viewpoint. In terms of capacity, the impact of the motorcycle has been assessed as a PCE (Passenger Car Equivalent), although the values of PCE are very divergent in those countries.

Motorcycles affect the intersection capacity severely if they share a large part of the traffic flow. They impede passenger car flow in two ways: motorcycles waiting at the stop line disturb the start of passenger cars behind them. This situation happens frequently because motorcycles can easily creep up to the top of the queue by weaving through passenger cars when the signals are red. This delay causes start-up lost time at the outset of the green phase. The number of rows formed by bunching motorcycles at the stop line is an influential factor in the delay. After the signals have turned green, motorcycles driving between or overtaking passenger cars also impede the passenger car flow by increasing the headway of passenger cars and eventually decreasing the saturation flow rate. The relative position of motorcycles to passenger cars has a crucial impact on this rate.

This study aims to analyze the effect of motorcycles on both start-up lost time and the saturation flow rate. The time headways between successive vehicles were measured during saturated situations and divided into two portions; the initial portion for start-up lost time and the stable portion for the saturation flow rate. The influential factors associated with these delays, such as the relative position to passenger cars, the number of rows caused by motorcycles bunching, and the total number of motorcycles stopped in front of the lead passenger car, were also investigated concurrently. A regression model for adjusting the influence of these factors was presented. Two capital cities in South East Asia, Hanoi in Vietnam and Bangkok in Thailand, were selected as the study area. Headway data from these two cities were collected and analyzed independently, although based on the same assumptions and procedures. In addition, a method of estimating the passenger car equivalent for motorcycles was proposed in conjunction with the adjustment factor of saturation flow rate.

2. Data Collection

Collection Sites

The importance of site selection cannot be overemphasized in conducting a study on intersection capacity. In this case, the intersections were selected so as to satisfy the following requirements:

- The motorcycle volume should be large enough to analyze the effects quantitatively. At the same time, the motorcycle positional pattern should be extensive enough to investigate the impacts qualitatively.
- The passenger car volume should also be large enough to obtain stable saturated flows: there should be at least five to six passenger cars queuing when the traffic signal turns green.
- There should be little influence from other factors, such as left/right turning, heavy vehicles, or pedestrians.

Another aspect of site selection is the difficulty in finding a building tall enough on which to place video cameras. It is often difficult to find such a site in developing countries in particular, even in capital cities. Although possibly not the optimum sites, intersections were selected in Hanoi and Bangkok.

*Keywords: Motorcycle, Saturation Flow Rate, Capacity, Start-Up Lost Time, Passenger Car Equivalent, Signalized Intersection
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a) Cua Nam Intersection in Hanoi

This intersection is located in central of Hanoi City. It intersects two major roads, Trang Thi Road and Cua Nam Road, leading to the two major administrative districts of Hanoi, and signalized with a pre-timed phasing scheme. Trang Thi Road has three through-traffic lanes, which do not permit turning. Trucks and heavy vehicles are prohibited during the day. The traffic composition comprises passenger cars, motorcycles and small buses.

Southbound traffic data on Trang Thi Road were collected on weekdays in October 1998 during the peak evening period from 4:00 to 6:00 p.m. using two sets of video cameras. The data were measured for the median lane only, which motorcycles and passenger cars shared. The other lanes were almost 100% occupied by motorcycles. The signal timing at the intersection was in good synchronization with those of the other intersections in the neighborhood. The queue length on the lane was not so long as to cause spilt-over phenomena even during the peak period. During these periods, headway data from 750 passenger cars were collected over 80 cycles. Motorcycles shared more than 30% of traffic on the lane. The lane is straight and level with 3.5m width.

b) Sathorn Intersection in Bangkok

The intersection selected in Bangkok is in the CBD, where Sathorn Road meets Narathiwart Rachanakarin Road. Both roads are divided highways with four full lanes and a right turn pocket in each direction. The shoulder lane is used exclusively for left turning traffic. The intersection is usually operated on a pre-timed signal control and occasionally on a manual control manned by police officers. Heavy vehicles other than buses are not allowed through during the day. Traffic drives on the left in Bangkok just as in Japan.

The westbound vehicular movements on the median lane and the right-sided mid-lane of Sathorn Road were measured using video cameras mounted on a nearby pedestrian bridge on weekdays in January 1999. The road section is straight and level with lane-width of 3.5m. A long queue was almost always formed at the stop line every cycle due to the long cycle length, usually a few minutes and sometimes more than five minutes especially when police officers manually control the traffic. However, the spillover from downstream rarely reached this intersection because of its distance from it. A total of 1754 headways were collected on the second and third lanes over 60 cycles. During these periods, motorcycles shared 15 to 50% of the total traffic volume with an average of 33%.

In this study, only passenger cars and motorcycles were treated. Passenger cars are defined to include passenger cars, pick-up trucks, station wagon and other vehicles with similar acceleration characteristics. Motorcycles include all motorized vehicles with two wheels.

2) Data Processing

Start-up lost time and saturation headway were calculated based on the HCM method (2). A time of 1/100-second precision was imposed onto videotapes frame by frame. The headway was measured by reading the time of a vehicle's rear bumper passing the reference line. As opposed to the influential analyses for other vehicle types, such as bus and truck, it is almost impossible to measure the headway between passenger car and motorcycle, or between motorcycles themselves, on a lane basis because there are often a few motorcycles driving side by side in one lane, which are frequently changing lane. In this study, the headway between successive passenger cars was measured by treating motorcycles as influential factors in order to investigate the impact quantitatively.

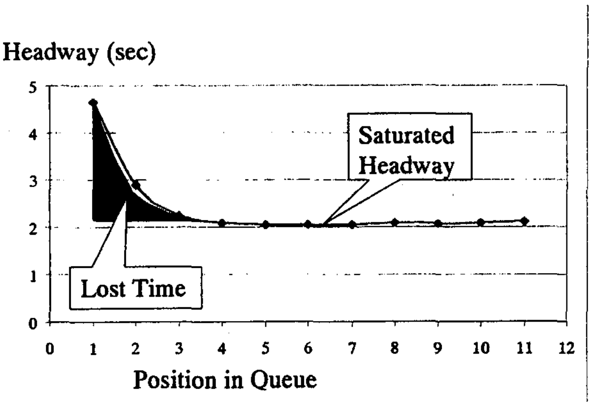

Fig. 1. Conceptual Drawing of Start-Up Lost Time and Saturated Headway

The headway of passenger cars was digitized until at least ten vehicles in the queue crossed the line by excluding the vehicles joining the back of the queue after the signal turned green. As shown in **Fig. 1**, the first four or five headways observed included some lost time due to the delay in driver reaction to the change in the traffic signal and low speed while accelerating. Thereafter, the headway varies with less fluctuation. Start-up lost time can be comprehensively defined as the total sum of the difference between the headways before and after stabilization:

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

The saturation flow rate is a reciprocal of the average headway after the fluctuation gets small sufficiently:

$$S = 3600/\bar{h} \quad \text{(pcu/ghl).} \quad (2)$$

where $\bar{h}$ is the saturated headway in seconds. In this study, the first four headways were used to calculate start-up lost time and the remainder up to the 10th or 11th vehicle were used for the saturated headway.

3) Motorcycle Position Relative to Passenger Cars

a) Saturation Flow Rate

The position of motorcycles relative to passenger cars seems to have a large influence on the saturated headway of passenger cars. The relative position was classified into several patterns after considering the formation actually observed at both intersections. The configuration was consequently classified into five patterns, as shown in Fig. 2:

Pattern 1: No motorcycle is in front of or alongside a passenger car (P-1).
Pattern 2: One motorcycle is alongside a following car, on either left or right side (P-2).
Pattern 3: One motorcycle is between two passenger cars although not directly in front of the follower (P-3).
Pattern 4: Two or more motorcycles are alongside passenger cars but not directly in front of the follower (P-4).
Pattern 5: One motorcycle is situated between two passenger cars, just in front of the follower (P-5).

For Pattern 2 to 4, the influence of whether motor cycle(s) is/are driving on either left or right side of passenger car(s) was not considered in this study.

c) Start-Up Lost Time

The amount of start-up lost time depends on not only how many motorcycles stopped in front of lead passenger car but also how close they are to each other. The configuration observed was classified into three patterns in accordance with the number of rows formed in front of the lead vehicle, as shown in Fig. 3:

Row 0: No motorcycle is directly in front of the lead passenger car (R-0).
Row 1: One row is formed in front of the lead passenger car (R-1).
Row 2: Two rows of motorcycles are formed in front of the lead passenger car (R-2).
No bunching of motorcycles with more than two rows was observed at either measurement site.

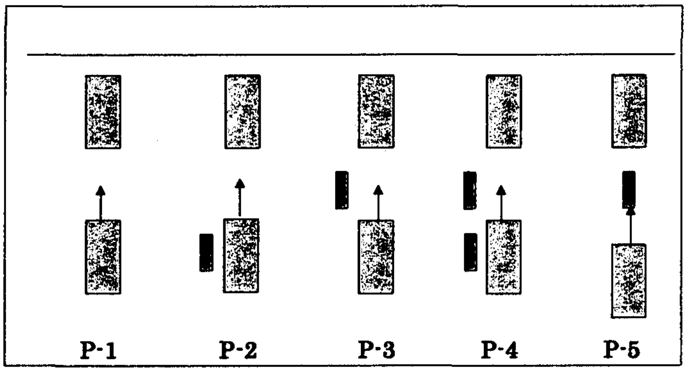

Fig. 2. Relative Position of Motorcycles to Passenger Cars for Saturated Headway Analysis

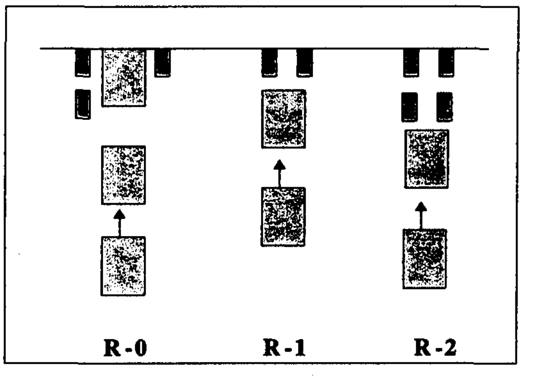

Fig. 3. Relative Position of Motorcycles to Passenger Cars for Start-Up Lost Time Analysis

4) Filtering

The original data actually measured at both intersections contained fairly short or long headway components that were caused by vehicles that responded too early or too late to the preceding vehicles. Since adjustment factors must be developed for average car-following situations, these biased data had to be excluded at the outset. In both saturation flow rate and start-up lost time analyses, headway data biased by more than one standard deviation from the mean were excluded for each position pattern. Moreover, the number of samples was usually quite different for each pattern. Such an imbalance in number would have created an unexpected bias in the regression analysis. In order to avoid such numerical biases, the headway data were thinned so often, while not losing their essential nature, so that the largest number of samples was no more than double that of the smallest.

Tables 1 and 2 show the number of samples, the mean, and the standard deviation of the saturated headway and start-up lost time for both the original and the filtered data. The P-1 data of the saturated headway as well as the R-0 data of start-up lost time were thinned to keep the number of samples balanced with the other patterns. The overall tendency in Tables 1 and 2 conforms to the underlining characteristics of saturated headway and start-up lost time: the mean and the standard deviation increase as motorcycles affect passenger cars more heavily both in Hanoi and Bangkok, except for a few standard deviation cases. The deviation of start-up lost time was somewhat larger than that of the saturated headway. Both saturated headway and start-up lost time measured at the Bangkok site were somewhat larger than those at the Hanoi one. This may stem from the difference in the driving habits in both the cities. The subsequent sections are devoted to a detailed discussion of how much relative position influenced the saturated headway and start-up lost time of passenger cars.

Table 1. Mean and Standard Deviation before and after Filtering (Hanoi)

(1) Saturated Headway Data

Pattern		P-1	P-2	P-3	P-4	P-5
Measured	Mean	2.06	2.30	2.40	2.71	3.40
	Std. Dev.	0.22	0.42	0.48	0.49	0.52
	# of Samples	282	68	42	52	68
Filtered	Mean	2.09	2.31	2.38	2.71	3.40
	Std. Dev.	0.11	0.25	0.23	0.26	0.29
	# of Samples	51	49	33	35	46

(2) Start-Up Lost Time Data.

Pattern		R-0	R-1	R-2
Measured	Mean	3.26	3.60	5.65
	Std. Dev.	1.59	1.60	1.35
	# of Samples	51	19	10
Filtered	Mean	2.89	3.33	5.39
	Std. Dev.	0.89	0.68	1.13
	# of Samples	17	13	9

Table 2. Mean and Standard Deviation before and after Filtering (Bangkok)

(1) Saturated Headway Data

Pattern		P-1	P-2	P-3	P-4	P-5
Measured	Mean	1.87	1.93	2.21	2.21	2.86
	Std. Dev.	0.67	0.67	0.65	0.65	0.92
	# of Samples	495	86	136	65	149
Filtered	Mean	1.72	1.80	2.06	2.18	2.73
	Std. Dev.	0.36	0.36	0.36	0.37	0.46
	# of Samples	62	63	53	47	55

(2) Start-Up Lost Time Data.

Pattern		R-0	R-1	R-2
Measured	Mean	2.02	3.09	4.12
	Std. Dev.	1.39	1.86	2.62
	# of Samples	22	50	30
Filtered	Mean	1.92	3.03	3.94
	Std. Dev.	0.75	0.95	1.54
	# of Samples	17	33	23

3. Analyses

1) The Regression Model for The Saturated Headway

In order to evaluate the effect of motorcycle positioning on the saturation flow rate, a regression analysis was applied to the filtered data with representing the position pattern as a dummy variable. In general, a linear multiple regression model was usually adopted to express the relationship between them (7). However, the following exponential equation is more convenient to describe the influence quantitatively:

$$S_M = e^{(a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_4 + a_5 x_5)} \quad (3)$$

where

S_M: Saturation flow rate (pcu/ghl).

x_i : 1 if position pattern is i, 0 otherwise

a_i: Adjustment factors of pattern i.

a_0: Constant.

The exponential model directly yields the adjustment factor by putting Exp(a_0) as S_0 and Exp(a_i) as f_i:

$$S_M = S_0 f_1 f_2 f_3 f_4 f_5 \quad (4)$$

In Eq. (3), x_i is Boolean such that it satisfies $\sum_{i=1}^{5} x_i = 1$.

To identify, therefore, the regression coefficients a_i (i=1,2,..5), one must be specified in advance, and normally a_1 is set as 0, in other words f_1=1. Since Pattern 1 has no motorcycles, f_i (i=2,3,4,5) represents the adjustment factor for each pattern in reference to Pattern 1.

2) The Regression Model for Start-Up Lost Time

The means and standard deviations listed in Tables 1 and 2 suggest that no regression model may work well in representing the start-up lost time with respect to the number of rows formed in front of the lead passenger car because the distribution of start-up lost time for each pattern overlaps each other due to the large deviation. Nevertheless, since the number of rows is still the most crucial factor, both linear and parabolic regression models were adopted to evaluate how much the number of rows x contributes to start-up lost time y:

$$y = a_0 + a_1 x \quad (5)$$

$$y = a_0 + a_1 x + a_2 x^2 \quad (6)$$

In this analysis, the exponential function was not used since it did not improve the regression precision.

3) Passenger Car Equivalent of Motorcycle

The passenger car equivalent for motorcycle is divergent from country to country (3). In order to assess the equivalent quantitatively, we assumed two virtual traffic flows; one is a mixed flow, which consists of both passenger cars and motorcycles driving sequentially one by one. The other is a homogeneous flow, which comprises only passenger cars. As shown in Fig. 4, h_M is the average time headway between passenger car and motorcycle, while h is the headway for the homogeneous flow. The adjustment factor for motorcycles on the mixed traffic flow is defined as

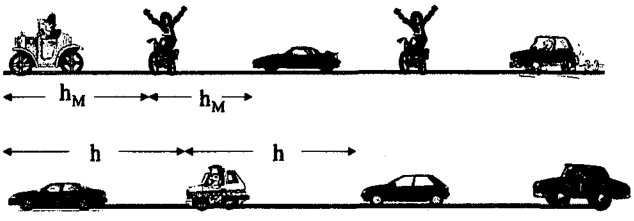

Fig. 4. Time Headways of Motorcycle and Passenger Car.

$$\alpha_M = \frac{100}{(100-M)+E_M M} = \frac{S_M}{S} = \frac{h}{h_M} \qquad (7)$$

where E_M is the passenger car equivalent of motorcycles and M is the motorcycle percentage. S_M is the saturation flow rate for the mixed traffic flow with taking into account the number of both motorcycles and passenger cars, while S is the saturation flow rate for the homogeneous situation. If the platoon of the mixed flow is long enough, the percentage of motorcycles, M, reduces to 50%. Therefore, provided the headways, h and h_M, are measured, the passenger car equivalent can be estimated as follows:

$$E_M = 2(\frac{h_M}{h}) - 1 = \frac{2}{\alpha_M} - 1 \qquad (8)$$

The mixed flow in Fig. 4 corresponds to Pattern 5 in Fig.2. The adjustment factor, α_M, should be related to the adjustment factor f_5 in Eq. (4). It should be noted here that Eq. (4) treats motorcycles merely as an impedance factor, whereas Eq. (7) takes them as vehicles in estimating the saturation flow rate. If the percentage of motorcycle is 50%, the saturation flow rate, S_M, in Eq. (7) should be double as the one in Eq. (4). In other words, α_M is $2 \times f_5$. Consequently, the passenger car equivalent reduces to

$$E_M = \frac{1}{f_5} - 1 \qquad (9)$$

4. Numerical Analyses

1) Saturation Flow Rate

In order to examine the validity of the estimated mean values, the difference in means was investigated by means of a T-Test as well as an equity of variance through an F-Test. Table 3 summarizes the results of both these tests for the filtered Hanoi data in Table 1. Only the equality of variance between P-1 and P-2 was not justified in the F-Test. The subsequent T-test identified a significant difference in the mean among all positional patterns except between P-2 and P-3. Since the p-value in the case of x3-x2 is fairly small, 10.7%, the headway data for all patterns were treated as independent from each other in the regression analysis.

Table 3. Assessment of Mean and Variance of Saturated Headway for Each Position Pattern (Hanoi, Significance Level:5%, Both-Sided)

F-Test (H_0:Variance is Equal)	Variance Ratio	V2/V1	V2/V3	V4/V3	V5/V4
	Test Statistic	5.11	1.13	1.25	1.22
	Critical Value	1.61	1.74	1.79	1.73
	Hypothesis	Reject	Accept	Accept	Accept
T-Test (H_0:Mean is Equal)	Difference	X2-X1	X 3-X2	X 4- X 3	X 5- X 4
	Test Statistic	5.80	1.25	5.49	11.19
	Critical Value	1.67	1.66	1.67	1.66
	p-value (%)	0.00	10.7	0.00	0.00
	Hypothesis	Reject	Accept	Reject	Reject

Vi: Variance in Saturated Headway for Pattern i Xi: Mean of Saturated Headway for Pattern i

The multiple regression analysis using MS-Excell produced the regression coefficients of Eq. (3) with treating the qualitative data of P-1 to P-5 as the dummy variable and taking the *log* value of the saturated headway for each pattern. Table 4 presents a summary of the regression analysis for the Hanoi data: the multiple correlation coefficient R^2 is sufficiently large and the p-values of the regression coefficient is small enough to justify their significance. The adjustment factors estimated by Eq. (4) indicate that the saturation flow rate decreases by 10%, 12%, 23%, and 38% for each pattern in reference to P-1.

Table 4. Regression Coefficient and Adjustment Factor of Saturated Headway for Hanoi Data

	a_0	a_1	a_2	a_3	a_4	a_5
Coefficient	7.4534	0.0	-0.1073	-0.1276	-0.2575	-0.4862
Std. Dev.	0.0122	-	0.0213	0.0177	0.0192	0.0178
T-Test Statistic	609.42	-	-5.03	-7.09	-13.43	-27.37
p-value (%)	0.0	-	0.0	0.0	0.0	0.0
Adjustment Factor	-	1.0	0.898	0.880	0.773	0.615
			Multiple Regression Coefficient R^2			0.817

Critical Value (Significance Level 5%, Both-Sided) 1.97

The results of the regression analysis for the Bangkok data were not as clear as for the Hanoi data: the F-test proved the variance among all patterns to be equal, as shown in Table 5. In the T-test, the difference in the means was not justified for either x3-x1 or x4-x2. However, the p-values were fairly small, less than 10% in both cases. Again, all patterns were treated as independent. Although all the regression coefficients are reliable except for a_3, the multiple correlation coefficient R^2 was just under 0.5, as shown in Table 6. The saturation flow rate consequently decreased by 17%, 5%, 22%, and 37% for each positional pattern, as shown in the adjustment factors in Table 6. The impact of motorcycles is still lighter in Patterns 2 and 3 than in Patterns 4 or 5. The difference in driving habits and characteristics between both cities may have caused the differences in Patterns 2 and 3. It is interesting to note that the adjustment factors in P-4 and P-5 for Bangkok were almost the same as those for Hanoi. In other words, the degree of impact of motorcycles appears to be almost the same in these patterns regardless of the driver characteristics in either city.

Table 5. Assessment of Mean and Variance in Saturated Headway for Each Position Pattern (Bangkok, Significance Level:5%, Both-Sided)

F-Test (H_0:Variance is Equal)	Variance Ratio	V2/V1	V2/V3	V4/V3	V5/V4
	Test Statistic	1.02	1.00	1.09	1.50
	Critical Value	1.53	1.55	1.60	1.61
	Hypothesis	Accept	Accept	Accept	Accept
T-Test (H_0:Mean is Equal)	Difference	X3-X1	X2-X3	X4-X2	X5-X4
	Test Statistic	1.36	3.88	1.54	6.61
	Critical Value	1.66	1.66	1.66	1.66
	p-value (%)	8.75	0.00	6.31	0.00
	Hypothesis	Accept	Reject	Accept	Reject

Vi: Variance in Saturated Headway for Pattern i Xi: Mean of Saturated Headway for Pattern i

Table 6. Regression Coefficient and Adjustment Factor of Saturated Headway for Bangkok Data

	a_0	a_1	a_2	a_3	a_4	a_5
Coefficient	7.6700	0.0	-0.1911	-0.052	-0.2443	-0.4715
Std. Dev.	0.0235	-	0.0346	0.0331	0.0358	0.0343
T-Test Statistic	326.18	-	-5.52	-1.57	-6.82	-13.75
p-value (%)	0.0	-	0.0	11.7	0.0	0.0
Adjustment Factor	-	1.0	0.826	0.949	0.783	0.624
			Multiple Regression Coefficient R^2			0.456

Critical Value (Significance Level 5%, Both-Side) 1.97

2) Resultant Adjustment Factor

The adjustment factor defined by Eq.(4) is not adequate for practical use because the actual traffic flow comprises various position patterns. The resultant factor that accounts for the variation of position pattern can be calculated as themean of adjustment factors weighted by percentage of each pattern. For example, the resultant factor for the Hanoi data is (1.0×282 + 0.898×68 + ... + 0.615×68)/512=0.902. Similarly, the factor for the Bangkok data is 0.901. It is interesting to note that both factors are almost the same despite the difference in the site conditions. This is primarily due to the fact that the percentage of Pattern 1 exceeds more than 50% for both sites.

3) Start-Up Lost Time

Before conducting the regression analysis, the difference in means among row patterns in the filtered data was examined. Table 7 summarizes the results of the T-Test for the Hanoi data shown in Table 1. The difference between R-1 and R-2 was justified, whereas the difference between R-0 and R-1 was not. However, the p-value was fairly small, only 13.2% in the latter case. Table 8 lists the regression coefficients and the corresponding statistics of both the linear and parabolic models of the Hanoi data. For the linear model, the regression coefficients are significant because the T-statistics are sufficiently large and the p-values sufficiently small. However, the multiple correlation coefficient R^2 is not satisfactory, just 0.51 as shown in Table 8. For the parabolic model, the coefficient R^2 improved a little to 0.60 but the significance of the regression coefficient a_1 is still low. These features stem from the large standard deviation shown in Table 1. Even so, both regression models are more than 50% successful in representing start-up lost time. In other words, the number of rows is the most influential factor on start-up lost time.

Table 7. Assessment of Mean and Variance in Start-Up Lost Time for Each Row Pattern (Hanoi, Significance Level:5%, Both-Sided)

	Difference	X2-X1	X 3-X2
T-Test (H_0:Mean is Equal)	Test Statistic	1.55	4.98
	Crit. Value	2.05	2.18
	p-value (%)	13.2	0.0
	Hypothesis	Accept	Reject

Xi: Mean of Start-Up Lost Time for Row Pattern i

Table 8. Regression Coefficient of Start-Up Lost Time (Hanoi, Significance Level:5%, Both-Sided)

	Linear		Parabolic		
	a_0	a_1	a_0	a_1	a_2
Coefficient	2.654	1.297	2.891	-0.497	0.938
Std. Dev.	0.238	0.207	0.233	0.657	0.329
T-Test Statistic	11.1	6.27	12.4	-0.756	2.85
p-value (%)	0.0	0.0	0.0	45.4	0.7
R^2	0.509		0.597		

Critical Value (Sig. 5%, Both-Side): 2.03

Similarly, Tables 9 and 10 exhibit the results of the T-Test and the regression analysis for the Bangkok data shown in Table 2. Each mean was proved to be significantly different for all the row patterns. The regression coefficients of the linear model are reliable enough but the multiple correlation coefficient R^2 is only 0.31, as shown in Table 10. The parabolic model made no improvement to the coefficient R^2, meaning that the number of rows is an influential factor but not a dominant one on start-up lost time in the Bangkok data.

A further regression analysis with adding the total number of motorcycles stopped in front of the lead passenger car to the explanatory variable improved very little the regression statistics for both the Hanoi and Bangkok data. This is due to the close correlation between the number of rows of motorcycles and the total number of motorcycles.

Table 9. Assessment of Mean and Variance of Start-Up Lost Time for Each Row Pattern (Bangkok, Significance Level:5%, Both-Sided)

	Difference	X2-X1	X 3-X2
T-Test (H_0:Mean is Equal)	Test Statistic	3.78	2.67
	Crit. Value	2.01	2.05
	p-value (%)	0.0	1.2
	Hypothesis	Reject	Reject

Xi: Mean of Start-Up Lost Time for Row Pattern i

Table 10. Regression Coefficient of Start-Up Lost Time. (Bangkok, Significance Level:5%, Both-Sided)

	Linear		Parabolic		
	a_0	a_1	a_0	a_1	a_2
Coefficient	2.140	0.899	2.151	0.850	0.0244
Std. Dev.	0.198	0.161	0.226	0.502	0.239
T-Test Statistic	10.8	5.59	9.51	1.69	0.102
p-value (%)	0.0	0.0	0.0	9.2	91.8
R^2	0.309		0.309		

Critical Value (Sig. 5%, Both-Side): 2.00

4) Passenger Car Equivalent

The substitution of the adjustment factor in Tables 4 and 6 into Eq. (9) yields the passenger car equivalent of 0.626 and 0.603 for both Hanoi and Bangkok data, respectively. The difference between them is fairly small despite the difference in the mean headways for Patterns 1 and 5 in Tables 1 and 2. By assuming that the mean headway, h_M, for the mixed flow in Fig. (4) is as half as the headway for Pattern 5 in Tables 1 and 2 and substituting them into Eq. (8), the passenger car equivalent was 0.627 and 0.587 for both sites. This justifies the precision of the adjustment factors.

5. CONCLUSIONS

Transportation systems do not work well without motorcycles in South East Asian countries since they are widely used as the most cost-efficient means of transport. In order to quantify the effects of motorcycles, time headways were measured at intersections in Hanoi and Bangkok. Major findings from the impact analyses with classifying the relative position into five patterns are:

- The position of motorcycle relative to passenger cars had a crucial effect on the saturation flow rate.
- The regression model defined as an exponential function was effective in quantifying the impact of relative position as an adjustment factor. The model was successful in representing the headway characteristics with a probability of 82% for the Hanoi data and of 46% for the Bangkok Data.
- The saturation flow rate lowered at most 40 % in accordance with the position pattern.
- The number of rows is an influential factor but does not represent all of start-up lost time.
- The regression model was almost 60% successful in representing the variation in start-up lost time in the Hanoi data and

only 31% successful in the Bangkok data.

- A procedure of estimating the passenger car equivalent for motorcycles was presented using the adjustment factor for saturation flow rate.
- The passenger car equivalent was 0.60 to 0.63 regardless the estimation method for both cities.

There was little difference in tendency between the Hanoi and Bangkok data, although the results from the Bangkok data had a somewhat larger deviation. More data must be accumulated to describe the complete sets of features in start-up lost time under conditions when lots of motorcycles are mixed with the traffic stream. Finally, the adjustment factor defined by Eq.(4) is not adequate for practical use. The formula is effective only when quantitatively assessing the influence of the position of motorcycle relative to passenger cars. Further analyses are necessary to improve the model structure by introducing an aggregate index that represents the constitution of the position patterns more practically.

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Effects of Motorcycle on Capacity of Signalized Intersections

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Little attention has been paid to the effects of motorcycles on the capacity of signalized intersections. They have so far been considered only from the viewpoint of traffic safety with respect to the design and operation of intersections. In South East Asian developing countries in, motorcycles are the most commonly used means of transport, making up a large part of the demand: for example, 25% in Bangkok, Thailand, and more than 50% in Hanoi, Vietnam.
Motorcycles impede passenger car flow in two ways: increasing start-up lost time and decreasing the saturation flow rate. The influential factors associated with these inefficiencies, such as relative position to passenger cars and the number of rows formed by motorcycles lined up behind the stop line, were examined through statistical tests and regression models using traffic data measured at intersections in two capital cities in South East Asia, Hanoi in Vietnam and Bangkok in Thailand.
The relative position of motorcycles to passenger cars significantly affected the mean headway. The saturation flow rate decreased at most 40% in accordance with the positional pattern. Start-up time also increased parabolically in proportion to the number of motorcycles in the Hanoi data and linearly in the Bangkok data. However, the characteristics of start-up lost time were too complex to describe it only by means of the number of rows.

二輪車が信号交差点の交通容量に及ぼす影響について

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二輪車が信号交差点の交通容量に及ぼす影響を定量化するために、二輪車混入率が30%を超えるハノイとバンコクの交差点において車頭間隔の計測を行った。飽和交通流率に関しては二輪車の相対位置、発進遅れに関しては、停止線後の二輪車車群数を説明変数とする回帰式を作成し補正係数を求めた。相対位置に応じて飽和交通流率に10～40%の減少が見られた。さらに、特定の相対位置に対する飽和交通流率の補正係数から二輪車の乗用車換算係数が求まる事を明らかにするとともに、両都市のデータからその係数がおおよそ0.6であることを示した。発進遅れに関する回帰式に関しては、説明変量の選択を含め改良の余地がある。