Adjustment Factor of Motorcycle For Saturation Flow Rate at Signalised Intersections

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1. INTRODUCTION

Motorcycle is a very popular transportation mode in South East Asian countries, especially in urban areas. In Bangkok, the number of motorcycles has increased rapidly for the past ten years. Motorcycle taxis are very convenient in traffic jams during peak period. There are 1.6million motorcycles registered in 1999. Also in Hanoi, motorcycle is the most popular transportation means. There are 0.7million motorcycles registered in 1999 and share 82% of travel demand along with bicycles [1].

Saturation flow rate is very important factor in the geometric design and operation of signalized intersections. So far, many studies have been conducted concerning the effect of road and traffic conditions on the saturation flow rate. They are summarized as HCM (Highway Capacity Manual) in many countries [2,3,4]. However, except for a few studies [5], little attention is paid to the effect of motorcycles because they share a small percentage in the transportation mode in the western countries. They are simply investigated from a traffic safety viewpoint. In terms of capacity, they are evaluated as PCU (Passenger Car Unit) despite the fact that the relative position to passenger cars has a crucial influence on it.

This study aims to analyze the effect of motorcycles on the saturation flow rate. The time headway between successive vehicles was measured during saturated flow periods as well as the relative position of motorcycle to nearby four-wheel. Two capital cities in South East Asian, Hanoi in Vietnam and Bangkok in Thailand, were selected as study area. Data from these two cities were collected and analyzed independently but on the same assumption and procedure.

2. HEADWAY DATA

2.1 Data Collection

Cua Nam Intersection in Hanoi

The intersection is located in the central area of Hanoi City. The intersection intersects two major roads, Trang Thi Road and Cua Nam Road, leading two major administrative districts. The intersection is operated with a pre-timed control scheme. All approaches of Trang Thi Road have three through-traffic lanes without allowing any turning movement. Trucks and heavy vehicles are prohibited daytimes. Passenger cars, motorcycles and a small number of microbuses comprise the main traffic.

The traffic data in the southbound direction on Trang Thi Road was collected on weekdays of October 1998 during evening peak period from 4:00 to 6:00 p.m. using two sets of video cameras. The data were measured only on the median lane, where motorcycles and passenger cars shared the lane. The shoulder and middle lanes were almost occupied by motorcycles and bicycles. The signal timing of the intersection was fairly in good coordination with the downstream intersection. The queue length was not so long as expected even during the peak period. The traffic situation in the opposite direction was too heavy in the morning peak period to observe the saturated flow. And unfortunately, there was no tall building available in the. During the observation periods, headway data of 750 passenger cars were collected over 80 cycles.

Sathorn Intersection in Bangkok

The intersection selected in Bangkok is in the CBD, where Sathorn Road , one of the busiest roads in Bangkok, meets with Narathiwart Rachanakarin Road. Both are divided highways with four full lanes and a right turn pocket in each direction. The shoulder lane is exclusively used for the left turning traffic. The intersection was usually operated with a pre-timed signal control and occasionally with a manual control by police officers. Heavy vehicles except for buses are not allowed to pass in daytime.

The vehicles bound for west on Sathorn Road were measured by video cameras installed on a nearby pedestrian bridge on weekdays in January of 1999. A long queue was formed at the stop line every cycle because of long cycle length. But, the spillover from the downstream rarely reached here because the downstream intersection was too far. Total of 1754 headways were collected on the second and third lanes over 60 cycles.

2.2 Digitization

Saturation headway was digitized based on the HCM method: A time of 1/100-second precision was imposed onto videotapes frame by frame. The headway was measured by reading the time of vehicle's rear bumper passing the reference line. The headway was digitized until at least ten vehicles in the queue cross the line with excluding the vehicles joining the back of the queue after the signal turned green. As shown in Fig. 1, the first three or four headways observed include some lost time due to the delay of lead vehicles to the change of signal timings and the low speed while accelerating. The excessive headways before the traffic gets stabilized provide the start-up lost time.

Saturation flow rate is defined as a reciprocal of the

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average headway after the fluctuation became small enough.

$$S = 3600/\bar{h} \quad (1)$$

where $\bar{h}$ is referred to as saturated headway.

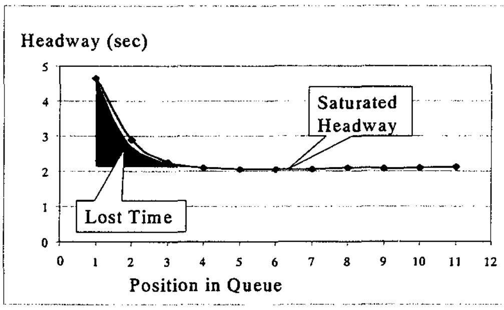

Fig. 1 Start-Up Lost Time and Saturated Headway

2.3 Adjustment Factor

This study is mainly concerned with the effect of motorcycle on saturation flow rate, in particular the influence of relative position to passenger car. As shown in Fig. 2, the position was classified into five patterns in accordance with the position of motorcycle in the lane:

1) A passenger car follows another car without being intervened by any motorcycle (P-1).
2) A motorcycle is situated beside a following car (P-2).
3) A motorcycle is between passenger cars but not on their path (P-3).
4) A motorcycle is beside a following car and another is between passenger cars but not on their path (P-4).
5) A motorcycle is situated between passenger cars and just on their path (P-5).

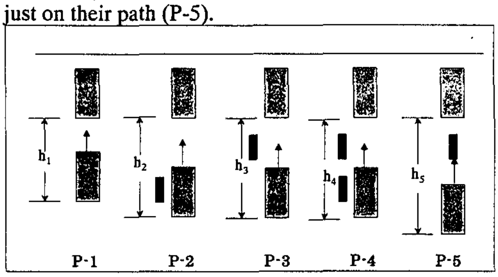

Fig. 1 Classification of Relative Position of Motorcycle to Passenger Car

In order o evaluate the effect of motorcycle position pattern quantitatively, a regression analysis was applied with representing the position pattern as dummy variable. In general, a linear multiple regression model used to be adopted to express the relationship [6], the following exponential equation was used in this study:

$$S = e^{(a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5)} \quad (2)$$

where

S: 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 advantage of the exponential model is that it directly reduces to the adjustment factor of saturation flow rate by putting S_0=Exp(a_0) and f_i=Exp(a_i):

$$S = S_o f_1 f_2 f_3 f_4 f_5 \quad (3)$$

In Eq. (2), x_i is such a boolean that satisfies $\sum_{i=1}^{5} x_i = 1$

Therefore, to identify the regression coefficients a_i (i=1,..5), one of them must be determined in advance, normally a_1 is put to be 0, in other words f_1=1. Since pattern 1 has no motorcycle, f_i (i=2,3,4,5) represents the adjustment factor for each pattern.

2.4 Filtering Processing

In addition to start-up lost time, original data measured at actual intersections contained very short or long headways that were caused by the vehicles that responded too early or too late to the preceding vehicle, sometimes intentionaly and sometimes unconsciouly. Since adjustmet factors should be developed for typical and average car-following situations, those biased data must be excluded before the analysis. Moreover, the number of samples used to be quite different for each pattern. Such an imbalance also would bring unexpected bias in the final results.

Cua Nam Intersection in Hanoi

Fig. 3 shows the variation of headway on the average over the whole measurement period. The first three headways are clearly large due to the start-up lost time. The standard deviation decreases with the passage of vehicles. Table 1 and 2 present the variation of the occurrence of each position pattern and mean/standard deviation over time, respectively.

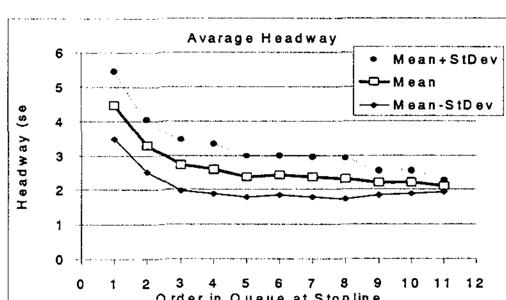

Fig. 3 Mean and Standard Deviation of Headways Measured at Cua Nam Intersection in Hanoi

First of all, to exclude the influence of start-up lost time, the headway data before the fourth vehicle were excluded from the data set. The upper row in Table 3 gives the mean and standard deviation of measured headways except for the first three vehicles. However, the deviation is still large due to the existence of short and long headway data. To erase the effect of such data, the headway smaller than mean minus S.D and larger than mean plus S.D. were deleted from the data set. In addition, to keep the number of data to be balanced among five patterns, the number of P-1 data was decreased by sampling one every four. The revised mean and S.D are listed below as "Filtered" data in Table 3.

Table 1. Number of Samples Vs. Order in Queue for Each Motorcycle Position Pattern (Hanoi)

Pattern	Order in Queue at Stop Line											Total
	1	2	3	4	5	6	7	8	9	10	11	
1	3	23	28	26	49	40	43	42	38	33	11	336
2	18	21	16	15	8	11	12	7	8	6	0	122
3	14	17	9	13	5	7	7	4	4	2	0	82
4	15	4	9	5	7	9	7	10	9	5	0	80
5	30	15	17	21	10	13	11	8	3	2	0	130
Total	80	80	79	80	79	80	80	71	62	48	11	750

Table 2. Mean and Standard Deviation of Headway for Each Motorcycle Position Pattern (Hanoi)

	Order in Queue at Stop Line										
	1	2	3	4	5	6	7	8	9	10	11
Mean(s)	4.47	3.29	2.72	2.60	2.37	2.42	2.37	2.32	2.20	2.21	2.11
S.D.(s)	0.99	0.77	0.74	0.73	0.59	0.58	0.58	0.60	0.36	0.34	0.17

Table 3. Mean and Standard Deviation Before and After Filtering (Hanoi)

Pattern		P-1	P-2	P-3	P-4	P-5
Measured	Mean	2.06	2.30	2.40	2.71	3.40
	S. D.	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
	S. D.	0.11	0.25	0.23	0.26	0.29
	# of Samples	51	49	33	35	46

Sathorn Intersection in Bangkok

In total, 120 sets of data are measured on two middle lanes over 60 cycles. There was no definite difference in traffic characteristics between both lanes because they were occupied almost by through-traffic. Fig. 4 depicts the variation of headway averaged over all cycles and lanes. The standard deviation is somewhat larger after eleventh vehicle passed because new vehicles joined the end of queue after the signal turned green. First, the headway data of such vehicles were omitted. The number of headways reduced to 1305, as listed in Table 4. Table 5 presents the variation of mean and standard deviation until the eleventh vehicle. The deviation is fairly large and it gets up to around 1 second. The subsequent procedure is quite same as the previous one for Hanoi: For P-1, P-2, and P-5, the headway was sampled every six, two, and two, respectively. The S.D. fairly reduced for all patterns as shown in Table 6.

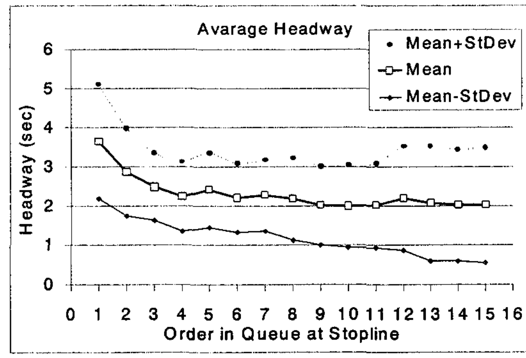

Fig. 4 Mean and Standard Deviation of Headways Measured at Sathorn Intersection in Bangkok

Table 4. Number of Samples Vs. Order in Queue for Each Motorcycle Position Pattern (Bangkok)

Pattern	Order in Queue at Stop Line											
	1	2	3	4	5	6	7	8	9	10	11	
1	8	37	51	44	50	55	57	68	75	73	73	591
2	8	22	10	30	23	15	16	21	13	12	14	184
3	7	11	14	13	13	15	18	8	9	7	11	126
4	6	25	25	14	9	11	8	3	5	9	6	121
5	91	24	19	17	25	23	20	20	18	16	10	283
Total	120	119	119	118	120	119	119	120	120	117	114	1305

Table 5. Mean and Standard Deviation of Headway for Each Motorcycle Position Pattern (Bangkok)

	Order in Queue at Stop Line										
	1	2	3	4	5	6	7	8	9	10	11
Mean	3.64	2.87	2.49	2.24	2.40	2.21	2.26	2.17	2.01	2.00	2.01
S.D.	1.46	1.13	0.86	0.88	0.95	0.89	0.91	1.04	1.01	1.05	1.08

Table 6. Mean and Standard Deviation before and after Filtering (Bangkok).

Pattern		X1	X3	X2	X4	X5
Observed	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

3. EFFECTS OF MOTORCYCLE

In order to justify the validity of estimated mean values, the difference of mean was investigated through T-Test as well as the equity of variance through F-Test. Table 7 summarizes the results of both tests for Hanoi data hatched in Table 3. Only the equality of variance between P-1 and P-2 was not justified. The subsequent T-test identified the significant difference in mean among position patterns except for the one between P-2 and P-3. Since the p-value for the case of x3-x2 is fairly small, 10.7%, the headway data for all patterns were treated as independent each other in regression analysis. Table 8 presents the summary of the analysis for Hanoi data: The multiple correlation coefficient R^2 is large enough and the p-values are also small enough to justify the significance of the regression coefficients. The adjustment factors indicate that the saturation flow rate decrease by 10%, 12%, 23%, and 38% for each pattern in reference to P-1.

Table 7. Assessment of Mean and Variance for Each Position Pattern (Hanoi, Significance Level:5%)

	Variance Ratio	X2/X1	X2/X3	X4/X3	X5/X4
F-Test (Variance is Equal)	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
	Difference	X2-X1	X3-X2	X4-X3	X5-X4
t-Test (Mean is Equal)	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

Table 8. Adjustment Factor for Each Position Pattern (Hanoi, Significance Level:5%)

	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
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	1725.8	1.0	0.898	0.880	0.773	0.615
Multiple Regression Coefficient R^2						0.817
R						0.904
Critical Value (Significance Level 5%, Both-Side)						1.97

The assessment and regression analysis for the Bangkok data were not so good as the Hanoi data: The results of F-test proves the equality of variance among all patterns, as shown in Table 9. In T-test, the difference of mean was not justified for both x3-x1 and x4-x2. However, the p-values were fairly small, less than 10% for both cases. Again, all patterns were treated as independent. The multiple correlation coefficient was just less than 0.5, as shown in Table 10. It should be noted that the adjustment factors for P-4 and P-5 were almost same as those for Hanoi data. Although the results are not presented here, another regression analysis by mixing the P-1 data with P-3 data and P-2 data with P-4 data improved the correlation coefficient to 0.54. The adjustment factors for P-2/P-4 and P-5 were 0.82 and 0.64, respectively. In this way, there was little difference in the adjustment factors regardless measurement data.

Table 9. Assessment of Mean and Variance for Each Position Pattern (Bangkok)

	Variance Ratio	X1/X3	X2/X3	X4/X3	X5/X4
F-Test (Variance is Equal)	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
	Difference	X3-X1	X2-X3	X4-X2	X5-X4
t-Test (Mean is Equal)	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

Table 10. Adjustment Factor for Each Position Pattern (Bangkok)

	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
Test Statistic	326.18	-	-5.52	-1.57	-6.82	-13.75
P Value (%)	0.0	-	11.7	0.0	0.0	0.0
Adjustment Factor	2143	1.0	0.826	0.949	0.783	0.624
Multiple Regression Coefficient R^2						0.456
R						0.676
Critical Value (Significance Level 5%, Both-Side)						1.97

CONCLUSIONS

The impact of motorcycles on saturation flow rate was quantified using the traffic data measured in Hanoi and Bangkok. The adjustment factor ranged 0.6 to 0.9 in accordance with the relative position to passenger cars regardless measurement data.

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