Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 1496 - 1508, 2005

THE SPEED, FLOW AND HEADWAY ANALYSES OF MOTORCYCLE TRAFFIC

Chu Cong MINH
Doctoral Student
Department of Civil and Environmental Engineering
Nagaoka University of Technology
Kamitomiokamachi, 1603-1.
Nagaoka, Niigata, 940-2188, Japan
Tel: +81–258–47–6635
Fax: +81–258–47–9650
Email: ccminh@stn.nagaokaut.ac.jp

Kazushi SANO
Associate Professor
Department of Civil and Environmental Engineering
Nagaoka University of Technology
Kamitomiokamachi, 1603-1.
Nagaoka, Niigata, 940-2188, Japan
Tel: +81–258–47–9616
Fax: +81–258–47–9650
Email: sano@nagaokaut.ac.jp

Shoji MATSUMOTO
Professor
Department of Civil and Environmental Engineering
Nagaoka University of Technology
Kamitomiokamachi, 1603-1.
Nagaoka, Niigata, 940-2188, Japan
Tel: +81–258–47–9615
Fax: +81–258–47–9650
Email: shoji@nagaokaut.ac.jp

Abstract: Although much knowledge about traffic characteristics was acknowledged, very little attention has been paid regarding motorcycle. The purpose of this study addresses a comprehensive analysis of motorcycle behavior and operation through videotaping of some roads that have significant motorcycle proportion. Four locations in Hanoi, Vietnam have been found to meet criteria for data collection, including exclusive motorcycle lanes, mixed traffic and undivided roadways. Speed – flow relationships were developed for all locations, in which the adjustment factor for the present of vehicles other than motorcycle was based on motorcycle equivalent unit. Statistical analyses of the empirical data were utilized to demonstrate the characteristics of motorcycle speed, time headway regarding to traffic flow. The present paper provides a basic understanding of characteristics of motorcycle traffic. The finding obtains from this research may be used to develop new procedures for Highway Capacity Manual (HCM), which adapt developing countries as well as provide the data needed to develop a motorcycle simulation model.

Key words: Motorcycle traffic, Mixed traffic, Speed – flow relationship, Headway, Traffic operation.

1. INTRODUCTION AND LITERATURE REVIEW

Transportation involved matters are usual in most urban areas in the world. Many developed countries confront troubles, which relate to four-wheel vehicles. Besides, in the other parts of the world, developing countries are facing with small size motorized vehicles, such as motorcycles, mopeds, etc. Several cities in developing countries have been suffering from a high degree of the congestion problem, which is mostly caused by two-wheel vehicles. In Hanoi, Vietnam, for example, where two-wheelers are more than 80% of the total transportation means, motorcycle reduces the speed of other modes and makes the traffic more congested due to its shapes and 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.

Very little empirical research has been conducted regarding the traffic operation of motorcycles up to now. The result may come from the fact that motorcycle proportion is insignificant in traffic flow in developed countries. Some analyses have been undertaken by Nakatsuji *et al* (2001) in order to scrutinize the effect of motorcycles on capacity at signalized intersections in Hanoi and Bangkok. These 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. Similarity, Hai (1999) also evaluated effects of motorcycle on saturation flow rate in Hanoi. He estimated motorcycle's influence to car start-up lost time by separating two cases: position and number of motorcycles in front of first car in queue. However, that correlation in both cases was very low (R^2 = 0.14 and 0.15). Holroyd (1963) estimated the effect of motorcycles on saturation flow at traffic signals and expressed the results in terms of passenger car unit (PCU). This was done at nine sites and also separately the first one-tenth minute of the green period and the remains of the saturated period. The average PCU value of motorcycle for the remains of the saturated period was calculated to be 0.33. Powell (2000) developed the model to describe motorcycle behavior at signalized intersections. An amended first order macroscopic model was used to represent motorcycle behavior and multiple regression analysis explained inaccuracies resulting from this technique. The model predicted the number of motorbike, which set off from the front of the queue before the end of the first 6 s of effective green time. Some research works concentrated on heterogeneous traffic to analyze the capacity and other characteristics in mixed traffic, motorcycle and other modes. Chandra *et al* (2003) identified the effect of lane width on the capacity of a two-lane road under heterogeneous traffic conditions. The speed is considered as a prime variable to determine the effect of individual vehicle on the traffic stream in term of PCUs. Capacities of different two-lane sections with varying lane width were determined from the relationship between speed and volume. Other studies of motorcycle traffic, such as the research has done by Wigan (2000), have been conducted in developed countries. However, for the most parts, the results of these studies have not been appropriate to apply in developing countries since the role of motorcycle, as a means of urban transportation characteristics, is not similar. Consequently, researches concentrated on motorcycle traffic operation have played a key role in order to better traffic condition in developing countries.

2. OBJECTIVES

To obtain a better understanding of motorcycle traffic operation, the present study aims (i) to draw the techniques applied for collecting and analyzing motorcycle speed, headway, and speed – flow relationships, (ii) to draw results from data analysis, and (iii) to explain and discuss for better understanding this mode. Moreover, effects of different traffic facilities on motorcycle traffic operation were also investigated. The question addressed is how motorcycle behavior differs between homogeneous and heterogeneous traffic flows, between divided and undivided roadways?

3. DATA COLLECTION

3.1. Data necessities

"Motorcycle" used in this research stand for motor vehicle with two wheels, involving normal motorcycles, mopeds, and scooters. The engine capacity of motorcycle ranges from 50cc to 150cc. In order to guarantee all required information would be collected correctly, it is necessary to set data necessities. The traffic data include homogeneity (motorcycle traffic only) and heterogeneity, both undivided two-lane and divided four-lane streets. The analytical data necessary for this study are described as below:

- Speed – The speed of motorcycle traffic flow mutually influences volume, density, headway and so on. Data collection for speed study at different traffic situation is necessary to better understanding traffic operation of motorcycle.
- Volume – Traffic volume data and capacity of motorcycle represent the differences between motorcycle and other transportation modes. It also shows the relationships between lane width and its capacity.
- Headway – Motorcycle headway delineates the behavior of individual traffic entities in the traffic stream. The value of headway reflects the capability of motorcycle, aggressiveness of motorcyclist and the time of wait.
- Road characteristics – The road characteristics including road geometry, number of lane, lane-width, grade… are important factors affecting speed, headway and traffic capacity. The data are used to explain the relationship between the speed, the headway and lane width, roadway facilities.

After clarifying data requirements, onsite data were collected by using video recording technique. One digital video recorder was set up at high buildings nearby the study sites, captured all traffic movements at specified time periods. This technique required two corresponding persons in the field in order to observe proper positions for video recording and install the video. The system consisted of a portable video camera, tripod, videotapes, a measuring roller, and manual counters. Then, the filming traffic operations captured onsite were converted into media video files, replayed in a computer and interpreted until entire necessary data were accomplished on the traffic laboratory.

Besides video recording technique, onsite surveys were essential for collecting roadway geometry and characteristics. The lane width were measured at various candidate road sections, varied from 3.25 m to 5 m. Grades, wide-ranging from 0% to 2% at study sites. It is noted that all data were collected under clear weather and dry pavements.

3.2. Site Selection

Due to high proportion of motorcycle in traffic flow, Hanoi is a good example to deal with this research. Four locations have been found and applied for data collection. The locations locate in Hanoi downtown, namely 1, 2, 3, 4. The lane widths of motorcycle traffic are 3.75m, 3.70m, 5.54m and 3.27m, respectively. First two sections are exclusive motorcycle flow and the remains are mixed traffic with non-motorized and four-wheel vehicles. In spite of exclusive motorcycle traffic lane, some car and bus join illegally when their lane is congested. Locations 1 and 2 are four-lane divided roads with raised median. Study sites, namely 3 and 4, are two-lane undivided streets. The selective locations had to meet the following criteria:

- Sufficient motorcycle volumes are required;
- Motorcycle trip purposes significantly influence characteristics such as speed, headway, ...;
- Not near a intersection to avoid unusual behaviors of motorcyclists; and
- The locations must not be near bus stop, gasoline station, etc. to eliminate modification maneuvers from road users.

In the study, the traffic composition was classified into five groups, named type 1 to type 5 for Cycle, Motorcycle, Car, Minibus, and Bus respectively. The detail for each type of vehicle is indicated on Table 1. The percentage of each type in traffic flow at different locations is shown on Figure 1. The data in first two locations were deliberated as motorcycle homogeneous traffic and the remains were considered as heterogeneous traffic.

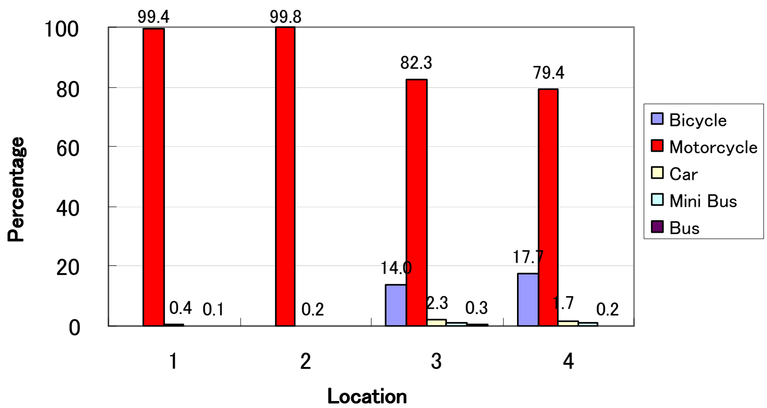

Figure 1. Traffic Composition at different locations

4. METHODOLOGY

4.1. Speed-Volume Relationship

Speed, density and volume play the key roles to evaluate how effective a road can handle a traffic stream. Among three, speed – volume relationship is usually applied as an efficient tool for calculating the traffic capacity of a carriageway. However, it is difficult to estimate the traffic volume under heterogeneous traffic flow unless different vehicle types are converted into a common unit. Due to significant proportion of motorcycle traffic, the accepted one is that of motorcycle. This motorcycle unit (MCU) for each type of vehicle in this study is developed with a consideration of dynamic characteristics of moving vehicles. That factor expresses the correlation about speed and occupied space between the mode taken into consideration and a motorcycle. Chandra *et al* (2003) developed the formula to convert other transportation modes into passenger car. The modified formula which was used for MCU conversion is described as below:

$$MCU_i = \frac{V_{mc} / V_i}{A_{mc} / A_i} \qquad (1)$$

Where, MCU_i : Motorcycle Equivalent Unit of type i vehicle;
V_{mc}, V_i : Mean speed of motorcycles and type i vehicle, respectively (Km/h);

A_{mc}, A_i : The respective projected rectangular area (length × width) of motorcycles and type i vehicle on the road, respectively (m^2).

Regarding to maneuver characteristics, motorcycles do not move in lane. In traffic with lane discipline, the occupancy is controlled by length of vehicle, which has been mostly suggested in literature for estimation of PCU (Chandra *et al* 2003). However, in the condition where vehicles do not follow lanes strictly, the occupancy is better reflected by area. Therefore, total physical size of the vehicle and not length alone has been considered in Equation 1. The tabulation of vehicle categories, along with average dimensions, is illustrated on Table 1.

Table 1. Vehicle categories and their sizes

No.	Type	Vehicles included	Average Dimensions (m)	Rectangular Area (m^2)
1	Cycle	Bicycles	1.90 × 0.45	0.86
2	Motorcycle	Scooter, Motorbike Mopeds	1.87 × 0.64	1.2
3	Car	Car, Jeep, Van	3.72 × 1.44	5.36
4	Minibus	Mini bus, mini truck	6.10 × 2.10	12.81
5	Bus	Bus	10.10 × 2.43	24.54

Adopted from Chandra *et al* (2003)

In order to estimate mean speeds of different types of vehicles (V_i), the spot speed technique was applied. The speeds of traffic entities were determined by the time required for traveling a known distance (trap length). In this study, the trap length was measured as the distance between two consecutive electric poles. The time required to travel given distance was captured by recording the entry and exit time of that length. The speed then obtained from the division between trap length and the travel time for each vehicle. Consequently, those speed values were converted into units of kilometer per hour. After computing respective projected rectangular areas and mean speeds of all vehicles, the MCU values are archived. Those values for different type of vehicles as calculated at different sections are given on Table 2. The wide variation in MCU values is attributed to change in traffic conditions at different sites 3 and 4. Sites 1 and 2 were not taken into consideration due to less proportion of other types of vehicles.

Table 2. MCU factors as estimated at different sections

Section	MCU for vehicle type				
	Cycle	Motorcycle	Car	Minibus	Bus
3	1.65	1.00	3.86	10.58	20.27
4	1.67	1.00	3.60	9.50	19.64

The values of MCU, computed from Equation 1, for each type at section 3 and 4 are significantly affected by the ratio between mean speed of motorcycle and mean speed of each type. The mean speeds of types of motorcycle, car, minibus, and bus at section 3 are higher than those at section 4, respectively. The reason is that although the lane width of section 3 is higher, its' traffic volume is nearly double than that of section 4. Therefore, the MCUs of types of motorcycle, car, minibus, and bus at section 3 are higher than those of motorcycle, car, minibus, and bus at section 4, respectively. From Table 2, the value of MCU of cycle type at section 3 is less than that of cycle type at section 4. It may be explained that due to low speed, usually cyclists prefer to ride near footpath side in addition the percentage of cycle in traffic composition at section 3 is lower than that at section 4. Furthermore, because cycle's speeds are slower and their projected rectangular areas are higher, bicycles occupy more dynamic spaces than motorcycles at the same unit of time. Consequently, the result indicates that the MCU values of cycle type at all section 3 and 4 are higher than 1.00.

Due to large variation in speed of different types of vehicles, the weighted mean speed is employed as stream speed and calculated by using the given equation:

$$V_m = \frac{\sum_{i=1}^{k} n_i V_i}{\sum_{i=1}^{k} n_i} \quad (2)$$

Where, k : Total number of vehicle types present in stream;
V_m : Mean stream speed (Km/h);
V_i : Mean speed for type i vehicle (Km/h);
n_i : Number of vehicles of type i.

The average stream speed calculated by above equation was plotted against traffic volume. The lines showing speed-volume relationships at locations 1+2, 3 and 4 are given in Figure 2.

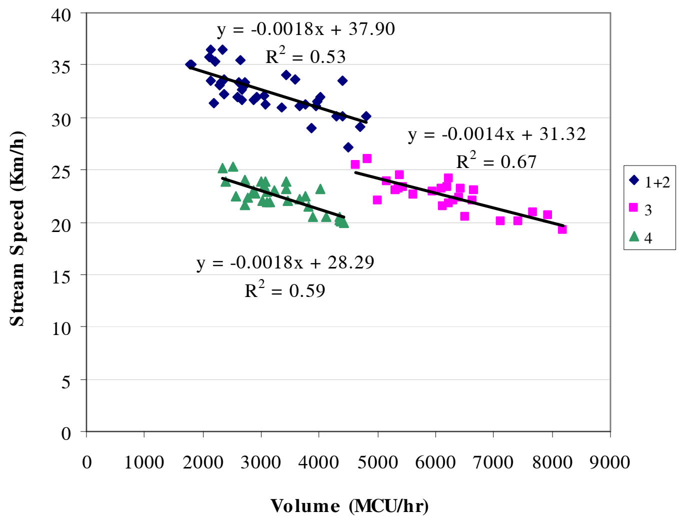

Figure 2. Speed-volume relationship at different locations

With different lane widths and dissimilar characteristics, the fluctuation of traffic volumes at each location is different. All data were collected at non-congested time and no traffic flow data was collected at or over the capacity. From Figure 2, at the same location, the speeds vary approximately 5 Km/h at different flows. Comparing location 4 with 1+2, even in case of similar traffic flows and wider lane-width, the average stream speed is lower. It can be explained that due to undivided roadway, drivers seem to reduce their speeds in order to reduce the risk of accidents from opposed traffic. Comparing site 4 with 3, due to the wider lane-width, 5.54 m of site 3 and 3.27 m of site 4, in case of similar traffic flow, the mean speed is higher. Therefore, for non-lane discipline traffic like motorcycle traffic, the lane width, divided or undivided roadway, traffic composition characteristic such as homogenous or heterogeneous traffic are crucial factors affecting to travel speed and traffic flow.

4.2. Distribution of Speed

Speeds of motorcycle traffic were measured from several motorcycle entities. The locations with sufficient distances from the intersections were selected to minimize the effect of extraordinary behaviors. The method to conduct speed study is spot speed technique. Table 3 indicates a summary of speed data, including mean, maximum, minimum speeds observed regarding various number of sampling at 4 corresponding locations. The average speed for all locations is calculated to be 27.3 Km/h, the speed ranges from minimum of 13.6 Km/h to maximum of 50.0 Km/h and the standard deviation is 5.2 Km/h. From this result, it can be concluded that although the speed limit of motorcycle traveling in Hanoi's urban area is 40 Km/h, sometimes it is ignored by motorcyclists.

The speed data of motorcycle trend to be similar for two locations 1 and 2 and the answer is the same for site 3 and 4. The mean, maximum and minimum speed of locations 1 and 2 are higher than those of 3 and 4. Note that the first two locations are exclusive traffic lane and remains are undivided roads, those differences may contribute to variations in the observed speeds. Under mixed traffic, as locations 3 and 4, motorcyclists have more constrains from other traffic modes. The lower speed but larger size modes, such as three-wheelers, buses and even passenger cars sometimes, are significant influence to motorcycle speed. Furthermore, under undivided roadway condition, motorcyclists tend to reduce their speed in order to reduce risks of accident by greater cautiousness on the traffic from opposed direction. It is worth to note that in spite of the same mixed traffic, a narrower lane width may achieve higher average speed than a wider one does, like location 3 and 4. It may be explained by following reasons: (i) although the lane width of third section is 2.3 (m) wider than that of forth section, its' traffic flow is nearly double; and (ii) the proportion of slow-moving vehicles in the traffic composition in section 3 is higher.

Table 3. Motorcycle Speed Data

Location	Motorcycle Volume	Number of Sampling	Observed Speed				
			Mean (Km/h)	Max (Km/h)	Min (Km/h)	St. dev. (Km/h)	St. dev. %
1	3,240	582	32.3	55.2	14.3	5.7	17
2	2,621	270	32.7	56.3	20.9	5.2	15
3	5,074	322	21.3	44.8	9.5	5.1	23
4	2,706	579	22.8	43.6	9.7	4.6	20

To compare characteristics of motorcycle mean speed among selective locations, the two-sample t-test is often the most appropriate test. However, it is important to ensure that the correct version of the test is being used (equal variances or non-equal variance). Therefore, in this research, in order to check whether or not the variances are equal, F-test was applied. Then, if the variances are not significantly different, the t-test with equal variances assumed can be used. Otherwise, the t-test with equal variances not assumed need to be used.

Firstly, the F hypothesis tests with 95% confidence level were utilized to examine whether speed variance of two locations were equal or not. Each pair would have equal variance if $F_{statistical} < F_{critical}$.

Table 4. Result of F-test for Varian of speeds at different locations

Location	1	2	3	4	$F_{statistical}$ values
1		1.21	1.27	1.55	
2	1.19		1.05	1.28	
3	1.18	1.21		0.82	
4	1.15	1.18	0.85		
t	$F_{critical}$ values				

Then, the t hypothesis tests with 95% confidence level were separately examined both cases, equal and unequal speed variance. The hypothesis test was mean speed difference between two locations equals to zero. Each pair would have equal mean speed if $t_{statistical} < t_{critical}$. The result revealed that location 1 and 2 have the same mean speed and the location remains have different mean speed. The statistic summary of t tests for all locations was described on Table 5.

Table 5. t-Test for mean speeds with 95% confidence level

Location	1	2	3	4	$t_{statistical}$ values
1		-0.83	29.83	31.03	
2	1.96		26.77	26.45	
3	1.96	1.96		4.67	
4	1.96	1.97	1.96		
t	$t_{critical}$ values				

The data plotted in Figure 3 describe the observed motorcycle speed and distribution frequency. The figure also displays the characteristic of normal distribution curve fitting for the speed frequencies. It was obtained from 582, 270, 322 and 579 speed observations of motorcycle entities at location 1, 2, 3 and 4, respectively. Because of (i) similar road characteristic, exclusive and divided carriageway; (ii) nearly same lane width, 3.75m and 3.70m; (iii) insignificant difference in traffic flow, 3262 Veh/h and 2617 Veh/h; (iv) homogeneous traffic, motorcycle only; (v) and especially mean, maximum, minimum and standard deviation of empirical speed data, the speed distribution at location 1 and 2 seem to be similar as shown on Figure 3.

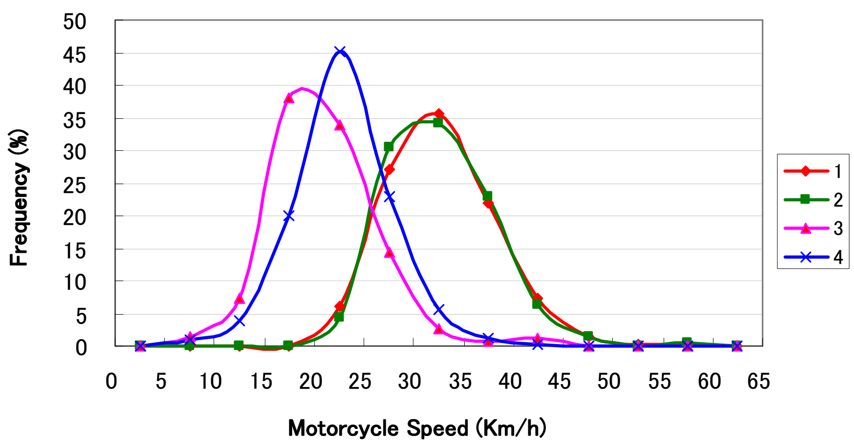

Figure 3. Frequency Distribution of Observed Motorcycle Speed

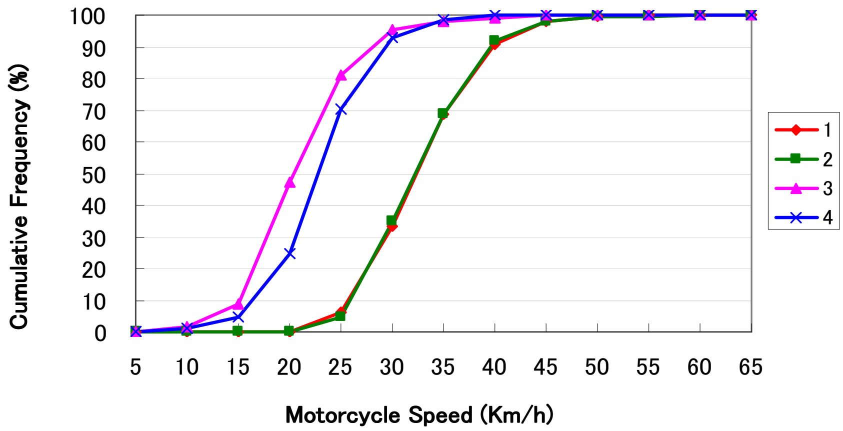

Figure 4. Cumulative Distribution of Observed Motorcycle Speed

The mean speed tends to be reduced in case of those locations 3 and 4. Comparing to site 1 and 2, all mean speed, maximum and minimum speed value reduce about 10 km/h. From site observations, under heterogeneous traffic condition like 3 and 4, motorcyclists trend to decrease their travel speed when maneuvering in order to overtake slower speed vehicles, such as bicycle, bus and three-wheeler. Moreover, due to psychological driving manner of motorcyclists, the effective space occupancy of motorcycle in case of adjacent large size vehicle is higher than in case of motorcycle nearby. In other words, the road space used for one motorcycle under mixed traffic is higher than under homogeneous traffic like location 1 and 2. Geometric characteristics of roadway also play the key factor in reducing motorcycle speed. Motorcyclists are more attentive to possible danger from opposed traffic in undivided carriageway. Road users must observe other vehicles not only at same direction but also at opposite direction. Therefore, they tend to driver slowly to avoid traffic accident from others.
Determined on the basis of the general shape of the data plotted in Figure 3, the theoretical normal distribution has been assumed for all distribution of observed speed at group location 1, 2, 3 and 4. By using SPSS software, according to Kolmogorov –Smirnov (K – S) test for distribution, the maximum discrepancy of locations 1, 2, 3 and 4 are $D_n = 0.305$, 0.313, 0.336 and 0.330 respectively. The critical value D_n^{α} at the 5% significance level is 0.368. Since the maximum discrepancies are less than the critical value, all frequency distribution of observed motorcycle speed at locations 1, 2, 3 and 4 correspond to normal function at the 5% significance level.

4.3. Distribution of Headway

For motorcycle traffic, an adapted definition of headway is expected since a stream of motorcycles cannot be assigned well-defined lanes as that of four-wheel vehicles can. The motorcyclists would not experience constrained in their maneuverability if motorcycles in front a little far from them laterally. In motorcycle homogeneous or mixed traffic, even in a single lane, two-wheelers move in parallel, creating a significant number of zero headways (Arasan *et al,* 2003).

According to Botma *et al* (1991), in order to analyze bicycle headway, the cross section at the measuring site was divided into sub-lanes of 15.6 cm width. The bicycle closest ahead that had touched any of five sub-lanes around the sub-lane of the bicycle in question was defined as the "bicycle in front" and the headway with respect to this bicycle was used. The similar definition was adopted for motorcycle headway in this study, sub-lane width was chosen from motorcycle effective space laterally. In order to obtain that value, the lateral distance between two motorcycles in paired riding was used. The later analysis revealed that one equals to 1.89 and 1.10 m for exclusive and undivided roadway, respectively. Consequently, from the technique above, the cross section at survey sites was divided into sub-lane of 1.89 m for exclusive motorcycle lane and 1.10 m for undivided roadway. The time between successive motorcycles running on the same sub-lane, as their back wheel pass a given point was defined as motorcycle headway.

More than 240 motorcycle entities crossing at each observed site were recorded to determine the headway characteristics of the motorcyclist. A summary of empirical headway data regarding to mean, maximum, minimum headways observed at various number of sampling at four corresponding locations is indicated on Table 6. The average headway for all locations is calculated to be 1.16 s, the headway ranges from minimum of 0.34 s to maximum of 4.31 s and the standard deviation is 0.65 s.

Table 6. Motorcycle Headway Data

Location	Motorcycle Volume	Number of Sampling	Observed Speed				
			Mean (s)	Max (s)	Min (s)	St. dev.	
						(s)	%
1	3,240	308	1.09	3.11	0.29	0.5	45
2	2,621	240	1.11	3.51	0.31	0.6	54
3	5,074	311	1.17	5.36	0.37	0.7	59
4	2,706	247	1.26	5.27	0.37	0.8	63

Arasan *et al,* 2003 proved that it was impossible, from the statistical analysis point of view, to adopt uniform headway class intervals for all the sets, as there was a wide variation in the range of observations at various flow levels. From this reason, in the paper, observed data set was classified into headway classes. The guideline, often used for grouping the data, is Sturg's rule, which stipulates that the width of class intervals should be equal to Range/($1+3.322\log_{10}n$), where, n is the number of observations, and Range, the difference between maximum and minimum values of observed headway data (Arasan *et al,* 2003). Consequently, the class intervals of 0.5s were considered in this research.

The frequency of motorcycle headway of given class interval at each site were plotted together in Figure 5. The figure reveals that at all locations, approximately, 50% of motorcyclists were accepted class headway of 0.5 s to 1 s. That value is only a haft of passenger car headway according to many previous researches.

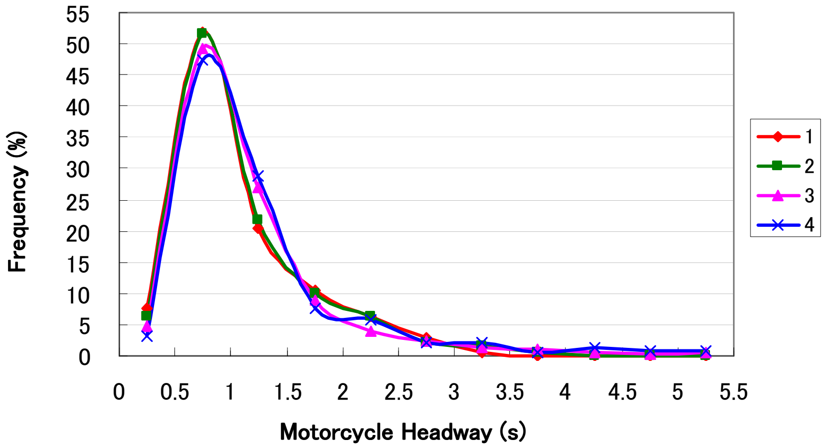

Figure 5. Frequency Distribution of Observed Motorcycle Headway

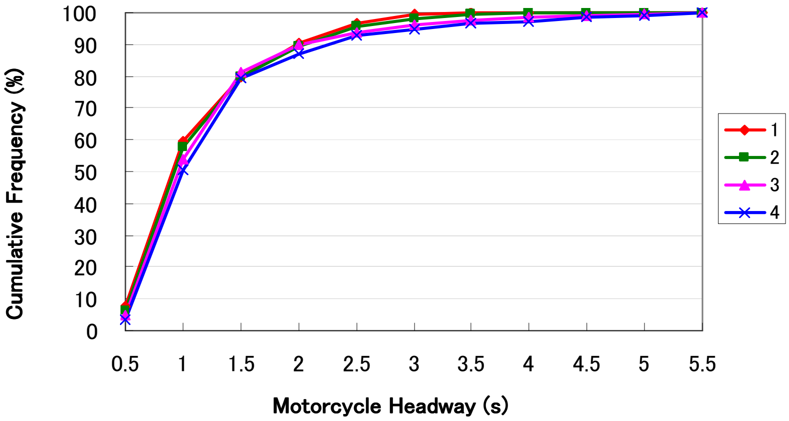

Figure 6. Cumulative Distribution of Observed Motorcycle Headway

As same as speed distribution, due to similar traffic characteristics, the headway distributions at location 1 and 2 are insignificantly different. Headway distribution of heterogeneous traffic tends to be higher than homogeneous traffic. Many motorcyclists accepted by much shorter headway to maneuver faster than normal although that behavior might cause risks of accident. The similar statistical analysis of speed data then is employed for headway data. F-test and t-test results are shown on Table 7 and 8, respectively. The results show that all locations have equal mean headway.

Table 7. Result of F-test for Varian of headway at different locations

<table>
<tr><td>Location</td><td>1</td><td>2</td><td>3</td><td>4</td><td rowspan="6">$F_{statistical}$ values</td></tr>
<tr><td>1</td><td></td><td>0.83</td><td>0.56</td><td>0.47</td></tr>
<tr><td>2</td><td>0.82</td><td></td><td>0.68</td><td>0.57</td></tr>
<tr><td>3</td><td>0.83</td><td>0.82</td><td></td><td>0.84</td></tr>
<tr><td>4</td><td>0.82</td><td>0.81</td><td>0.82</td><td></td></tr>
<tr><td>t</td><td colspan="4">$F_{critical}$ values</td></tr>
</table>

Table 8. t-Test for mean headways with 95% confidence level

Location	1	2	3	4	$t_{statistical}$ values
1		-0.1	-0.41	-2.67	
2	1.96		-1.18	-2.31	
3	1.96	1.96		-1.21	
4	1.96	1.96	1.96		
t	$t_{critical}$ values				

5. CONCLUSIONS

The study was carried out in Hanoi about traffic operation of motorcycle at some road segments by using the video recording technique. The specific conclusions drawn from this research included the following:

- The speed – volume relationships were constructed for all candidate sites by converting all transportation modes into a common unit, motorcycle. The motorcycle unit (MCU) for each type of vehicle was developed with a consideration of dynamic characteristics of moving vehicles;
- Even wider lane width, the mean stream speed of roadway which is undivided and mixed traffic is lower than that of roadway which is divided and homogenous traffic as the same traffic flow;
- The average speed of motorcycle on: (i) 3.7 m wide of homogeneous motorcycle traffic lane is 32.5 Km/h, with a standard deviation of 5.5 Km/h; (ii) undivided and mixed traffic roadway 5.54 m wide is 21.3 Km/h, with a standard deviation of 5.1 Km/h; and (iii) 3.27 m wide of undivided and mixed traffic roadway is 22.8 Km/h, with a standard deviation of 4.6 Km/h;
- The empirical speed study on different traffic compositions and road characteristics exposed different speed levels. Exclusive motorcycle lanes were expressed higher average speed than undivided and heterogeneous traffic roadway did about 10 Km/h;
- The frequency distribution of speed data normally distributed for all observed locations;
- The average headway for all locations was calculated to be 1.16 s. The headway ranges from 0.34 s and 4.31 s and the standard deviation is 0.65 s;
- The hypothesis testing results indicated that all locations had the same mean headway although they had different traffic operation and characteristics.

No any adjustment factor for motorcycle has been made for 2000 Highway Capacity Manual (HCM). The procedures cannot be applied successfully in most of developing countries because of large differences in traffic composition, roadside facilities and driver behavior. The present paper provides a basic understanding of the traffic operation of motorcycle, which is necessary to conduct analytical models that serve the motorcycle traffic. The findings provide useful information that can be used to develop speed – flow relationship, to improve geometric designs of motorcycle facilities as well as to provide the data necessary to develop a motorcycle simulation model.

REFERENCES

a) Journal papers

Nakatsuji, T., Hai, N.G., Taweesilp, S., and Tanaboriboon, T. (2001) Effect of Motorcycle on Capacity of Signalized intersections, **Infrastructure Planning Review**, Sep, 935 – 942.

Holroyd, E. M. (1963) Effect of Motorcycles and Pedal Cycles on Saturation Flow at Traffic Signals. **Roads and Road Construction**, Oct., 315 – 316.

Powell, M. (2000) A model to represent motorcycle behaviour at signalized intersections incorporating an amended first order macroscopic approach, **Transportation Research Part A, No. 34,** 497 - 514.

Chandra, S., and Kumar, U. (2003) Effect of Lane Width on Capacity under Mixed Traffic Condition in India, **Journal of Transportation Engineering**, Mar. Apr., 155 – 160.

Arasan, V. T., and Koshy, R. Z. Headway Distribution of Heterogeneous Traffic on Urban Arterials (2003), **Journal of The Institution of Engineers**, **Vol. 84**, 210 – 215.

Botma, H., and Papendrecht, H. (1991) Traffic Operation of Bicycle Traffic, **Transportation Research Record 1320**, TRB, National Research Council, Washington, D.C., 65 – 72.

b) Other documents

Hai, N. G. (1999) Analysis of motorcycle effects on saturation flow rate in Hanoi, Vietnam. AIT Thesis, No. TE-98-5, Asian Institute of Technology, Thailand.

Wigan, M. R. (2000) Motorcycles as Transport: Vol. 1 – Powered Two Wheelers in Victoria. VicRoads, Melbourne, Australia.

Transportation Research Board. Highway Capacity Manual (CD-ROM), Version 1.0, National Research Council, Washington, D.C., 2000.