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CHARACTERISTICS OF PASSING AND PAIRED RIDING MANEUVERS OF MOTORCYCLE

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Abstract: The purpose of this study addresses a comprehensive analysis of the characteristics of passing and paired riding maneuver of motorcycle based on video technique. Two locations in Hanoi, Vietnam have been used for data collection, including exclusive motorcycle lane and undivided roadway. The passing characteristics in this research include (i) individual speeds and speed differences between passing and passed motorcycles; (ii) lateral spacing of passing and passed motorcycles; (iii) longitudinal distances from beginning and ending of passing event. For paired riding maneuvers, statistical analyses of speed and lateral spacing were revealed useful information. The threshold for paired riding including speed difference was also determined. The present study provides a comprehensive understanding of the characteristics of passing and paired riding maneuvers. These findings can be used to develop more accurate procedures for the analysis of the quality of service of motorcycle paths as well as to develop a comprehensive simulation model.

Key words: Motorcycle traffic, Passing maneuver, Paired riding maneuver, Motorcycle behavior, Motorcycle characteristics.

1. INTRODUCTION

In the developing countries in South East Asia, where the motorization has developed rapidly in the last few decades, motorcycles are a major transportation mode and effect to traffic flows. That transportation mode widely differs from automobiles in size, motive power and control as well as performance capability. The differences between motorcycles and four-wheelers in static and dynamic characteristics make significant differences in traffic operation. Variations in dimension of vehicles significantly affect overtaking and paired riding maneuvers. Four-wheel vehicles such as trucks, bus as well as passenger cars occupy the full lane while moving, besides, motorcycles can travel side by side within one lane.

So far, very little attention has been paid to passing and paired riding maneuvers of motorcycle traffic. This is probably a result of the fact that motorcycling is not popular in developed countries. Some analyses have been conducted for similar means, two-wheeler, by Botma *et al*, (1991) to scrutinize the characteristics of passing and paired riding of bicycle. That research methodology has been applied for the procedure in the 2000 Highway Capacity Manual (HCM) to determine the level of service of exclusive bicycle paths. The thresholds of passing and paired riding, the shape of passing maneuver were analyzed. The positions, the lateral distance between passed and passing bicycles and the longitudinal spacing of the passing maneuver were investigated from the data collected at some locations of the bicycle paths in Netherlands. Another research has been undertaken by Khan *et al* (2001) in order to identify the behavior and maneuver of cyclists. On the basis of the detailed data collected by using video technique at 3 m wide paths in Colorado, United States, the speed during passing maneuvers, length of passing and the distribution of speeds for both passed and passing bicycles during passing event were analyzed. The lateral spacing during passing, the correlation between the lateral spacing and the speeds of bicycles, the relationship between passing and passed bicycle speeds were also described.

Up to now, no study has conducted on the characteristics of passing and riding in pair on exclusive and undivided motorcycle lanes. No research has collected micro-level data or motorcycle trajectory data to develop a comprehensive model, which presents motorcyclist behaviors during passing and paired riding situations. Therefore, researches about that matter are necessary to develop an appropriate model for motorcycle traffic in order to improve urban transportation systems, particularly in developing countries.

2. RESEARCH OBJECTIVES

The present study proposes the characteristics of passing and paired riding maneuvers of motorcycle on exclusive motorcycle lane and undivided roadway. The analyses were based on video data collected at two locations in Hanoi, Vietnam. The data were interpreted to identify maneuvers of each motorcycle during passing and pair riding events. Based on traffic operation data, the speed during passing, the lateral and longitudinal distance between passed and passing motorcycle were investigated. In addition, statistics of paired riding were also carried out.

3. DATA COLLECTION AND REDUCTION

The terminology “motorcycle” used in this research refers to fast-moving two-wheelers. In Hanoi, Vietnam, the engine capacity of motorcycle mostly ranges from 50cc to 150cc, including mopeds, scooters and normal motorcycles. The speed limit of motorcycle traveling in Hanoi’s urban area is 40 Km/h. However, its’ speed limit is sometimes ignored. The data collected involved the identification of data needs; measuring device list; data collection methodology; site selection and data reduction.

3.1. Data requirements

The first step in the study regards to the establishment of data necessities. It is essential to determine data requirements to ensure that all selective information would be collected in an efficient and accurate way. The traffic data include both undivided and divided lane streets. The operation data determined the needs for this study include the following:

- Speed – The speed of motorcycle during passing and paired riding event significantly affects to longitudinal and lateral spacing between two motorcycles. It is vital to determine running speeds of motorcycle for accurate analyses of motorcyclist behaviors;
- Position – Position data represent the lateral, longitudinal position of motorcycle and relative distance between passing and passed vehicles during entire passing event or between two motorcycles during paired riding situation;
- Road characteristics – Geometry, number of lane, lane-width, grade… play main agents in affecting passing and riding in pair maneuvers. The data are used to explain the motorcyclist behaviors traveling on exclusive motorcycle lane or undivided carriageway.

3.2. Measuring Devices and Data Collection Methodology

Fundamentally, a manual procedure may be utilized in order to accomplish all required data. However, such procedure facilitates several observers on sites and may have various inaccurate manipulations. Due to impractical aspects of the manual technique, an alternative method by using measuring devices is a feasible solution. This technique requires only two corresponding persons in the field and possibility interpreted until all necessary data were obtained on the laboratory. The system consisted of a portable video camera, video recorder, videotapes, and a measuring roller.

One camera set up at the top of the building nearby the study site was used to record the motorcycle traffic. The time images, which passed each one-tenth second, permit one to observe accurately event times from the recording films. The filming traffic operations converted into media video file then replayed in a computer. The films were reviewed at either slow speed to scan full-required observation of nominative road segments or high speed to skip unnecessary data. Also, the recorder allowed the film stopped at any time and any point to isolate a single traffic scene for detailed observation or analysis. A single person could promptly handle those all measuring devices both on site and on traffic laboratory.

The variation of the motorcycle operation and behavior across the locations can be attributed to both geometric and natural conditions. Since the lane width plays a key factor influencing traffic operation of the motorcycle, that values were measured at candidate road sections. Grades, wide-ranging from 0% to 2%, have much more interference on two-wheeler speeds than on motorcars. It should be noted that entire data set was collected under conditions of clear weather and dry pavements. Last but not least, although no previous research indicates the magnitude and direction of wind effecting motorcycle operations and motorcyclist behavior, in present study, one should consider for the average prevailing magnitude of wind on the selected sites.

3.3. Study Sites

With high proportion and remarkable characteristics of motorcycle, Hanoi is a good representative to conduct this research. Several candidate road sections were on-site observed for evaluation of traffic and environmental conditions. Data collection was selected from the list of the following criteria:

- Advantage locations exist not near the intersection to permit discrete observation of traffic operations and thus to avoid abnormal behavior; and

- The locations must not be near bus stop, petrol station, etc. to keep off modification maneuvers from road users.

It is difficult to find out proper locations satisfying all criteria above. Several locations were investigated in the preliminary research. However, among them, only 2 satisfied the criteria and were applied for data collection. All locations locate in Hanoi downtown, Vietnam. The first section, Cau Giay, is six-lane divided roadway. For each direction, the roadway is divided into non-motorized vehicle lane (2.75m), motorcycle lane (3.75m) and four-wheeler lane (3.75m). The second section, Kham Thien, it is two-lane undivided street, lane width is 5.54m.

One camera set up at the top of the building nearby the study site was used to record the motorcycle traffic. The camera captured a path of the section of more than 35m. Data was collected over 4 hours for each location in the sunny morning on April 20 and April 22, 2004. 80 samples for each passing and paired riding study at each location were using for analysis. The example of different traffic conditions at divided and undivided roadways at location 1 and 2 are represented on Figure 1.

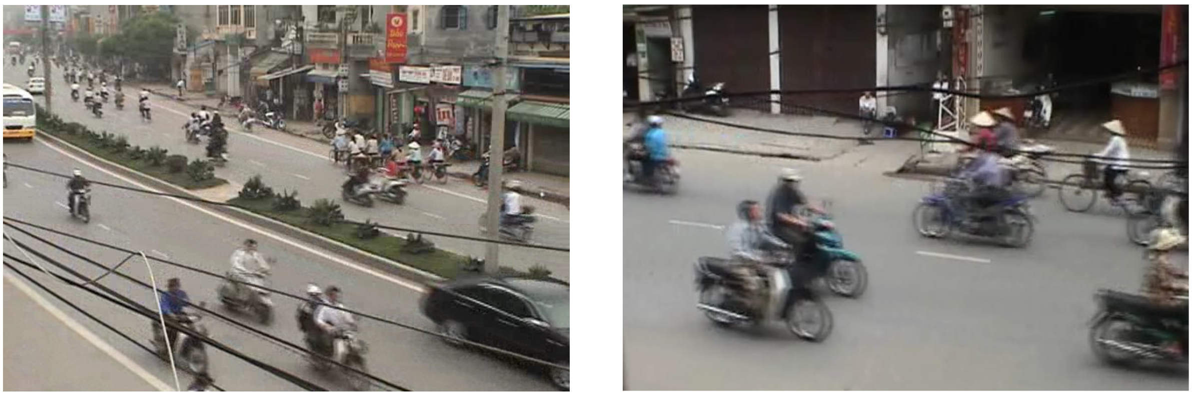

Figure 1. Traffic Composition at Different Locations (divided and undivided roadways)

3.4. Data extraction

The data extraction technique was employed to select information from raw data in the videotapes, converts data into digital video image file format and carries out statistical analysis. All traffic movements from study sites were captured into videotapes at 10 frames for every second. Then, vehicle positions were identified from image video file every one-fifth second interval. These positions regarding time events were calculated according screen coordinates then converted into roadway coordinates by using the transformation method.

4. METHODOLOGY

4.1 Passing Maneuver

Passing occurs when a motorcycle encounters a motorcycle ahead traveling in the same direction at a lower speed and decides to overtake it. Passing is the common behavior of motorcyclists, which is legal in most circumstances. Overtaken by faster motorcycles causes intellectual interference and thus has an outstanding influence on the level of service. Figure 2 illustrates a typical passing maneuver and defines some technical terminology used in this research.

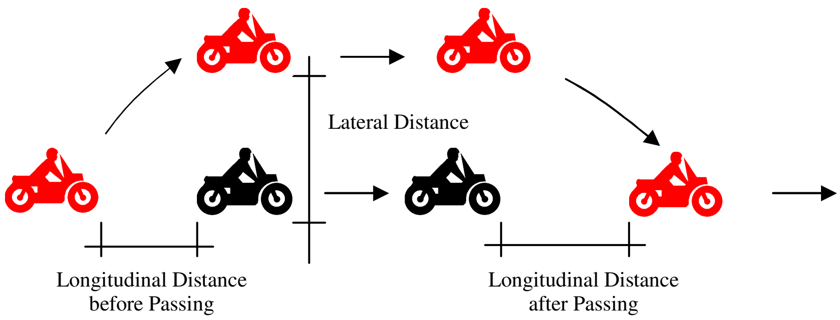

Figure 2. Passing Maneuver

In order to describe passing events of motorcycles, the procedure considered is as follows:

- Individual speeds and speed differences between passing and passed motorcycles at measuring sites;
- Individual lateral positions of passing and passed motorcycles and their lateral distances;
- Individual longitudinal positions of passing and passed motorcycles and their longitudinal distances at observed sites.

In order to obtain the longitudinal and lateral positions of motorcycle entities, according to Khan *et al.* (2001), motorcycle location data on screen coordinates were converted into roadway coordinates by using the rectification technique. Four fixed points on each site, which were captured by video camera, were used as points of origin. Then, positions of each motorcycle at different time in roadway were achieved by solving eight equations based on those known points. In the present study, a passing event was defined if the follower experiences from a motorcycle in front as his obstruction, that motorcyclist would take passing action and then return to his path. Other passing maneuvers, out of the definition above, would not take into consideration.

Speed During Passing Event

From video interpretation, several passing situations were chosen for each exclusive motorcycle lane (location 1) and the undivided two-lane roadway (location 2). Due to no significant error, one assumption, which would be made to simplify the passing maneuver, was to adopt stable speed for both passing and passed vehicles during the event. On the basis of speed motorcycle data, passed motorcycle speeds of location 1 ranges from 14.3 and 25.5 Km/h and passed motorcycle speeds of location 2 ranges from 12.5 to 24.8 Km/h. Passing speeds vary from 17.5 to 37.0 Km/h and from 16.6 to 38.7 Km/h for locations 1 and 2, respectively. The detail summation of the motorcycle speed for each location, including mean, maximum and minimum as well as standard deviation speeds, was presented on Table 1.

The difference between passed and passing motorcycle speed of location 2 is higher than that of location 1, 11.4 Km/h and 6.3 Km/h. This statistic shows that during passing event, followers moving on undivided roadway tend to finish this event by increasing their speed to reduce the risks of accidents from moving vehicles on the opposed direction. The later lateral and longitudinal analyses will prove this finding in detail.

Table 1. Motorcycle Speed Data during Passing Event

Location	Passed Motorcycle Speed (Km/h)					Passing Motorcycle Speed (Km/h)				
	Mean	Max	Min	St. dev.		Mean	Max	Min	St. dev.	
				Km/h	%				Km/h	%
1	19.4	25.5	14.3	3.0	15.4	25.7	37.0	17.5	5.6	21.7
2	17.4	24.8	12.5	3.2	18.3	28.8	38.7	16.6	6.4	22.2

The relationship between passing and passed motorcycle speeds during passing event for both exclusive motorcycle lane and undivided carriageway is plotted on Figure 3. In the present research, the simple linear regression analysis is used for depicting relationships due to following reasons:

- Other types of regression, such as logarithmic, polynomial, power, exponential, etc. did not present much better results. Some of them even make results worse;
- It is pair comparisons between sections 1 and 2 for each kind of relationship. It is strange if applying different types of equations for different sections at the same kind of study.

The below equations describe correlations between speeds of passing and passed vehicles in both locations.

Location 1: $V_{passing} = 1.67 \times V_{passed} - 4.77$ with $R^2 = 0.82$; (1)

Location 2: $V_{passing} = 1.76 \times V_{passed} - 3.70$ with $R^2 = 0.80$ where (2)

$V_{passing}$: Speed of passing motorcycle (Km/h);
V_{passed} : Speed of passed motorcycle (Km/h).

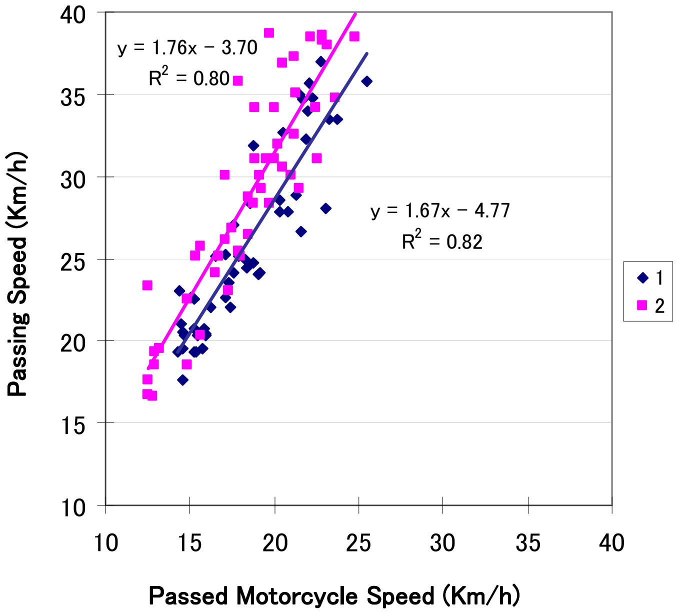

Figure 3. Passed vs. Passing Motorcycle Speed of Location 1 and 2

Onsite closer examination revealed that data of difference between passing and passed motorcycle speeds would be more fluctuant in case of high passed motorcycle speed than in case of low passed motorcycle one. In other words, when approaching a high-speed leader, following motorcyclists would have speeds that are much different from one by one according to their behavior and experience. Therefore, the correlation tends to increase in case of the slow speed, and to reduce at the high speed in both locations.

Lateral Distance During Passing

In this study, the lateral distance during passing was defined as the lateral spacing when passing and passed vehicles have the same longitudinal position in the carriageway. That distance was calculated from center to center of motorcycles. On the basis of motorcycle position data, the statistics expose that lateral distance for exclusive motorcycle lane data and undivided carriageway range between 1.51 and 2.47 m, 1.22 and 1.78 m, with the average of 1.93 and 1.50 m, respectively. Table 2 provides a summary of the lateral distance data of entities.

Table 2. Motorcycle Lateral Distance Data during Passing Event

Location	Lateral Distance (m)				
	Mean	Max	Min	St. dev. (m)	St. dev. %
1	1.93	2.47	1.51	0.22	11.3
2	1.50	1.78	1.22	0.12	8.0

The effect of passed motorcycle speed and facility on the lateral distance was analyzed to determine if any significant influence existed. The linear regression technique was employed to obtain their correlation in two locations. The equations below describe the directly proportional relationship between the speed of passed motorcycle and lateral distance. L is lateral distance (m) and V_{passed} (Km/h) is the speed of the passed motorcycle.

Location 1: $L = 0.05 \times V_{passed} + 0.44$ with $R^2 = 0.38$ and (3)

Location 2: $L = 0.03 \times V_{passed} + 0.38$ with $R^2 = 0.49$. (4)

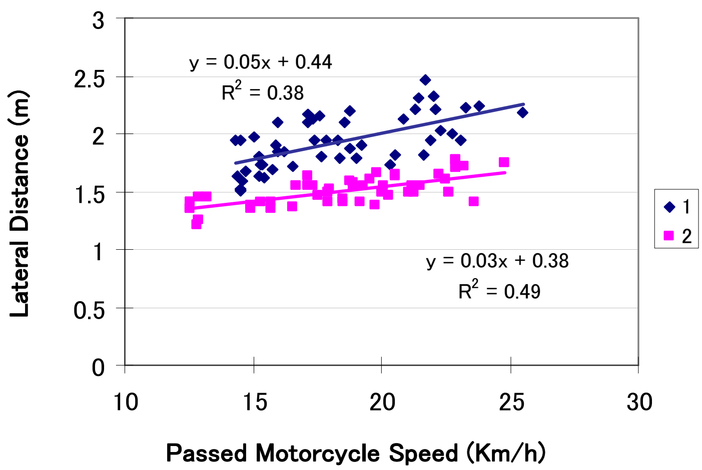

Figure 4. Passed motorcycle Speed vs. Lateral Distance of Location 1 and 2

The above equations indicate that, as the same speed of passed motorcycle, lateral distance of exclusive lane is higher than that of the undivided roadway. On the undivided condition, motorcyclists have not much vacant space for passing maneuver as they have on the exclusive lane. Due to care of moving vehicles on unopposed and opposed directions, they try to reduce passing event in both temporal and spatial matters. That behavior also explains the reason why the correlation between speeds of the passed motorcycle and the lateral distance of location 2 is higher than that of location 1, 0.49 and 0.38 m.

Longitudinal Distance of Passing Maneuver

Concerning longitudinal distance, two critical points, which were taken into consideration in this research, are the points when overtaking vehicle starts and finishes the passing movement. Longitudinal distances before and after passing were defined on Figure 2. The statistical summary on Table 3 describes average, maximum, minimum and standard deviation of the longitudinal distance for both locations.

Table 3. Motorcycle Longitudinal Distance Data during Passing Event

Location	Longitudinal Distance before Passing					Longitudinal Distance after Passing				
	Mean (m)	Max (m)	Min (m)	St. dev. (m)	St. dev. %	Mean (m)	Max (m)	Min (m)	St. dev. (m)	St. dev. %
1	2.83	3.66	2.02	0.39	0.13	2.87	3.64	2.22	0.34	0.11
2	2.37	3.01	1.69	0.27	0.11	2.26	3.22	1.53	0.38	0.16

Statistical data reveals that facility types, the exclusive and undivided roadway, significantly influenced not only to relatively different speed and lateral distance but also to both longitudinal distances before and after passing event. Without the effect of vehicles traveling on the opposing direction, the average longitudinal distance before and after passing event are 2.83 and 2.87 m with 0.39 and 0.34 m of standard deviation, respectively. Otherwise, those values reduce to 2.37 and 2.26 m with 0.27 and 0.38 m of standard deviation. Similar to lateral distance during the passing event, motorcyclists running on the undivided roadway tend to reduce the longitudinal distance to reduce risks of accidents from moving vehicles on the opposite direction.

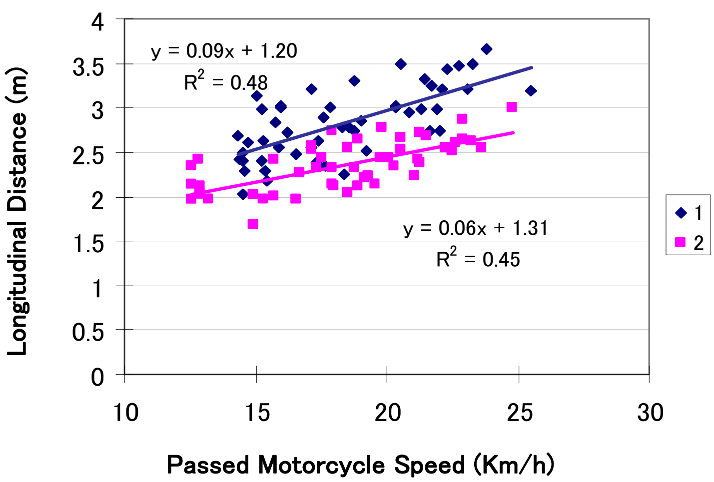

Figure 5. Passed Motorcycle Speed vs. Longitudinal Distance before Passing Event

The relationships between speed of passed motorcycle and longitudinal distance before passing of locations 1 and 2 were indicated on Equations 5 and 6. By using the linear regression technique, those relationships are represented as below.

$D_{before} = 0.09 \times V_{passed} + 1.20$ with $R^2 = 0.48$ and (5)
$D_{before} = 0.06 \times V_{passed} + 1.31$ with $R^2 = 0.45.$ (6)

Equations 7 and 8 describe the relationship between the speeds of the passed motorcycle and longitudinal distance after passing of locations 1 and 2.

$D_{after} = 0.07 \times V_{passed} + 1.56$ with $R^2 = 0.40$ and (7)
$D_{after} = 0.09 \times V_{passed} + 0.53$ with $R^2 = 0.63$, with (8)

D_{before} : Longitudinal distance before passing (m);
D_{after} : Longitudinal distance after passing (m);
V_{passed} : Speed of passed vehicle (Km/h).

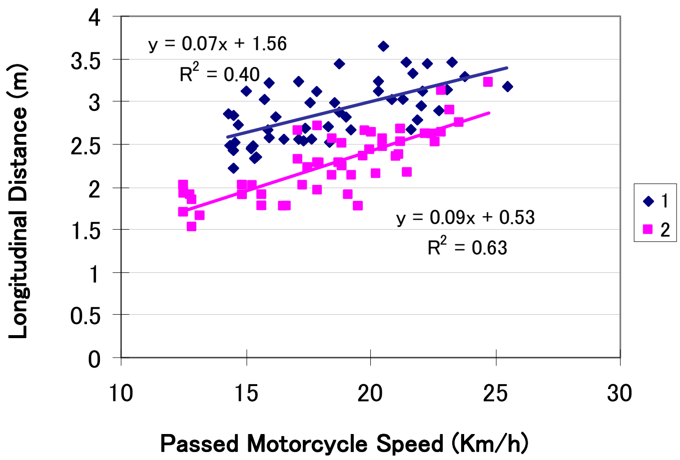

Figure 6. Passed motorcycle Speed vs. Longitudinal Distance after Passing Event

4.2. Paired Riding Maneuver

Not only passing events, riding in pairs also may cause serious disturbance and thus have a significant influence on determining the level of service on motorcycle path. Riding in pairs longer the given distance is common behavior of motorcyclists, which is legal in most cases. In the present study, the paired riding of motorcycle is defined when motorcycles travel abreast together as a pair over 10 m section while maintaining a maximum 1.5 m of longitudinal distance and no any effort to pass over.

Similar to passing maneuver analysis, from video data, several riding in pair situations were chosen for each exclusive motorcycle lane and the undivided two-lane roadway. On the basis of speed motorcycle data, speed differences between motorcycles in pair for each location are summarized on Table 4.

Table 4. Speed Difference of Motorcycle for Paired Riding Event

Location	Speed Difference (Km/h)		
	Mean	Max	Min
1	1.03	3.09	0.09
2	0.90	2.80	0.00

The statistics for relative speed difference between motorcycles in pair exposes that paired riding occurs when that value is less than 3 Km/h in both exclusive motorcycle lane and undivided carriage width.

From several motorcycle entities collected for paired riding, the statistics reveal that lateral clearance between paired motorcyclists for exclusive motorcycle lane data and undivided carriageway range between 1.69 and 2.18 m, 0.93 and 1.58 m, with the average of 1.89 and 1.10 m, respectively. Table 5 provides a summary of the lateral distance data of sampling entities.

Table 5. Motorcycle Lateral Distance Data for Paired Riding Event

Location	Lateral Distance (m)				
	Mean	Max	Min	St. dev.	
				(m)	%
1	1.89	2.18	1.69	0.11	5.82
2	1.10	1.58	0.93	0.14	12.72

The linear regression technique was utilized to obtain the correlation between the average speed and lateral distance in two locations. The equations below describe the directly proportional relationship between both variables. L is lateral distance (m) and V_{tb} (Km/h) is the average speed of motorcycle in pair.

Location 1: $L = 0.03 \times V_{tb} + 1.03$ with $R^2 = 0.46$ and (9)

Location 2: $L = 0.02 \times V_{tb} + 0.37$ with $R^2 = 0.46$. (10)

The above equations indicate that, as the same average speed, lateral distance of exclusive lane is higher than that of the undivided roadway. Figure 7 indicates both average speed and lateral distance of exclusive lane is higher than that of the undivided roadway. It can be explained that on the undivided condition, motorcyclists have not much vacant space as they have on the exclusive lane due to care of moving vehicles on both unopposed and opposed directions.

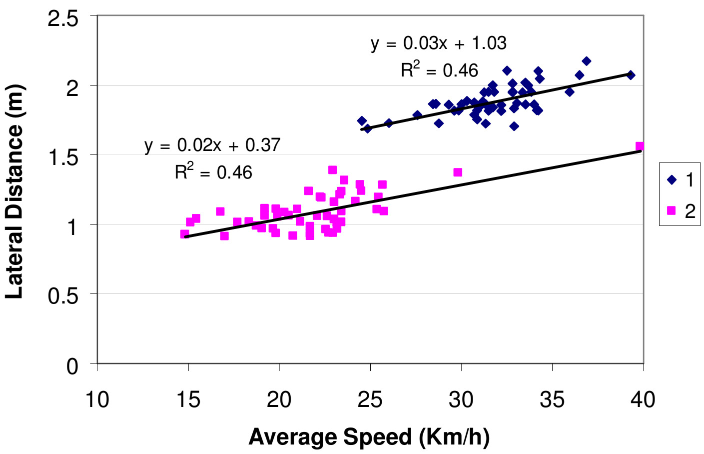

Figure 7. Average Speed vs. Lateral Distance during Paired Riding Event

5. CONCLUSIONS AND RECOMMENDATIONS

The analysis of the onsite data collected at urban road segments by using the video recording technique revealed valuable information about passing and paired riding maneuvers. The major findings of this study are summarized as below:

- During passing event, on exclusive motorcycle lane, average speed of passed motorcycle is 19.4 Km/h with standard deviation of 3.0 Km/h. On undivided roadway, average speed is 17.4 Km/h with standard deviation of 3.2 Km/h;
- For passing maneuver, on exclusive motorcycle lane, average speed of passing motorcycle is 25.7 Km/h with standard deviation of 5.6 Km/h. On undivided roadway, average speed is 28.8 Km/h with standard deviation of 6.4 Km/h;
- The speed of passing vehicle is directly proportion to the speed of passed motorcycle. That relationship was very high correlation coefficient for both locations, 0.82 and 0.80 for exclusive motorcycle lane and undivided carriageway, respectively;
- Averagely, the relative different speed between passing and passed motorcycles on exclusive motorcycle lane and undivided carriageway are 6.3 and 11.4 Km/h. The statistic reveals that during passing event, followers moving on undivided roadway tend to finish this event by increasing their speed to reduce the risks of accident from moving vehicles on opposed direction;
- When approaching a high-speed leader, following motorcyclists have speeds much different from one by one according to their behavior and experience. The correlation tends to be fitter in case of slow speed, and reduce at high speed in both locations;
- The average lateral distance during passing between passed and passing vehicles on exclusive motorcycle lane and undivided roadway are 1.93 and 1.50 m, respectively;
- The average longitudinal distance before and after passing between passed and passing vehicles on exclusive motorcycle lane are 2.83 and 2.87 m. And the average longitudinal distance before and after passing between passed and passing vehicles on undivided roadway are 2.37 and 2.26 m, respectively;
- As the same speed of passed motorcycle, average lateral longitudinal distance before and after passing maneuver of exclusive lane is higher than that of undivided roadway;
- Due to care of moving vehicles on unopposed and opposed directions at the same time, motorcyclists on undivided roadway try to reduce both temporal and spatial matters in passing events;

- For paired riding maneuver, the speed difference between motorcycles is less than 3 Km/h in both exclusive motorcycle lane and undivided carriage width;
- The statistics reveal that lateral spacing between paired motorcyclists maintained during paired riding for exclusive motorcycle lane data and undivided carriageway range between 1.69 and 2.18 m, 0.93 and 1.58 m, with the average of 1.89 and 1.10 m, respectively. The results indicated that lateral spacing of riding in pair is less that that of passing maneuver;
- The average speed of vehicle in pair is directly proportion to the lateral clearance. The correlation coefficient of this relationship was 0.46 and 0.46 for exclusive motorcycle lane and undivided carriageway, respectively.

However, some analyses with coefficients of determination falling below 0.5 indicate that the study has some limitations. The following recommendations should be added in further study:

- The number of sections for data collection should be increased to reduce abnormal behaviors which may have at a specific section;
- Because traffic volume affects to behaviors of motorcyclist during passing and paired riding events, it should be considered in further study;
- Movements of motorcycle in traffic stream are very complicated, different from time by time, person to person. In order to increase the accuracy of results, the further research should divided data collection into groups, such as male group, female group, etc.

According to HCM 2000, the criteria used to determine the level of service of exclusive bicycle paths are a weighted sum of the number of passing and paired riding events. This technique can be extended for motorcycle paths, which are very popular in most of developing countries. The findings of this study assist to better understanding of the maneuvers of motorcycle traffic. The information presented here can be used to construct criteria for the level of service, estimate capacity of motorcycle traffic or create comprehensive motorcycle simulation models in developing countries.

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