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Traffic Characteristics of Motorcycle-dominated Urban Street Considering the Effect of Light Vehicle

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Abstract: Urban traffic in Phnom Penh is characterized by the high level of mixed traffic with an extremely high proportion of motorcycle. Rapid growth of motorcycle with its behavior in traffic is the main cause of road congestion and accident. Recently, there is also a drastic increase in number of light vehicles including car, pick-up, and van causing a more serious problem on traffic capacity and safety. Firstly, this paper investigates the traffic performance of motorcycle-dominated urban street under the impact of light vehicle, whereby particular observation on how motorcycle responds under different proportions of light vehicle is conducted. Data was collected using videotaping technique. Secondly, the present paper examines motorcyclists' perception on traffic safety issue and the extent to which they involve in traffic accident based on motorcycle driver interview survey. Finally, discussion on how to improve capacity and safety is made.

Key Words: *motorcycle, light vehicle, urban street, mixed traffic*

1. INTRODUCTION

Phnom Penh traffic differs significantly from other countries in many respects. The wide variety of vehicles and the disparity in their sizes and speeds create a number of problems. Vehicles do not respect lane markings and tend to use every possible lateral or longitudinal gap. Motorcycle, which constitutes of more than 70% of the traffic composition, moves abreast with other vehicles either parallel or staggered utilizing the entire width of carriageway and sometimes a part of the carriageway of the opposite traffic. Since there is no bus service or other conventional public transport exists in the city, motorcycle has also been extensively used as paratransit, locally known as Motodop. Depending on driver and usage, some motorcycles excessively fast and some others are excessively slow. To some extent, this situation might be similar to those of Hanoi and Ho Chi Minh City in Vietnam; however, it is observed from previous studies that these cities have smaller proportion of light vehicle in traffic, which is often below 10% (Minh *et al.*, 2005; Nguyen and Montgomery, 2007). Phnom Penh has more light vehicles in the traffic with an approximate of 15% of the traffic composition, and this mode has been remarkably increased in the recent years. Annual average of newly registered light vehicle, which used to be around 6000 vehicles per annum before 2005, has reached an approximate of 13,000 vehicles per annum for 2005, 2006, and 2007 (DPWT).

The rapid growth of light vehicle under the existing motorcycle-dominated traffic condition and driving behavior results in not only severe traffic congestion but also more fatal traffic accidents in Phnom Penh. A newly established National Road Safety Committee (NRSC) reported that number of people died of traffic accidents in Phnom Penh had been increased by 54% from 2006 to 2007 and the majority of them were motorbike-four wheeler collisions (NRSC, 2007). In addition to loss of lives, the accident also causes casualties, disabilities, and damages to private and public assets. Some important key indicators of traffic accidents in 2006 and 2007 are summarized in Table 1. Unfortunately, the data presented in this table was collected from hospitals and police offices. Therefore, there are many other accidents not reported, especially light traffic accidents where there is no police intervention and where casualties are not sent to hospital. It is very common in Phnom Penh that accident involvers negotiate based on common sense about the compensation for the damage to vehicles and the self-medical treatment.

Table 1 Summary of road accident indicators in Phnom Penh in 2006 and 2007

	2006		**2007**	
Number of people injured from traffic accident	5,547		6,395	
Types of road user				
Motorbike users	83%	4,627	83%	5,310
Others	17%	920	17%	1,085
Causes of accident				
High speed	35%	1,889	47%	2,829
Alcohol or drug abuse	18%	991	16%	943
Dangerous overtaking	19%	1,009	15%	899
Others	28%	1,658	22%	1,724
Types of collision				
Motorbike – Motorbike	44%	2,399	51%	3,186
Motorbike – Light vehicle	28%	1,418	22%	1,378
Motorbike – Pedestrian	9%	491	8%	455
Others	19%	1,239	19%	1,376

Source: National Road Safety Committee, 2007

Although Table 1 could underestimate the real number of traffic casualties, it provides basic evidence that motorcycle is of primary concern for road safety issues in Phnom Penh. Similarly, light vehicle tends to have an increasing role in traffic accidents as motorbike – car collisions become the second leading type of accident and the first leading cause of fatality. From the viewpoint of capacity, the growth of the number of light vehicle also marks a substantial impact on the traffic performance of urban streets, particularly on motorcycle traffic. Therefore, knowledge of road capacity under the impact of light vehicle as well as road safety issues from the viewpoint of motorcyclists is of great importance to find appropriate solutions for improving both capacity and safety.

Despite the fact that road traffic in many Asian cities constitutes an extremely large proportion of motorcycle, empirical studies on the characteristics of this traffic mode in the region remain very few. Hsu *et al.* (2003) summarized and compared speed of motorcycle and car in some Asian cities. Minh *et al.* (2005) investigated motorcycle speed in Hanoi showing that motorcycles running in heterogeneous traffic having considerably lower speed than those in homogenous traffic though the former drives on larger lane width. Rongviriyapanich and Suppattrakul (2005) evaluated the effects of motorcycles on traffic operation both at signalized intersection and at mid-block in Bangkok. At intersection, they observed motorcycle impact on start-up lost time of passenger car, and at mid-block, impact of motorcycle was interpreted as variation of PCU for motorcycle under different traffic condition. Another interesting study by Nguyen and Montgomery (2007) discussed the influence of flow counting period on the study of saturation flow for urban road dominated by motorcycle in Hanoi. Though these studies show meaningful results, none of them observes the effect of passenger car on motorcycle traffic operation.

As for motorcycle safety, many studies have been conducted for the case of developed countries. Previous studies in relation with motorcycle accidents in Asian countries where number of motorcycles is significant are still little in number. Pang *et al.* (2000) examined the accident characteristics of injured motorcyclists aiming at identifying the most vulnerable types of riders in Malaysia using data from hospital and traffic police, followed by an interview with the victims being hospitalized. Kulanthayan *et al.* (2000) investigated the compliance of helmet usage among motorcyclists in Malaysia based on interview survey. Iamtrakul and Hossain (2007) focused on drink-driving and disregard of helmet use among motorcyclists in Thailand as the two factors for risk ratio estimation. They found out that economic loss due to alcohol-related motorcycle accident was as much as US$ 1,444 million per year.

Although existing studies reveal meaningful and practical results, capacity and safety have been separately considered. For many cases, these two fields are strongly related, i.e. factors influencing capacity could also affect safety in one way or another. This paper covers both safety and capacity issues for urban street in Phnom Penh. The specific objectives of this paper are:

- To investigate the traffic performance of motorcycle-dominated urban street under the impact of light vehicles, whereby particular observation on the response of motorcycle under different traffic situation. Data was collected using videotaping technique.
- To examine motorcyclists' perception on traffic safety issue and the extent to which they involve in traffic accidents based on motorcycle driver interview survey.
- To discuss the possibilities for improving traffic capacity and safety.

2. EFFECT OF LIGHT VEHICLES ON TRAFFIC PERFORMANCE OF URBAN STREET DOMINATED BY MOTORCYCLES

Even though the traffic in Phnom Penh is comprised of various traffic modes, the focus is merely made on two main modes, i.e. motorcycle and light vehicle. This section is concerned with identifying the speed variation of light vehicle and motorcycle under different traffic conditions, evaluating how the two modes affect mean stream speed, and examining the response of motorcyclists to the presence of light vehicle in terms of speed and lateral position choice.

2.1 Data Collection

To observe the effect of light vehicles on traffic performance of motorcycle-dominated urban street, the study sites were selected with the considerations that the total traffic is mainly composed of motorcycle and light vehicle, in which share of motorcycle is considerable while share of light vehicle varies from low to as high as possible. Moreover, the traffic flow at study sites should varies from light to heavy trafficked so that the light vehicle impact can be observed in different traffic conditions.

Two locations in downtown Phnom Penh, referred to as location 1 and location 2 throughout this paper, are chosen in order to obtain different proportions of light vehicle in the traffic. While location 1 was generally observed to have considerable share of light vehicles regardless of time of the day, location 2 seemed to have lower proportion of this traffic mode especially during off-peak period. Based on this observation, data was collected just after the morning peak hour 08:40-09:40 for location 1 and during afternoon off-peak hour 14:50-15:50 for location 2 on April 2nd, 2008. The difference in data collection time for the two locations enables this study to cover not only different proportions of light vehicle but also a wide variety of traffic flow rates, i.e. the traffic flow at location 1 is considerably heavier than at location 2. It should be noted that geometrical characteristics of location 1 and location 2 are almost identical to avoid any geometric effect from study sites. Both sites were mid-block sections of two six-lane undivided urban streets with 9.0 m and 9.1 m wide carriageways for location 1 and location 2 respectively (Figure 1). The study sites are located sufficiently far from junctions, straight, level, and free from any restriction to traffic movement.

Videotaping technique was used as a means for data collection, and the traffic videos were converted to media files and replayed on a computer. SEV Software, developed by other researchers and used in their study (Minh *et al.*, 2006), was employed to extract speed and trajectories of 749 motorcycles and 287 light vehicles at every 0.5 second. Table 2 provides the six vehicle categories considered in this study with their corresponding average projected rectangular areas adopted from Chandra and Kumar (2003). The traffic compositions of these locations are shown in Figure 2. In order to look at the detailed behavior of traffic stream, investigation and measurement were made within 15-second intervals for composition and flow. In this study, only sixty minutes (one hour) data is used for each location, in which investigation on vehicle speed and trajectory is made on only one of the four 15-second intervals belonging to each minutes except for a few cases where additional investigations are necessary.

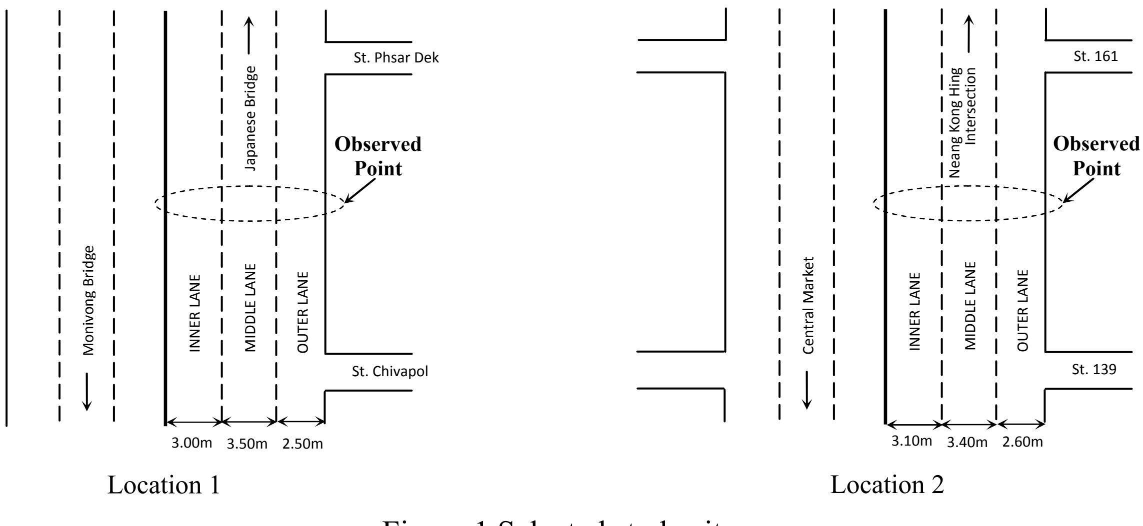

Figure 1 Selected study sites

Table 2 Vehicle categories and their physical sizes

Category	Vehicle included	Projected rectangular area on road (m^2) [a]
Motorcycle	Motorbike, moped, scooter	1.20
Light vehicle	Car, pick-up, van	5.39
Bus	Bus	24.74
Light Truck	Light truck	12.81
Cycle	Bicycle, Cyclo (tricycle)	0.85
Three-wheeler	Tuk-tuk, motorcycle trailer	4.48

[a] Value adopted from Chandra and Kumar, 2003

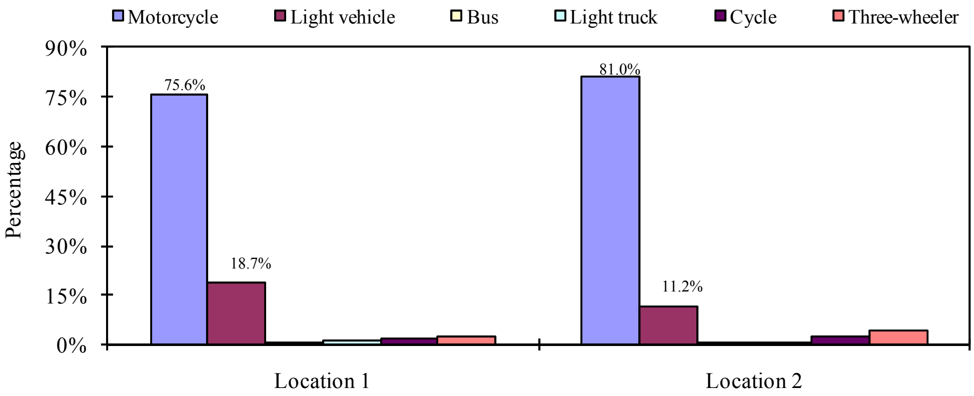

Figure 2 Traffic compositions at study sites

2.2 Travel Speed and Compliance to Speed Limit

Using the output from SEV software, speed of individual vehicle was obtained by calculating the average of the speeds recorded at every 0.5 second during its displacement over the displayed screen.

Table 3 Statistics of travel speed of motorcycle and light vehicle

Location	Vehicle Category	Traffic Volume	No. of Sampling	Observed Speed (Km/h)			
				Mean	Max	Min	Std. Dev
1	Motorcycle	3273	403	24.74	44.52	8.72	6.13
	Light vehicle	809	136	18.88	31.72	3.61	6.62
2	Motorcycle	2954	346	26.42	47.50	8.22	5.97
	Light vehicle	410	151	25.42	43.59	13.42	5.41

Table 4 Percentage of vehicles exceeding various speeds

Percentage of vehicle	Location 1		Location 2	
	Motorcycle	Light vehicle	Motorcycle	Light vehicle
P(Speed > 10km/h)	99.8%	89.7%	99.7%	100.0%
P(Speed > 20km/h)	79.4%	46.3%	88.2%	88.1%
P(Speed > 30km/h)	16.4%	4.4%	22.8%	18.5%
P(Speed > 40km/h)	1.7%	0.0%	2.9%	1.3%

The speed statistics are listed in Table 3. At location 1, mean speed of motorcycle is almost 6 km/h higher than that of light vehicle though the standard deviation of motorcycle speed is a just little higher. Result from Mann-Whitney test shows that mean speed of motorcycle is significantly larger than light vehicle ($p=0.000$). At location 2, however, mean speed and standard deviation of motorcycle are a little higher than light vehicle, and the difference is not statistically significant ($p=0.072$). Given that location 1 and 2 had the same geometry and that location 1 had heavier traffic flow, this difference in speed shows that under different traffic situations, motorcycle has more choices on speed comparing to light vehicle. Between location 1 and 2, there is only a small difference in average speed of motorcycle, yet this difference is statistically significant ($p=0.000$). For light vehicle speed, there is a large difference between the two locations, and this is supported by statistical testing ($p=0.000$).

According to traffic law, motorcycle speed limit is 30 km/h and light vehicle speed limit is 40 km/h when they drive in urban area. Nevertheless, it is observed that some motorcyclists ignore the speed limit. Table 4 reveals that the 16.4% and 22.8% of motorcycle being observed at respective location 1 and 2 over-speed. Even though some light vehicles at location 2 violate speed limit, the rate of over-speeding is very small.

2.3 Effects of Motorcycle and Light Vehicle on Traffic Stream Speed

As the speed of light vehicle is dramatically reduced under heavy traffic, it could be inferred that when proportion of light vehicle increases, the traffic stream speed will significantly affected as their large sizes obstruct other modes, thus reduce road capacity. This section attempts to see different impacts motorcycle and light vehicle have on speed characteristic of the urban street where motorcycle is dominant. These impacts seem to vary under different traffic conditions; this section, therefore, considers two traffic flow rates for each location classified into four cases:

- Case A1: flow rate 1300-2000 pcu/h at location 1
- Case A2: flow rate 2000-2700 pcu/h at location 1
- Case A3: flow rate 1300-2000 pcu/h at location 2
- Case A4: flow rate 2000-2700 pcu/h at location 2

To represent the traffic stream, speed measurement is not only made for motorcycle and light vehicle but also every other vehicles running in the traffic. Among 131 data points of the 15-second intervals, where speeds and trajectories of motorcycle and light vehicle are measured, only 62 data points were selected for other vehicles speed measurements. As a result, only a small number of data was used for the analysis in this section. Flow and composition observed on 15-second interval was converted to 1-hour based. Moreover, different vehicle types were also converted to an equivalent number of a standard vehicle, namely passenger car unit (PCU), using the concept proposed by Chandra and Sikdar (2000), such that:

$$\mathrm{PCU}_i = \frac{V_c / V_i}{A_c / A_i} \tag{1}$$

where V_c , V_i : mean speed for cars and vehicle type i
A_c , A_i : projected rectangular area on the road shown in Table 2.

Under a mixed traffic situation, a large variation in speeds among slow and fast moving vehicles exists. Therefore, to tackle with the heterogeneous traffic condition, this study uses a weighted space mean speed, or simply mean stream speed. Before estimating stream mean speed, an average speed of each category of vehicles is calculated. Then, the mean stream speed is given by:

$$V_m = \frac{\sum_{i=1}^{k} n_i v_i}{\sum_{i=1}^{k} n_i} \tag{2}$$

where k : total number of vehicle categories present in the stream
n_i ,v_i : number and average speed of vehicle category I.

Figure 3 establishes relationship between mean stream speed and proportion of motorcycle. It shows that at volume level of 1300-2000pcu/h, motorcycle has minor influence on mean stream speed at both locations (case A1 and A3) despite its extreme high share. However, when traffic volume increases up to 2000-2700pcu/h, stream speed considerably decreases with the rise of motorcycle proportion (case A2 and A4). Table 5 reveals that the slopes of regression lines are as small as -6.17 and -3.85 for case A1 and A3 respectively, and they are not significant given small t-statistics and large p-values. For these two cases, the correlation coefficients R^2 are close to zero indicating that the linear regressions with only motorcycle proportion (P_{MC}) as independent variable do nothing to explain the variation of mean stream speed at low traffic flow rate (1300-2000pcu/h). Nevertheless, at high traffic flow rate, the linear regressions produce reliable results. Table 5 shows that the slopes of the regression lines are as large as -26.96 and -25.61 for case A2 and A4, and all regression coefficients are statistically significant. Their corresponding R^2 values are also satisfied. It is also observed from Figure 3 that, under the same traffic flow and the same motorcycle proportion, the mean stream speed of location 1 is generally lower than that of location 2, which possibly resulted from the different traffic densities between the two locations.

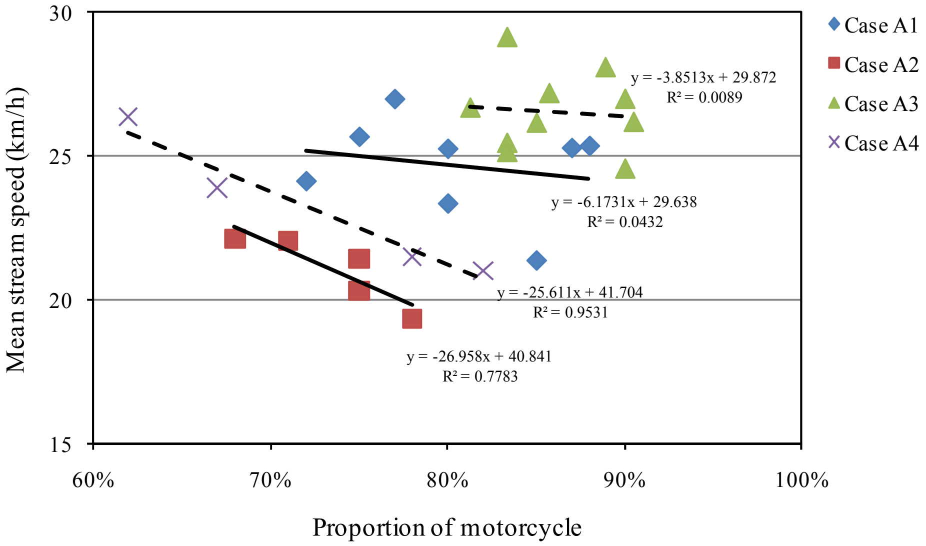

Figure 3 Mean stream speed under the effect of motorcycle

Table 5 Regression coefficient of mean stream speed considering motorcycle impact

	Case A1		Case A2		Case A3		Case A4	
	P_{MC}	Const	P_{MC}	Const	P_{MC}	Const	P_{MC}	Const
Coefficient	-6.173	29.638	-26.958	40.841	-3.851	29.872	-25.611	41.704
Standard Error	11.862	9.570	8.307	6.104	14.329	12.350	4.016	2.919
t-statistic	-0.520	3.097	-3.245	6.691	-0.269	2.419	-6.378	14.285
p-value	0.621	0.021	0.048	0.007	0.795	0.042	0.024	0.005
R^2	0.043		0.778		0.009		0.953	

Note: P_{MC} refers to the proportion of motorcycle

Similarly, Figure 4 shows the relationship between mean stream speed and light vehicle proportion, but its results are notably different from Figure 3. There is a tendency that the mean stream speeds tremendously decrease with the increase of light vehicle share regardless of low or high traffic volume. An exception of case A1, where the proportion of light vehicle is very low, is observed to have slighter impact on stream speed. Table 6 shows that the regression coefficients are significant for all four cases (A1, A2, A3, and A4). The R^2 are found to be large except for the case A2 where R^2 is only 0.51. This could be understood that proportion of light vehicle is just one of the influential factors that reduce stream speed at location 1 where traffic density is high.

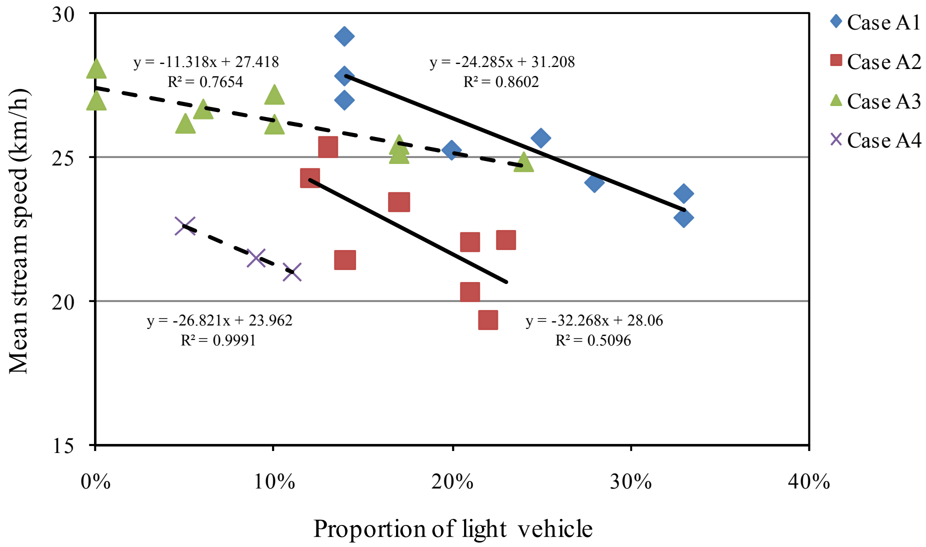

Figure 4 Mean stream speed under the effects of light vehicle

Table 6 Regression coefficient of mean stream speed considering light vehicle impact

	Case A1		Case A2		Case A3		Case A4	
	P_{LV}	Const	P_{LV}	Const	P_{LV}	Const	P_{LV}	Const
Coefficient	-24.285	31.208	-32.268	28.060	-11.318	27.418	-26.821	23.962
Standard Error	3.997	0.956	12.922	2.371	2.369	0.297	0.804	0.070
t-statistic	-6.076	32.652	-2.497	11.835	-4.778	92.315	-33.353	342.548
p-value	0.001	0.000	0.047	0.000	0.002	0.000	0.019	0.002
R^2	0.860		0.510		0.765		0.999	

Note: P_{LV} refers to the proportion of light vehicle

It is interesting to note from Figure 4 that mean stream speed at location 1 tends to be higher than location 2 under the same traffic condition. This contradicts with what was shown in Figure 3. One potential reason behind the discrepancy in Figure 4 could be explained by the conversion of motorcycle into PCU using Equation (1). At location 1, where the light vehicle speed is very much lower than that of motorcycle, the PCU for motorcycle becomes very small. Therefore, inside the traffic stream with the volume level of 1300-2000pcu/h or 2000-2700pcu/h, there must be a large number of motorcycles whose individual speed is comparatively high. By using Equation (2), the mean stream speed remains high due to the over-representation of motorcycle. This situation persists unless the proportion of light vehicle is large enough, i.e. more than 25%. This explanation seems to support the idea to use motorcycle unit (MCU) instead of PCU for the case where motorcycle is dominant proposed by other studies such as Minh *et al.* (2005).

2.4 Effect of Light Vehicle on Motorcycle Traffic

As the mean stream speed of traffic on an urban street dominated by motorcycle is led by the motorcycle speed, evaluation of the impact of light vehicle on the speed of motorcycle could provide a close look on the interaction of these two modes.

First of all, this section examines the impact of light vehicle on motorcycle speed. To avoid any possible effect of other modes, we primarily selected only the cases where the flow is composed only of motorcycle and light vehicle from the 131 data points of the 15-second interval. However, there was too small data received, so we also accepted the data points where maximum number of tricycle and cycle are one and two respectively. Under the hypothesis that mean speed of motorcycle reduces with the increase of light vehicle number, the speed data of motorcycle in these selected data points were classified according to the number of presenting light vehicle ranging from 0 to 6. The average speed of motorcycle in each group is then calculated. Data filtering was made to remove some motorcycles whose speeds unusually deviate from the mean. Traffic flow rate, defined as number of motorcycle per15 seconds (mc/15s), is categorized into three different levels, namely:

- Case B1: 7-12 mc/15s
- Case B2: 13-18 mc/15s
- Case B3: 19-24 mc/15s

To confirm that the differences in motorcycle mean speed when vehicle number varies from 0 to 6 are statistically significant, an analysis of variance (ANOVA) test was performed. The result shows that at a 95% confidence level, at least one of the means is different (F-statistic = 26.10, p = 0.000). Then, Fisher's least significant difference (LSD) test was perform to check if the motorcycle mean speed gradually decreases with the increase of light vehicle number. Table 7 shows the computation of LSD for the six comparisons and the difference in mean speed of motorcycle at 95% confidence level. The observed differences in mean speed are greater than the computed LSD, except the pair "4 vs 5". Therefore, the speed difference for all pairs other than the pair "4 vs 5" is statistically significant. As the observed speed differences generally show positive sign, it could be inferred that the mean speed reduces gradually as the number of light vehicle increases from 0 to 6.

Table 7 Results of Fisher's LSD test for comparison of motorcycle mean speed

	Comparison of number of light vehicle					
	0 vs 1	1 vs 2	2 vs 3	3 vs 4	4 vs 5	5 vs 6
Difference in mean speed of motorcycles (km/h)	1.586	1.220	1.768	1.676	-0.91	2.260
LSD	1.331	1.195	1.205	1.392	1.509	1.523
p-value	0.020	0.047	0.004	0.019	0.235	0.004
Conclusion	Different	Different	Different	Different	Equal	Different

Next, the relationship between motorcycle mean speed and number of light vehicle (N_{LV}) is established. Figure 5 shows that when there is no light vehicle in the traffic, the motorcycle speed remains the same for all three levels of flow (case B1, B2, and B3). However, as light vehicle increases, the different impacts are observed according to the flow rate of motorcycle, i.e. slightest speed reduction occurs in case B1 and largest speed reduction occurs in case B3. Table 8 shows that regression coefficients are statistically significant for case B1 and B2, but not case B3 where the traffic flow rate is very high. It is also implied that motorcycle mean speed would be around 28 km/h for all case when there is no light vehicle in the traffic in all levels of traffic flow rate.

Table 8 Regression coefficient of motorcycle mean speed

	Case B1		Case B2		Case B3	
	N_{LV}	(Const)	N_{LV}	(Const)	N_{LV}	(Const)
Coefficient	-0.832	28.464	-1.477	28.527	-1.795	28.033
Standard Error	0.075	0.266	0.142	0.513	0.560	1.534
t-statistic	-11.042	106.818	-10.389	55.647	-3.205	18.278
p-value	0.000	0.000	0.000	0.000	0.085	0.003
R-square	0.968		0.956		0.837	

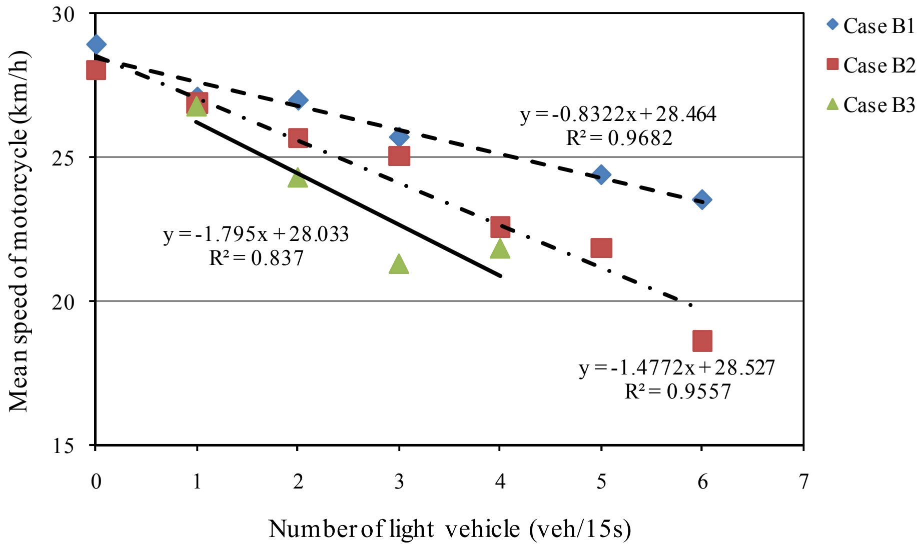

Figure 5 Effect of light vehicle on speed of motorcycle

From traffic observation, faster motorcycles tend to use the inner lane (lane farthest from the curb, see Fig. 1). Therefore, one possible reason for motorcycle speed reduction under the increase of light vehicle could be because the presence of light vehicle limits the choice on lateral position among motorcyclists. This section extends our observation on how light vehicle simultaneously affect speed and lateral position of motorcycle under three different cases, namely:

- Case C1: 7-12 mc/15s with light vehicle proportion < 20%
- Case C2: 13-18 mc/15s with light vehicle proportion = {20%, 30%}
- Case C3: 19-24 mc/15s with light vehicle proportion > 30%

Data selection procedure for this analysis is similar to case B1, B2, and B3; however, there is no exclusion of motorcycles with large speed deviation from this sampling.

Figure 6 illustrates the relationship between motorcycle speed and lateral position under different flow rates and different proportion of light vehicle denoted as case C1, C2, and C3. At lower traffic volume with proportion of light vehicle lower than 20% (case C1), many motorcycles could reach higher speed (higher than speed limit 30km/h) and they are also in freer condition to choose lateral position. As the traffic volume increase to 13-19 mc/15s with light vehicle proportion rises between 20-30% (case C2), motorcycle speed generally decreases. Only a few of them could go faster than speed limit. Moreover, number of motorcyclists who uses inner lane also dramatically reduces. Further increase of traffic volume to the rate of 19-25 mc/15s with more than 30% of light vehicle proportion result in strong impedance on both speed choice and lateral position choice of motorcyclists. One possible reason is when a large proportion of light vehicle presents in the heavy traffic flow, some light vehicles use middle lane to avoid slow car traffic in the inner lane.

Chi-square (X^2) test was performed for case C1, C2, and C3 to check how the relationship between motorcycle speeds and lateral positions were affected under different traffic flow rates and different light vehicle proportions. Table 9 shows the values of computed X^2 and the X^2-critical for each case. In case C1, the values of computed X^2 is greater than X^2-critical, so the relationship between speeds and lateral positions are statistically significant, i.e. faster motorcycles drive farther from curbside while slower motorcycles drive closer to curbside.

However, in case C2 and C3, there is no statistically significant relationship between speed and lateral position of motorcycle as the computed X^2 values appear to be smaller than X^2-critical and the p-values are large. This result reflects that the presence of light vehicle in the traffic flow is the underlying cause of reducing speed and limiting lateral position choice of motorcycle.

From sites observation, some vehicles from the opposite direction use the inner lane of the studied direction for overtaking when the subject direction has lower volume. Therefore, among motorcycles in the first group described above, those that have high speed and locate in the inner lane are exposed to danger from the opposed traffic in these undivided urban roads in addition to the possible collision with other vehicles in the same direction.

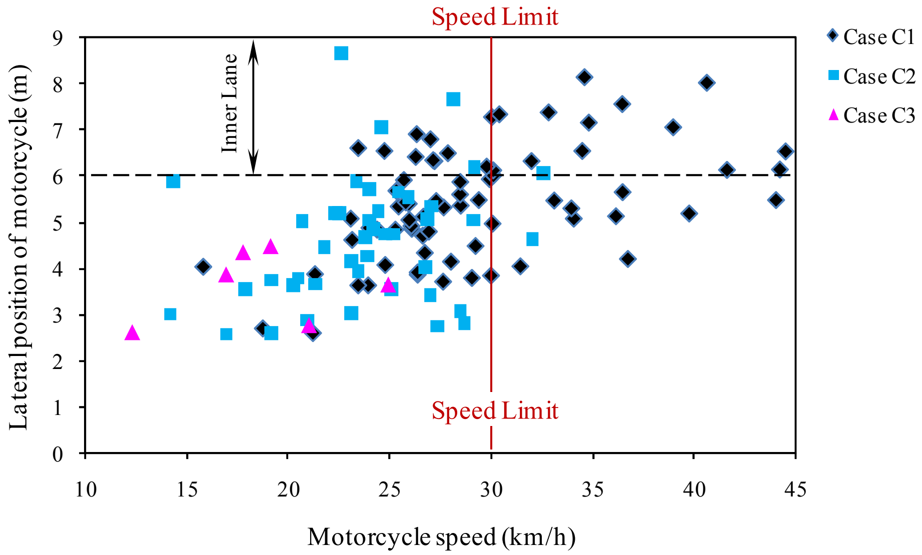

Figure 6 Lateral positions vs speed of motorcycles

Table 9 X^2-test for relationship between motorcycle mean speed and lateral position

	Case C1	Case C2	Case C3
X^2	45.511	25.613	5.000
X^2-critical	31.410	36.410	9.49
p-value	0.001	0.373	0.287

3. MOTORCYCLISTS' PERCEPTION AND INVOLVEMENT IN ROAD ACCIDENT

Since there are many accidents happening in Phnom Penh without being reported, this study explores the real condition of road safety perceived by the motorcyclists and the extent to which they, as motorcycle drivers, involve in the accident.

3.1 Data Collection

An interview survey on motorcycle drivers was conducted in Phnom Penh between December 15 and December 18, 2008. Since the data collection was targeted at motorcycle drivers, the interview was conducted at thirteen gas stations and one parking area in order to ensure that the respondents are motorcycle drivers. These sites were randomly selected throughout the urban districts of Phnom Penh. From these fourteen sites, this study collected 439 motorcycle drivers that were required to answer to the questions from surveyors. This sample size was chosen as the representation of the motorcycle drivers, not to represent the population in Phnom Penh. The respondents were selected using the simple random sampling method.

The questionnaire includes a variety of items, yet those relevant to this paper are: socio-demographic, daily driving distance, impression on car increase in traffic, anxiety of having an accident, frequency of seeing accident, accident involvement when driving motorcycle, and unsafe driving behavior. Besides the question items shown above, surveyors also recorded the occupancy of motorcycle (i.e. number of people riding on one motorcycle including driver) whose driver participate in the interview.

3.2 Characteristics of Sample

The general characteristics of sample are provided in Table 10. It illustrates that male motorcyclists is the majority (74.5%) in this sample. More than half of the sample is between 20 and 29 year old (54%). In terms of education background, around 51% reaches university level. Among those who agreed to participate in our interview are mostly university students.

Table 10 Characteristics of the samples

Characteristics		Sample	
Gender	Male	327	(74.5%)
	Female	111	(25.3%)
		(*1 missing*)	
Age	Less than 20	80	(18.2%)
	20-29	237	(54.0%)
	30-39	67	(15.3%)
	40-49	40	(9.1%)
	50-59	11	(2.5%)
	60 and older	3	(0.7%)
		(*1 missing*)	
Educational background	Primary school	26	(5.9%)
	High school	183	(41.7%)
	University	223	(50.8%)
	Vocational school	3	(0.7%)
	Other	3	(0.7%)
		(*1 missing*)	
Occupation	Government staff	67	(15.3%)
	Company/NGO staff	88	(20.0%)
	University student	138	(31.4%)
	High school student	53	(12.1%)
	Self-employed	77	(17.5%)
	Unemployed	8	(1.8%)
	Other	8	(1.8%)
		(*0 missing*)	

3.3 Findings and Discussions

First of all, it would be interesting to show the motorcycle occupancy recorded by our surveyors. It is quite common for a motorcycle to have one or two passengers (including driver); however, in Phnom Penh, some motorcycles carry three persons or more. According to the data, 18.2% (82 samples) of motorcycle interviewed carry three persons, 1.4% (6 samples) carries four persons, and 0.2% (1 sample) carries five persons. This case is quite unique for this city.

Regarding the impression on the increase of car traffic, respondent were asked to answer "*Do you agree that the increase of car in the traffic worsen traffic congestion?*" by rating from 1 if "strongly disagree" to 5 if "strongly agree". Of 439 samples, 53.3% are strongly agree followed by 26.4% who are somewhat agree. Also, another question "*Do you agree that the increase of car in the traffic cause severe traffic accident to motorcyclist?*" was asked for answer by rating in the similar way. It shows that 32.6% and 24.6% are strongly agree and somewhat agree respectively. This shows that motorcyclists seem to blame light vehicle for causing congestion and accident among motorcycle users.

In terms of the anxiety of having traffic accident, respondents were asked how much the statement "*I am always worried about having traffic accident*" matches with them by rating from 1 if "Not at all" to 5 if "Very much". The absolute majority, 74.4% of the respondents choose "Very much". This means that traffic safety in Phnom Penh is very poor and must not be neglected.

For the frequency of seeing accident, respondent were asked "*How often do you see traffic accident?*" The finding is surprising; 13% of the respondents see the accident almost every day, followed by 40.1% who see the accident several times a week (Figure 7). Chi-square (X^2) test was performed to test the relationship between frequency of seeing accident and daily driving distance. The result shows that there is a statistically significant relationship between the frequency of seeing accident and driving distance ($X^2 = 27.2$, $p < 0.01$). As shown in Figure 8, those who travel longer distance a day see accidents more often than those who travel shorter.

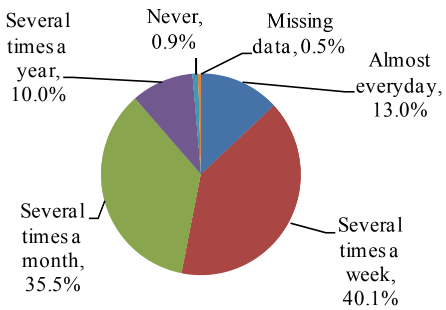

Figure 7 Frequency of seeing accidents

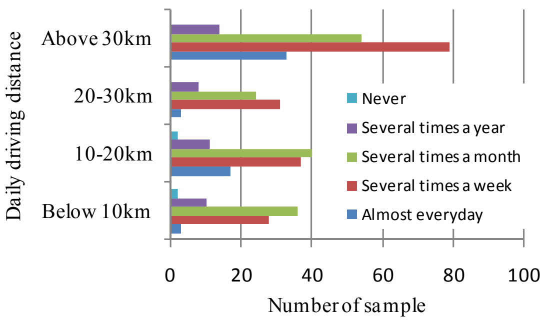

Figure 8: Frequency of seeing accidents by types of daily travel distance

It is even more interesting when we found out that 44.4% of the sample has been involved, as motorcycle drivers, in at least one accident in the last three years (Figure 9). They were also asked to report how severe they were during each accident by choosing "*Hospitalized*" meaning seriously injured and need to stay in hospital, "*Medical treatment*" meaning slightly injured and may receive medical treatment at home, and "*Property damage only*". Although some of respondents reported more than one accident in the last three year, the severity of accident shown in Figure 10 is that of their first accident. It should be mindful that, very often, light accident with the level "*Medical treatment only*" and "*Property damage only*" are not recorded by the police or the hospital. However, these kinds of accident together constitute more than 80% of the total accidents in our survey. Accident involvement were also classified by age group and shown in Figure 11. Moreover, even though more accidents are observed among those who have longer daily driving distance, there is no statistically significant relationship between accident involvement and the daily driving distance ($X^2 = 10.89$, $p = 0.538$). Figure 12 illustrates that almost in all cases of daily travel distance, number of respondents who experienced accidents and those who never experienced accidents are not much different, except for the case where the distance is in between 20-30 km per day.

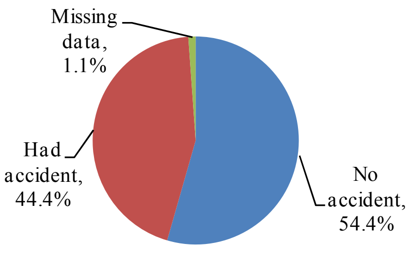

Figure 9 Accident involvement

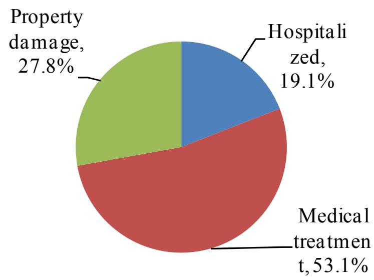

Figure 10 Severity of the accident

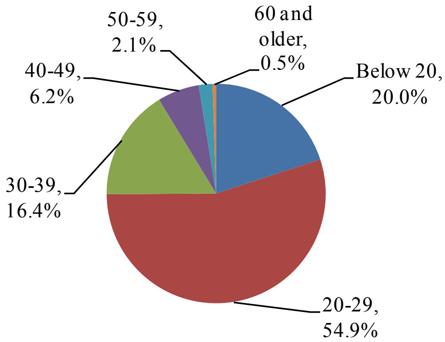

Figure 11 Accident involvement by age group

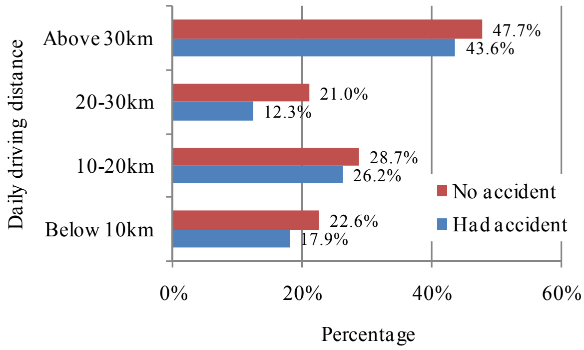

Figure 12 Accident involvement by type of exposure

Respondents were also asked to provide their answers related to driving behavior. Seven kinds of unsafe driving practices commonly observed in Phnom Penh were included in this questionnaire. Respondents were required to report how often they behave following the items provided by rating from 1 if "Never" to 5 if "Very often". These question items are summarized in Table 11.

Table 11 Question items on unsafe driving behavior (1= Never, …, 5 = Very often)

Notations		**Items in the questionnaire**
Speeding	-	Driving more than 10km/h faster than others on the street
Tail-gating	-	Driving too close to other vehicles/motorcycles in front
Pair-riding	-	Driving alongside with other motorcycles in the same lanes
Overloading	-	Driving with three people or more on one motorcycle
Driving in the opposite direction	-	Driving in the opposite direction before crossing the street
Drink driving	-	Driving after drinking alcohol
Running the traffic light	-	Running red light at signalized intersection

Accidents are often caused by risky driving, thus a comparison of driving behavior between two groups of respondents in our sample. Group one refers to those respondents who had involved in accident and group two refers to those who had not involved in accident within this three years. Table 12 shows that those who had involved in accident generally exhibit more frequent unsafe driving behaviors than those who had not involved in accident. Exception is noticed for the "overloading" and "running the red light" where there is no significant difference between the two groups. Interestingly, it is observed that "Overloading" is the most frequent type of behavior conducted by both groups and "Running red light" seems to be the less frequent one.

Table 12 Mean (and standard deviation) of self-reported driving behavior

Items of self-reported driving behaviors	Respondents who involved in accident N = 194	Respondents who did not involved in accident N = 237	Significance of difference[1]
Speeding	2.58 (1.09)	2.28 (1.13)	$p < 0.01$
Tail-gating	2.65 (1.04)	2.34 (1.11)	$p < 0.01$
Pair-riding	2.82 (1.09)	2.46 (1.13)	$p < 0.001$
Overloading	2.87 (1.11)	2.72 (1.17)	*not sig.*
Driving in opposite direction	2.53 (1.05)	2.30 (1.07)	$p < 0.05$
Drink driving	2.04 (1.06)	1.76 (0.95)	$p < 0.01$
Running red light	1.87 (1.06)	1.70 (0.97)	*not sig.*

[1] Mann-Whitney Test; (In parenthesis is the standard deviation)

4. DISCUSSION

The present study shows that motorcycle is more efficient than light vehicle from the viewpoint of capacity, but this mode is vulnerable to traffic accident. Since accident is found to be related with risky driving, changing these unsafe driving behaviors among motorcyclists should be prioritized. Phnom Penh authority, with technical support from Japanese experts, is applying 3Es concept (Engineering, Education, and Enforcement) to deal with traffic congestion and accident in which changing driver behaviors is one of the major concerns. It is noticeable that this work has yield successful result.

In the long run, however, changing driver behavior alone may not be the solution. As the majority of motorcyclists perceive that motorcycle is an unsafe mode, there is a strong tendency that motorcycle users will shift to car if their income levels increase provided that conventional public transport is unavailable in Phnom Penh. In this case, congestion will be tremendously worsened. Before this event happens, it is necessary to shift a portion of motorcycle users to HOV, i.e. transit modes, in order that both capacity (in term of total number of passenger flow) and safety can be maintained. With this regard, thorough studies on required incentives for moving trip makers in Phnom Penh from using motorcycle to riding public transit are of great importance.

5. CONCLUSION

From our observations on the two sites, the following conclusions are drawn:

- Under mixed traffic, the speed of light vehicle greatly reduces, especially when the traffic flow is high; therefore, the capacity decreases accordingly.
- Motorcycle has minor impact on means stream speed, but light vehicle strongly affect mean stream speed regardless of traffic flow level.
- When the proportion of light vehicle in traffic increase, speed of motorcycle reduces, and freedom in choosing lateral position decrease.

Result of the interview survey indicates that traffic accident is an alarming issue for motorcycle users. While many respondents reported about frequent chance to see the scene of accidents, as many as 44% of them had involved in at least one accident within the last three years. Therefore, traffic safety improvement should be the priority to save many lives as well as property loss or other damages caused by accidents.

As for future research, the following directions will be followed:

- Enlarge the data size for the traffic flow analysis to improve the reliability of findings in the present study.
- Conduct in-depth analysis to identify the main cause leading motorcyclists to drive in the risky way so that appropriate and effective measures can be implemented.

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