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Examining Exposure of Motorcycles at Signalized Intersections

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ABSTRACT
Crash statistics in Singapore from 2001 to 2005 have shown that motorcycles are involved in about 54% of intersection crashes. The overall involvement of motorcycles in crashes as the not-at-fault party is about 43% but at intersections, the corresponding percentage is increased to 57%. Quasi-induced exposure estimates show that the motorcycle exposure rate at signalized intersections is 41.7% even though motorcycles account for only 19% of the vehicle population. This study seeks to examine in greater details, the problem of motorcycle exposure at signalized intersections. In particular, the exposure arising from potential crashes with red light running vehicles from the conflicting stream at four signalized intersections is investigated. The results show that motorcycles are more exposed because they tend to accumulate near the stop-line during the red phase to facilitate an earlier discharge during the initial period of the green which is the more vulnerable period. At sites where there are more weaving opportunities because the lanes are wider or where there are exclusive right-turn lanes, the accumulation is higher and hence an increased exposure is observed. The analysis also shows that the presence of heavy vehicles tends to decrease motorcycle exposure as their weaving opportunities become restricted as well as there is a greater reluctance for them to weave past or queue alongside the heavy vehicles and their effects intensify for narrower lane width.

Key Words: Motorcycle, Exposure, Signalized Intersection, Weaving Maneuver, Vulnerability

INTRODUCTION

Compared to other vehicle types, motorcycles have distinct advantages such as affordability, mobility and accessibility, but they have poor safety records. Based on a 5-year Singapore crash statistics from 2001 to 2005, motorcycles constitute about 36% of the total traffic crashes, even though their share in vehicle population is only 19% (1). Moreover, motorcyclists account for almost 49% of fatalities and about 53% of injuries on the road.

The situation is even more acute at signalized intersections which account for 33% of all crashes on the road network. Motorcycle crashes at signalized intersections represent about 54% of all crashes (1). Furthermore, while the involvement of motorcycles as the not-at-fault party is about 43% nationwide, the corresponding percentage at signalized intersections is higher at 57%.

The vulnerability of motorcycles at signalized intersections is affected by their risk as well as their exposure. They may be at a high risk due to various reasons, e.g., relatively low conspicuity leading to the apparent failure of motorists to see the motorcycles early. A number of studies (2, 3) have reported that drivers often overlook the motorcyclists in the traffic stream. The motorcycles may also be subjected to a higher exposure at signalized intersections but this has not been well explored in most safety studies. This may be because it is generally difficult to estimate the exposure from field studies.

One method to overcome the difficulty of measuring exposure is the quasi-induced exposure technique (4-7). Using this method, the quasi-induced exposure estimate of motorcycles at signalized intersections from the 5-year database is 41.7% which is much higher than the expected 19%, if exposure is based on vehicle distribution. Hence while it is often concluded that high motorcycle involvement is due to higher risk in motorcycle riding (e.g., 2, 8), this may suggest that the higher involvement rate may be due to a higher exposure as well. This paper examines if indeed motorcycles are more exposed at signalized intersections. This is done by conducting a detailed field study of motorcycle maneuvers at four signalized intersections. Before describing the field experiment in detail, the method of estimating induced exposure is first explained, followed by a description on how the data are collected and analyzed to verify if motorcycles have a higher exposure at signalized intersections.

ESTIMATE OF INDUCED EXPOSURE

Exposure can be defined as the extent to which road users are exposed to the environment resulting in crashes. Measuring the exposure to crashes is a great challenge in traffic safety research. Several measures of exposure have been suggested, for example, vehicle mileage in network study, entry flow or product of conflicting flow for particular traffic location or traffic site (for a detailed review see 9). However, these measures require extensive data collection which is time consuming. To circumvent this problem, the quasi-induced exposure technique (e.g., 4-7) has been used as an indirect measurement of exposure. The strength of this method is that it can make use of the crash dataset, instead of exogenous estimates like vehicle miles traveled, to estimate the exposure experienced by different road users.

Two major assumptions are made in this method: first, drivers and riders involved in multi-vehicle crashes can be identified as either the at-fault or not-at-fault party; and second, at-fault drivers and riders in crashes will “choose” their not-at-fault victims randomly from all vehicles present. Hence the distribution of the not-at-fault drivers and riders will represent the exposure to the accident hazards (e.g., 6, 7).

According to Stamatiadis and Deacon (6), relative exposure as measured by the quasi-induced exposure technique, can be taken as the relative measures of the traffic exposure experienced by various driver/vehicle categories. Relative exposure (RE) for any road user group j can be estimated as follows. Suppose the actual exposures of category j and for the entire population are E_j and E_{all} respectively. According to the second assumption, the probability of being involved in a crash as the not-at-fault party for unit exposure of any category is the same, say P_0. Hence, RE of road user group j is the ratio of the not-at-fault crash involvement in category j to that in entire population, i.e.,

$$RE_j = \frac{E_j}{E_{all}} = \frac{E_j p_0}{E_{all} p_0} = \frac{F_j}{F_{all}} \tag{1}$$

where, F_j and F_{all} denote the frequencies of the not-at-fault crash involvement in category j and in population respectively.

The exposure for different road user groups in Singapore is thus estimated using the crash data from 2001 to 2005. Among the 9228 multi-vehicle intersection crashes, 8167 cases of driver(rider)/vehicle units are identified as the not-at-fault party involved in crashes from a total of 19052 driver(rider)/vehicle units. The RE estimation for three types of vehicles (i.e., motorcycles, light vehicles, and heavy vehicles) is presented in Table 1.

The Table shows that the highest relative exposure estimate are for light vehicles (RE = 0.451). This is expected as light vehicles constitute a majority of vehicles on the road. However, RE for motorcycles is 41.7% which is rather surprising as motorcycles only account for 19% of total vehicle population. This means that motorcycles are more vulnerable at signalized intersections because they experience a higher exposure than expected.

MEASUREMENT OF OBSERVED EXPOSURE

In most cases, crashes due to red light running affect the first few vehicles discharging from the stop-line of the conflicting approach. Hence the vehicles queuing just behind the stop-line of the approach during the red phase are most vulnerable. The zone behind the stop-line can be regarded the affected zone, because the vehicles within this zone are more likely to be exposed to red running crashes. Moreover, Huang et al. (10) have found that most red running occur during the first few seconds of red and Bonneson and Zimmerman (11) have indicated that 98% of red runners run the red within the first four seconds of red. It is generally difficult to identify the vehicles that are more exposed in red-running crashes because the crash potential is affected by the red-running behavior as well as the intersection geometry, both of which vary from site to site as shown in a number of studies (e.g., 9, 12). For the purpose of identifying the vehicles that are exposed to the red light running crashes, vehicles queuing within 6 m of the affected zone in the approach and discharging within the first 4 seconds of green are sampled.

To assess the level of exposure of motorcycles at signalized intersections, four signalized intersections were selected and the traffic flow in each signal cycle video filmed. These intersections tend to have a high concentration of motorcycle usage and have different geometric conditions that may affect motorcycle maneuvers. As the data are to be grouped on a signal cycle basis, it mattered little when the observation is to be made. Nevertheless, to ensure a good vehicle queue during each cycle and a high proportion of motorcycles in the traffic, the morning period was chosen as the flow of motorcycles and other vehicles tend to peak together in the morning. A total of 25 signal cycles were observed at each of the site. Table 2 shows the intersection characteristics.

The four intersections are taken from various locations in Singapore. All have 4 lanes for straight-through and right-turn movements. Woodlands (W) and Riverside (R) have one shared lane and one exclusive right-turn lane while Jurong (J) and Ang Mo Kio (A) have one exclusive right-turn lane. Woodlands (W), Jurong (J) and Riverside (R) have standard lane widths giving an average value of 3.6 m while Ang Mo Kio (A) has a narrower approach width, averaging 3.3 m per lane. The percentage of motorcycles using the intersections varies from about 10% to 20% with Woodlands having the highest percentage and Riverside (R) with the lowest percentage. On the basis of the average lane width and number of right-turn lanes, the sites are categorized into high, medium and low degree of freedom for motorcycle maneuvers, i.e., HF, MF, and LF. Similarly the sites are also grouped according to high, medium and low percentage of motorcycles, i.e., HM, MM, and LM.

RESULTS

Observed Motorcycle Behavior

Visual observation from the video films shows that motorcyclists travel at their desired speed to the back of the queue of the traffic. Within the vehicle queue, they weave through the queue of vehicles at a reduced speed to reach as close to the stop-line as possible. This common behavior is also observed elsewhere (13). It is noted that where an exclusive right turn lane exists, (in Singapore, driving is on the left side of the road) motorcyclists will make use of the lane as a bypass if it is not fully utilized. As it is common for the right-turn phase to follow the straight-through phase, the straight-through lane will fill up first before the right-turn lane. Hence the unoccupied right-turn lane offers an added opportunity for motorcyclists to move to the front of the queue, including the use of the right-turn lane for straight through movement.

Motorcycle Accumulation in the Approach

The accumulation of motorcycles in the first 6 meters of the approach during the red phase is graphically presented in the figure 1. Accumulation is measured as the percentage of motorcycles of the total vehicles queuing within the 6-meters zone from the stop-line. To make a meaningful comparison between intersections which have different cycle and red times, the accumulation is plotted against the percentage of time into red.

The results show that in general the motorcycle accumulation increases with time into the red. However Ang MoKio (A) reaches a maximum accumulation percentage much earlier. The maximum accumulation appears to depend both on the degree of freedom for motorcycles to weave to the front of the queue and the percentage of motorcycles in the traffic. The high to medium freedom sites have final motorcycle accumulation percentages ranging from 53% to 71% with those having higher motorcycle proportions giving higher accumulation percentages (71% for HM-HF, 65% for MM-MF and 53% for LM-HF). But for low freedom site, though the flow of motorcycles is as high at 15.8% of all vehicles, the final accumulation of motorcycles is lower with only 39%. This maximum accumulation is also reached earlier. All these show that a higher amount of motorcycles will concentrate near the stop line if there is sufficient opportunity to weave through the queue.

Motorcycle Discharge from Stop-line

It is also likely that motorcycles will enter into the intersection earlier than other vehicle types since they form a higher concentration in the front of the queue. Motorcycles tend to accelerate from stop earlier and at a higher rate because of their higher power-to-weight ratio compared to other vehicles (14). To observe the discharge behavior, the distribution of motorcycle flow (vehicles/second) is plotted against the initial period of green in the figure 2. The figure shows that motorcycle flow increases rapidly within the first few seconds. In fact for the high and medium freedom sites, the motorcycle queues have fully discharged after about 12 seconds. For the low freedom site, the motorcycle queue has discharged over a significantly longer period with a well-defined maximum value. The flow profile follows the typical discharge pattern of other vehicles during the green phase.

The discharge profiles of motorcycles shown in figure 2 imply that motorcycles are spatially distributed differently depending on the degree of freedom to weave through the queue. Where weaving is highly restricted, the pattern follows the usual flow profile of other vehicles as shown the solid line in figure 3. Where there is greater freedom, the profile will follow the pattern indicated in the dashed line of figure 3. A comparison of the 2 curves in figure 3 shows that given the freedom to weave through the queue, motorcycles will utilize the early portion of the green. This has a significant impact on their exposure to right-angled collisions during the phase-change periods.

Estimation of Observed Motorcycle Exposure

Assuming the critical period of conflict is within the first four seconds of green, the observed relative exposure of motorcycles can be computed as the probability of motorcycles found in this initial green period. The results are plotted in figure 4. For comparison, the probability of a motorcycle found in the traffic stream, as determined by the ratio of motorcycles to the total vehicles over the cycle, is plotted alongside the observed relative exposure. The observed relative exposure is higher among the high and medium freedom sites (from 0.675 to 0.755). This is marginally dependent on the proportion of motorcycles in the traffic stream (0.10 to 0.19) but is at a significantly increased rate. On the other hand, the low freedom site gives a lower observed relative exposure (0.383) even though this is still higher than the proportion of motorcycles over the cycle (0.16).

In all cases, the relative exposure is significantly higher than the proportion of motorcycles in the traffic stream. Hence even if the crash risk of motorcycles is the same as for other vehicles (which is not necessarily true), a higher motorcycle involvement rate is expected because of the high relative exposure. This finding is consistent with Presusser et al. (15) who reported that motorcyclists are over-involved in collisions at signalized intersections, particularly when there are violations by the opposing traffic.

The results also indicate that the crash problem is more acute at sites where there is a higher degree of freedom for motorcycle weaving because of an increased observed relative exposure. If the motorcycles are completely restricted from weaving through the queue, i.e., they will queue just like any other vehicles, the observed relative exposure would be the probability of motorcycles found in the traffic. Hence for high and medium freedom sites, the observed relative exposure has increased by about 0.56 while for the low freedom site, it has increased by 0.22.

DISCUSSION

From the results it is clear that motorcyclists tend to accumulate in the front of the queue for earlier access to the intersection, but this behavior leads them to be highly exposed to red-light runners from the conflicting stream. It would be useful if the influential factors, i.e., those affecting the accumulation of motorcycles, can be analyzed systematically.

The relationship between the number of motorcycles accumulated in the first 6 meters of the approach and motorcycle flow is established for each of the site and presented in figure 5. For every site each data point in this figure represents the average number of accumulated motorcycles grouped at intervals of 5 veh/hr motorcycle flows. The relationship for each of the site is found to be highly correlated (R^2 ranging from 0.49 to 0.77). The regressed line for each of the intersections demonstrates the effect of motorcycle flow and geometry (governed by the lane width and the number of right-turn lane).

From figure 5, it can be seen that generally, the accumulation of motorcycles is found to increase with the motorcycle flow. A higher accumulation is found in the 3 sites (W, J and R) which correspond to the cases where the average lane width is 3.6m. In contrast, the site with a narrower average lane width (3.3m) experiences a lower accumulation value. The sites with wider lanes also experience a higher rate of accumulation. This is reasonable as there is a higher opportunity for motorcycles to move to the front of the queue if the lanes are wider. Notice also, that the number of right-turn lane appears to affect the rate of increase in the accumulation, i.e., J and A have lower slopes compared to W and R.

A similar graph of accumulation of motorcycles is plotted against the percentage of heavy vehicles in the traffic stream in figure 6. For the purpose of examining the trend, the accumulation data are grouped at intervals of 2% of heavy vehicles. The effect of heavy vehicles on motorcycle accumulation is shown by the slopes of the regressed lines in figure 6. Generally the accumulation of motorcycles decreases with increasing percentage of heavy vehicles. For the sites with high and medium freedom of motorcycle weaving (i.e., W, J and R), the slopes are almost similar and gentler than that of the site with low freedom of weaving (i.e., A). The findings reflect the restriction on motorcycles to move to the front of the queue as well as the reluctance of motorcyclists to pass or queue alongside the heavy vehicles. The effect of lane width intensifies this phenomenon resulting in a steeper reduction in accumulation with increased presence of heavy vehicles.

CONCLUSION

This study attempts to examine the exposure of motorcycles at signalized intersections. To achieve this, the motorcycle movements at four selected signalized intersections were observed. Using the phase-change period as a measure of opportunity for potential conflicts between opposing traffic and the accumulation of vehicles during the red phase and discharge of vehicles during the initial period of green as measures of exposure, the study shows that motorcycles are more exposed at signalized intersections compared to other vehicles.

The increased exposure may be due to a number of factors. The tendency of motorcycles to move to the front of the queue increases the likelihood of a higher motorcycle discharge during the initial period of green. Furthermore, the ability of motorcycles to accelerate faster and easier makes them more prone to be involved in crashes during the initial period of green. Wider lanes and the provision of right-turn lanes will enable motorcycles to weave more easily to the front of the queue and hence increases the level of exposure. The presence of heavy vehicles in the traffic stream has a restricting effect on motorcycle weaving maneuver and hence exposure and this effect is even more acute when the lanes are narrower.

Crash statistics shows that over 60% of the crash-involved motorcycles at signalized intersections are involved in the right-angled crashes. From the point of right-angled crashes at signalized intersections, restricting motorcycle accumulation during the red phase may be an effective way of reducing motorcycle exposure to crashes. This may lead to a reduction in motorcycle right-angled crash involvement. However, this may be very difficult to implement. More innovative research could be conducted to find a way to stop their accumulation in front of the queue at signalized intersections.

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TABLE 1 Exposure Estimation by Quasi-Induced Exposure Method

Vehicle Type	Multi-vehicle crash involvement as the not-at-fault party at intersections						Relative Exposure
	2001	2002	2003	2004	2005	Total	
Motorcycle	844	816	592	677	474	3403	0.417
Light Vehicle	863	894	689	733	506	3685	0.451
Heavy Vehicle	266	248	185	225	155	1079	0.132

TABLE 2 Site Location and Characteristics of Video Data Collection

Intersection Name	Data Collection Approach	Location in Singapore	% of Avg. MC flow	Avg. Lane width(m)	No. of Right turn lane	Category*
Woodland (W)	W Ave2	North-West	17.6	3.6	2	HM-HF
	W Ave7		19.8	3.6	2	
Jurong (J)	J Town Hall Rd	South-West	15.1	3.6	1	MM-MF
	J East Ave1		13.0	3.6	1	
Riverside (R)	R Rd	North-West	10.3	3.6	2	LM-HF
	W Ave5		10.1	3.6	2	
Ang Mokio (A)	AM Ave3	North-East	16.2	3.3	1	MM-LF
	AM Ave6		15.4	3.3	1	

* HM-HF: High motorcycle flow, high freedom;
MM-MF: Medium motorcycle flow, medium freedom;
LM-HF: Low motorcycle flow, high freedom;
MM-LF: Medium motorcycle flow, low freedom

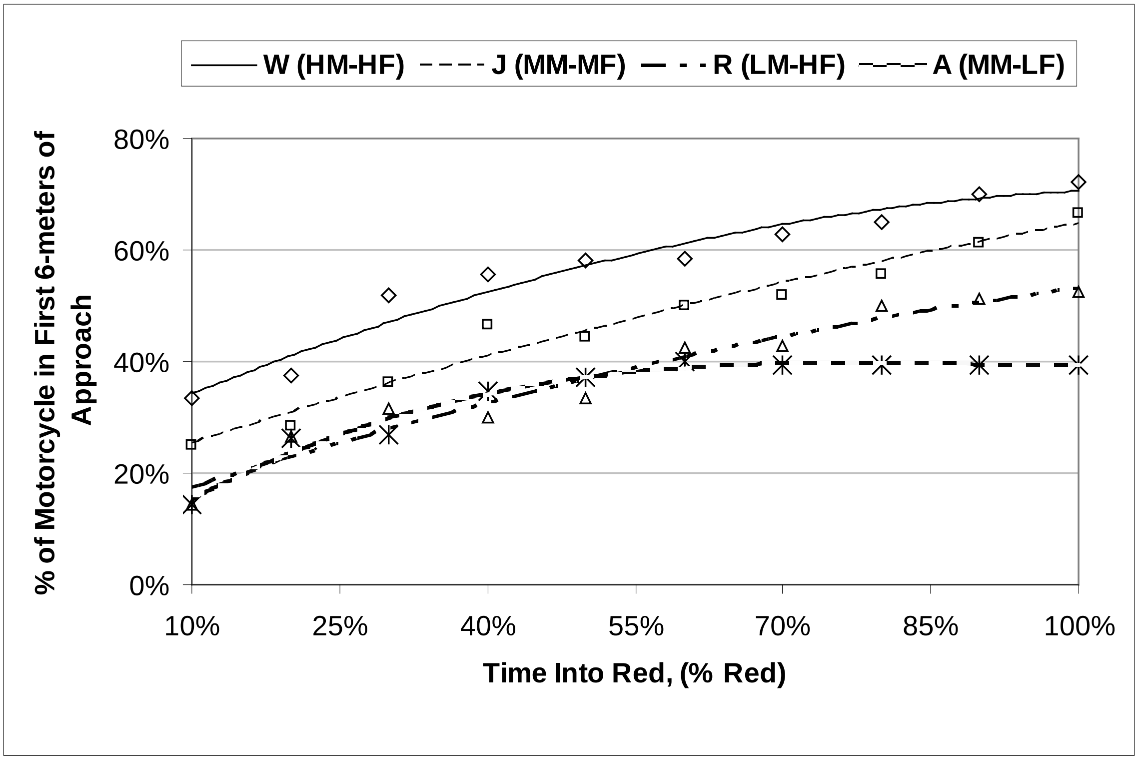

FIGURE 1 Accumulation of motorcycles in the front of the queue

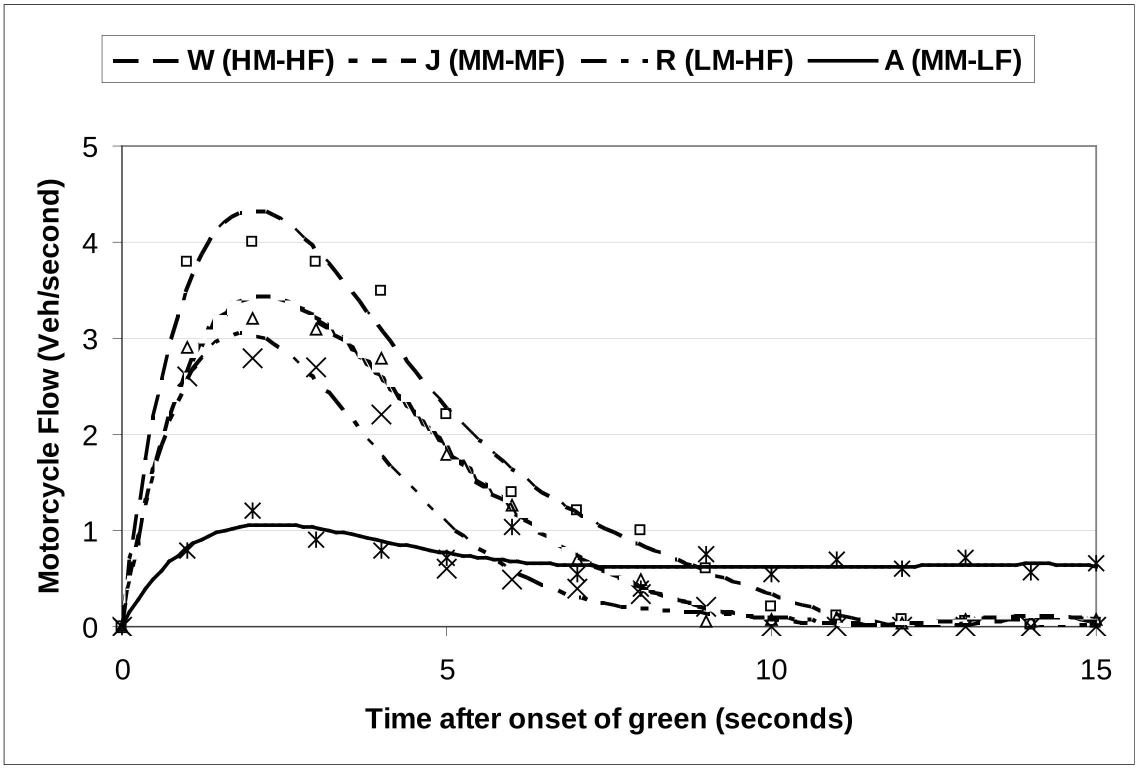

FIGURE 2 Motorcycle flow distribution after onset of green

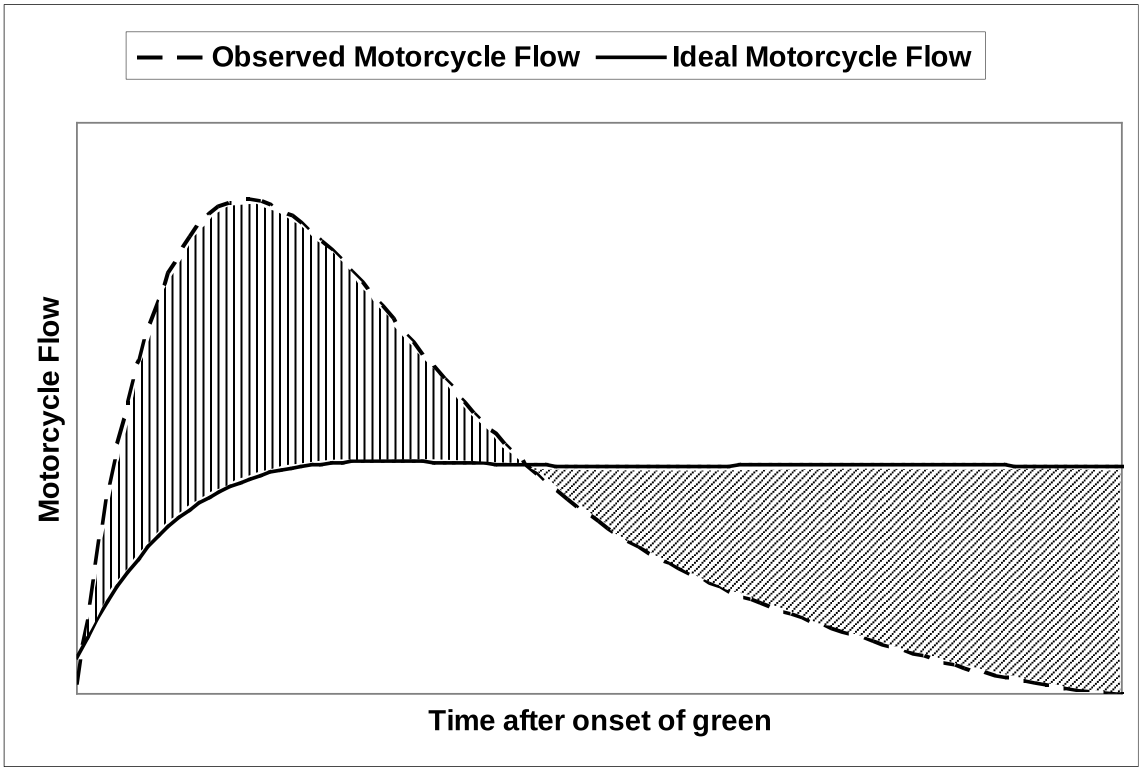

FIGURE 3 Explanation of motorcycle exposure at signalized intersection

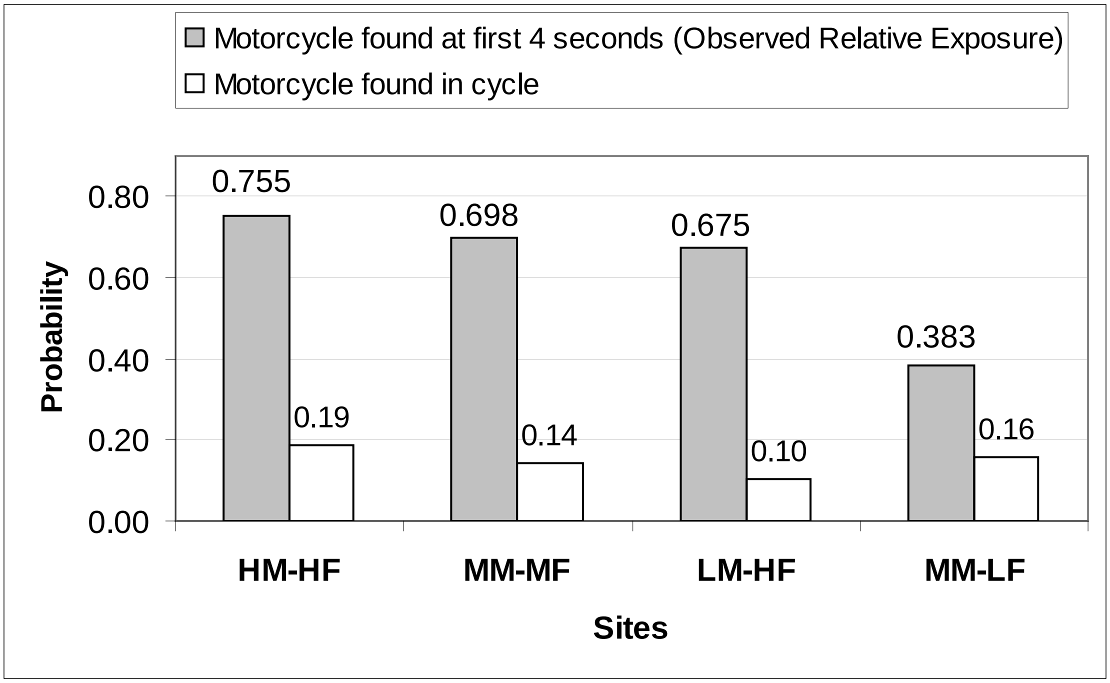

FIGURE 4 Observed motorcycle exposure at different Sites

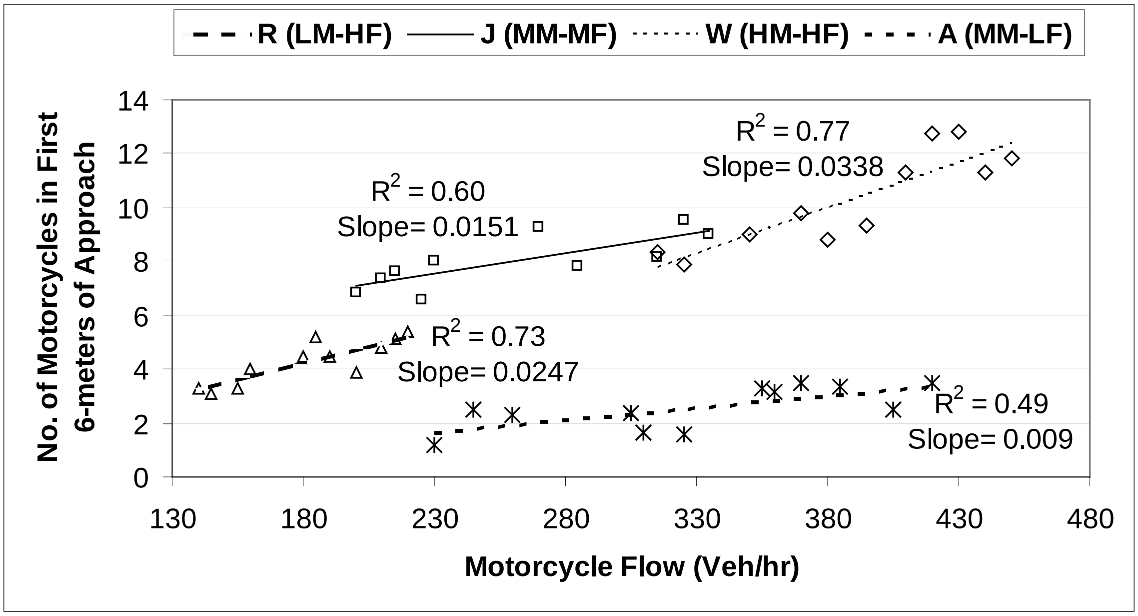

FIGURE 5 Frequency of motorcycles in the front of the queue as function of motorcycle flow for different sites

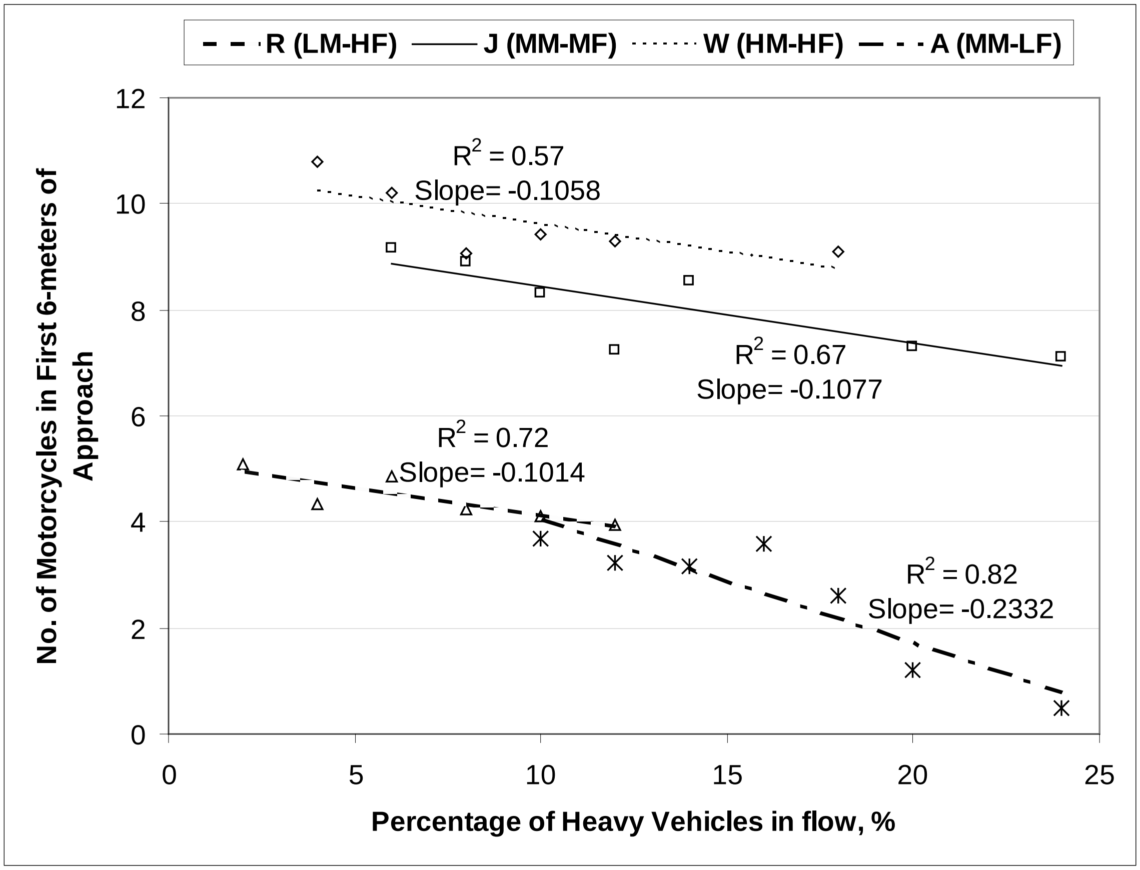

FIGURE 6 Frequency of motorcycles in the front of the queue as a function of heavy vehicle percentage