

## An analysis of the interactions between vehicle groups at intersections under mixed traffic flow conditions

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**Abstract:** “Grouping” behavior is a unique characteristic of the mixed traffic with the dominance of motorcycles. At two-phased signalized and non-signalized intersections in Hanoi city there are increasingly serious conflicts between vehicles groups, especially between the unprotected left-turn and straight-go groups, thereby reducing traffic speeds and increasing accidents. This study was aimed to investigate the mechanisms of the inter-group interactions and suggest measures to manage the intersections. First, a general analysis was conducted to initially understand the interactive strategies by each group and determinant factors. Then, a gap acceptance model was developed to deeply analyze the gap decision-making process by the left-turn groups and capture behavioral differences between the motorcyclists and car drivers who lead the groups. The study found that the total gap, which combines the longitudinal and lateral gaps, strongly influenced the gap decision of both the drivers. Interestingly, the number of motorcycles in the left-turn group could make its leading motorcyclists more aggressive. The leading car drivers appeared to be sensitive to the expected waiting time while the motorcyclists did not.

**Key Words:** *driver behavior, group interactions, gap acceptance model, mixed traffics, intersection management*

### 1. INTRODUCTION

Mixed traffics which consist of motorcycles and automobiles (or autos) are very popular in many developing cities. Hanoi city of Vietnam has experienced a drastic increase in the number of motorcycles for more several decades. Due to the rapid economic growth, the motorcycle and automobile ownerships are growing at rates of 14% and 16% per year, respectively (Hanoi Police Department, 2007). As the results, road traffic safety has become very serious since 1990s. Annually, there are about 14,000 road accidents, killing more than 11,000 people in the whole country (Vietnam National Traffic Safety Council, 2005). Motorcycles and automobiles have involved in 90% of the total accidents and the risky behaviors of the drivers are the dominant causes, contributing to over 70% of the total causes.

JICA (2006) reported that around 80% of the urban intersections in Hanoi are prone to increasingly serious accidents and heavy congestions. Thus, it is critical to study the driver behaviors at intersections to help address the problems.

Managing the mixed traffic flows, particularly at intersections, is a challenging task for big cities in Vietnam. There have been increasingly serious conflicts between motorcycles and automobiles at intersections because the share of automobiles in the traffic flows is increasing dramatically. While negotiating at intersections, non-cooperative behaviors of the drivers, both motorcyclists and car drivers, have caused significant speed reduction and high accident risks. Deep understanding of the interactions will be useful for introducing effective policies or measures to enhance mixed traffic performance (Hsu et al., 2003).

Interestingly, the motorcycles usually move in groups while crossing the intersection. This is a unique characteristic of the mixed traffics and hardly observed in the car dominated traffics. In this study, we called it as “grouping” behavior. The question is why the motorcycle drivers prefer to cross the intersection in groups. It would be a matter of psychology that the drivers may feel safer to cross the intersection or more confident to fight against the other groups and/or automobiles if they cross the intersection in a group. As a result, the conflicts between vehicles become the conflicts between vehicle groups. Because the majority of the intersections in Hanoi city are two-phased signalized, the conflicts between groups of vehicles going straight (through groups) on the main road and groups of vehicles turning left from the opposite direction of the main road (unprotected left-turn groups) become the most dangerous (Figure 1). Thus, it is important to understand the interactions between the vehicle groups (or inter-group interactions) and the determinant factors of the interactions to help suggest management measures.



Figure 1(a) A conflict between a left-turn bus and a straight-go vehicles group



Figure 1(b) A conflict between a straight-go and left-turn groups of vehicles

There were a number of studies on motorcycle behavior and modeling mixed traffic, however, most of the studies focused on analyzing movement behaviors of an individual motorcycle in the mixed traffic flows. For example, Lawrence and Chiung-Wen (2003) attempted to develop a particular-hoping model with fixed moving rules to describe motorcycle's moving behavior in mid blocks of mixed traffic flows. Chan and Yuh-Ting (2004) assumed that the movement of a motorcycle was a two-dimensional movement, in which the longitudinal one makes the motorcycle go forward while the lateral one makes it get appropriate positions. In the same line, Nguyen (2004) introduced a concept of personal space to explain the movement behavior of the motorcycle under the influence of surrounding motorcycles at both signalized and non-signalized intersections. Chu et al. (2005a, 2005b, 2006) analyzed several specific behaviors of the motorcycle traffic, such as overtaking and paired riding behaviors at mid-blocks, deceleration behavior at signalized intersections, and the speed-flow-headway relationships of motorcycle traffics. Unfortunately, there seems to be no study on the conflicts and/or interactions between groups of mixed vehicles at intersections.

The objectives of this study are to address several key questions. First, what is the behavioral mechanism of the inter-group interactions at intersections? In particular, how one group interacts with another? What factors significantly influence the interactions? What are effects of grouping behavior on the interactions? Second, how differently left-turn car drivers behave as compared to left-turn motorcycle drivers in term of gap decision? Finally, the study is to suggest some management concepts based on the findings.

The remainder of this paper is organized as follows. Section 2 encompasses the survey sites and data collection. Section 3 presents the general analysis of gap decisions by vehicle groups to understand key characteristics of the inter-group conflict negotiations. Section 4 develops a gap acceptance behavior model to analyze the gap decision by the unprotected left-turn group and examine the behavioral differences between the motorcyclists and auto drivers, who lead the unprotected left-turn groups. Section 5 summarizes the findings and suggests several management measures.

## **2. DATA COLLECTION**

### **2.1. Surveyed Intersections**

Since this study was also intended to examine the effect of automobile share increase on the conflicts as well as behavioral differences between car and motorcycle drivers, totally 4 two-phased signalized intersections were selected, 2 dominated by motorcycles and the rest of high automobile share. Each intersection was video based surveyed twice a day, from 6.30 to

9.00 in the morning (peak hours: 7.30-8.00) and from 3.30 to 5.30 in the afternoon (peak hours: 5.00-5.30). The gap events were randomly extracted from the video tapes recorded.

## 2.2. Data Requirements

To analyze the interaction behavior and estimate behavioral models, it was required to collect time-series information on every vehicle getting involved in the interactions. The basic information included types and positions of all vehicles in the left-turn and straight-go flows. Then, the information was used to derive secondary information, such as speeds, accelerations, relative distances, group identification, and group leading vehicles. Also, intersection characteristics such as road geometry, lanes, signal system and so forth were also collected.

## 2.3. Data Extraction

The data extraction technique was employed to construct the database. All vehicle movements at the site were captured into the videotape at a pace of 5 frames per second. Vehicle positions which belonged to the screen coordinates system were identified from the images extracted from the videotape at a 0.5 second interval, then were converted into roadway coordinates using the coordinate transformation method (Khan et al., 2001).

## 3. CHARACTERISTICS OF THE INTER GROUP INTERACTIONS

### 3.1. Definition of a Group of Vehicles

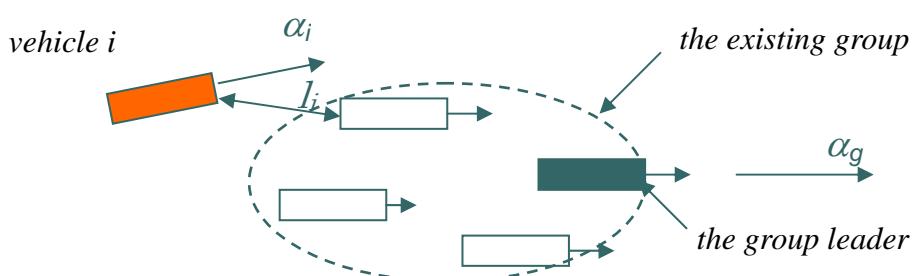


Figure 2 A method for defining a group of vehicles

It was very important to define a group of vehicles and thus a method to define a group was developed in this study. As shown in Figure 2, vehicle  $i$  will be included in the existing group if two criteria are satisfied. First, the relative distance,  $l_i$ , between the vehicle  $i$  and the nearest member of the existing group must be smaller than a critical value,  $l_0$ . In this study,  $l_0$ , was assumed to be 4.0 m since the average speed was about 4.0 m/s and hence it would take 1s for vehicle  $i$  to catch up the nearest vehicle. Second, the relative movement direction between

vehicle  $i$  and the whole existing group is smaller than a critical value,  $\alpha_0$ . It is assumed that  $\alpha_i$  is an angle between the moving direction of vehicle  $i$  and some virtual fix line (such as a heart line of the main road) and  $\alpha_g$  is an angle between the average moving direction of the whole existing group and the virtual fix line (both measured in degrees). The value of the relative movement direction is the absolute difference between  $\tan(\alpha_i)$  and  $\tan(\alpha_g)$ . The  $\alpha_0$  was given by 0.20 because the maximum lateral deviation from the current movement line of a vehicle was observed to be around 0.20. In other words, an average vehicle could not make a lateral deviation of over 0.20m per 1.0m traveled longitudinally. If the relative movement direction is greater than 0.20, the vehicle may not want to join the existing group.

### 3.2. Interactive Strategies

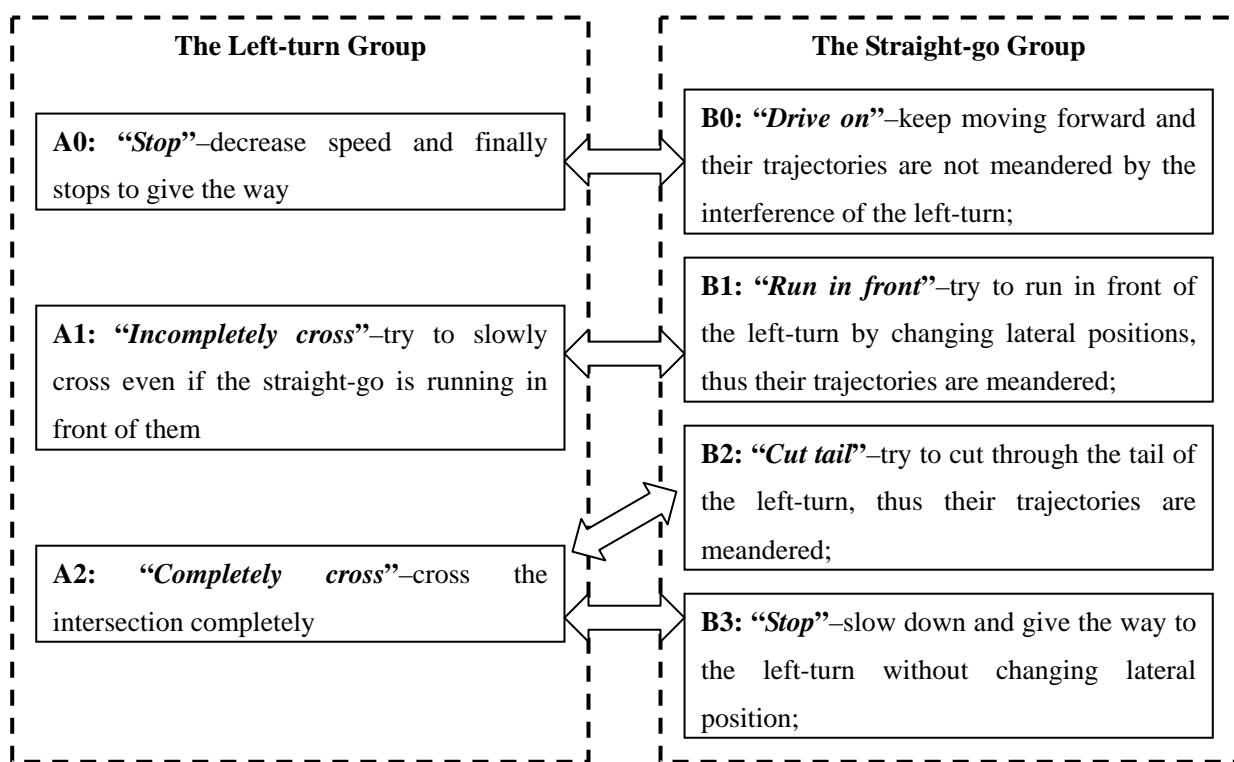


Figure 3 Interactive strategies available to each group

As explained previously, at two-phased signalized intersections when the lights turn green, motorcycles and cars from directions of the main road start to go through (or straight) and to turn left in groups, not in platoons. The conflict between the two groups can be explained using the two-player non-cooperative game (Kita, 1999), in which each player or group chooses one strategy to move from their set of available strategies. The outcome of the interaction is a combination of the two strategies chosen by the two groups and the decision made by one group may be dependent on the strategy selected by another group. As illustrated in Figure 3, there are basically four combinations of interactive strategies in the reality. First, if the left-turn group stops and rejects the current gap (A0), the straight-go group will

continue moving forward without changing lateral positions, or its trajectory is not meandered (B0). Second, if the left-turn group decides to cross the intersection completely (A2), the straight-go may slow down without changing its lateral positions and give way to the left-turn group (B3). Third, however, sometimes the leaders of the straight-go group are so aggressive that they would try to cut through the tail of the left-turn group (B2) while the left-turn group is crossing the intersection (A2), thus its trajectory is meandered. Lastly, while the left-turn groups is slowly crossing the intersection (or incompletely cross; A1), the straight-go group may run in front of them, therefore the trajectory of the straight-go group is meandered (B1). In short, the four strategy combinations are coded as A0-B0, A1-B1, A2-B2, and A2-B3.

### 3.3.Behavioral Characteristic of the Left-turn Groups

Totally 653 gap events were collected to initially understand the gap acceptance and rejection behavior of the left-turn groups. As shown in Figure 4, the gap size can be one of the important factors that influence the strategy by the left-turn group. It is noted here that the gap is called as the longitudinal gap as it is measured by dividing the longitudinal distance between the two groups by the speed of the straight-go group leader. Particularly, the “reject” action was often chosen if the gap was shorter than 3s and “completely accept” action was chosen if the gap was longer than 4s. Interestingly, “incompletely cross” action was mostly chosen if the gap ranged from 1s to 3s. This finding means that the straight-go vehicles are more likely to take “run in front” if the gap is relative small.

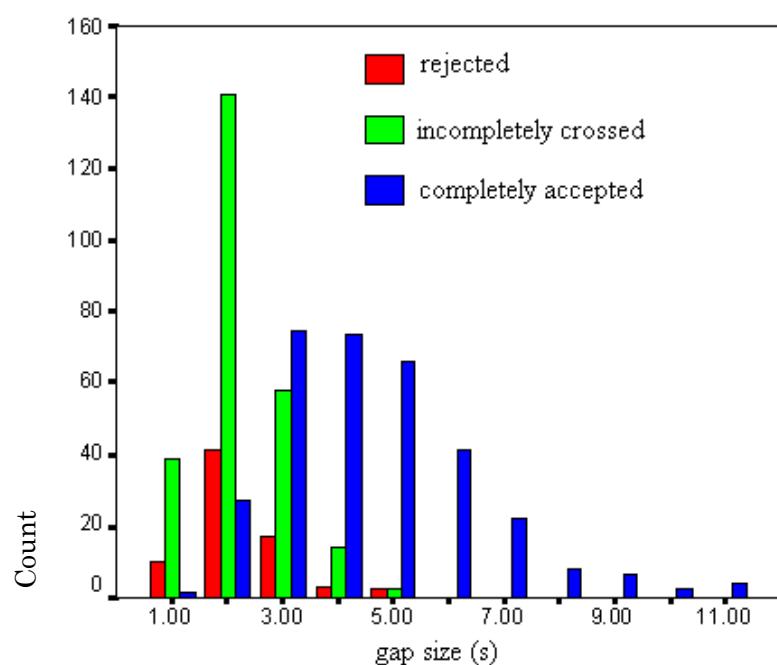


Figure 4 Left-turn group's action by gap size

### 3.4. Behavioral Characteristics of the Straight-go Groups

It is also important to know how the straight-go group, especially the group leading vehicle, had responded to the action by the left-turn group. First, the analysis of total 326 gap events shows that most of the “run in front” and “cut tail” actions occurred when the gap ranged from 2s to 4s (Figure 5), which is quite consistent with the previous finding. If the gap was 5s or longer, the straight-go leader was more likely to slow down and stop, without changing its lane. If the gap was shorter than 3s, the leader was more likely to drive on.

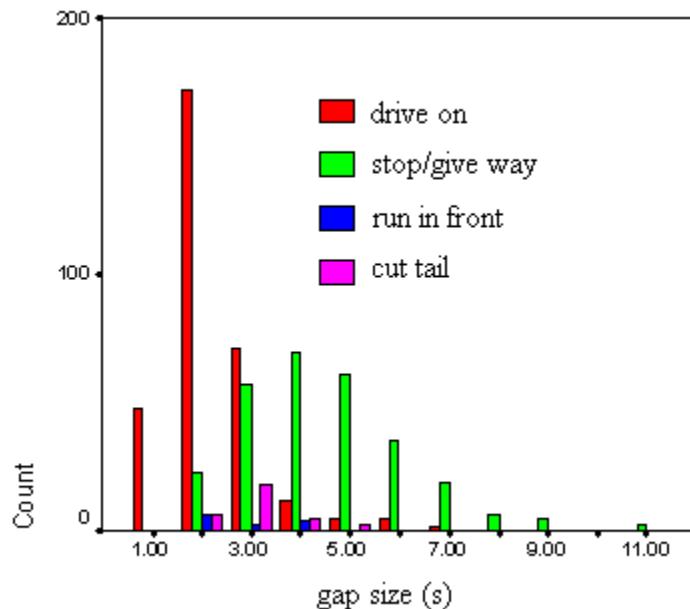


Figure 5 Straight-go group leader's action by gap size

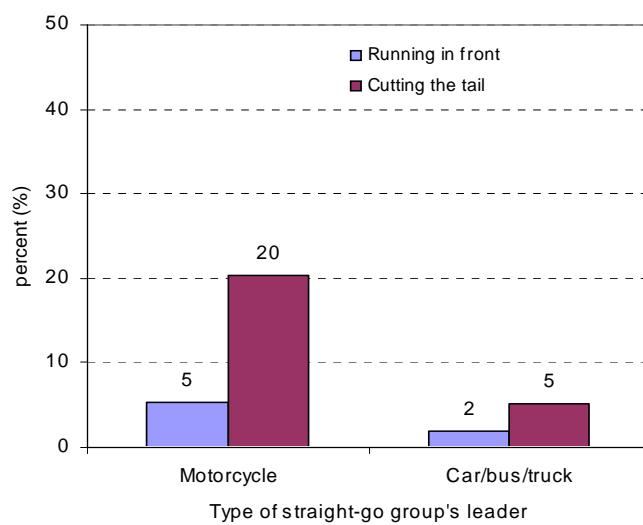


Figure 6 Percentages of “run in front” and “cut tail” actions by the type of the straight-go leading vehicles

Moreover, it is found that if the leader is a motorcycle, he/she is more likely to run in front or cut through the tail of the left-turn group. As shown in Figure 6, the analysis also shows that both straight-go motorcycles and cars performed “run in front” and “cut tail” behaviors. However, the percentage of cutting tail actions dramatically dropped from 20% to 5% of the total observations when the leader type changed from motorcycle to automobile. It is seemed that the motorcycles find it easier to perform the actions of running in front and cutting the tail than the autos.

Also, if the leader of the left-turn group is an auto, the straight-go leader is more likely to cut through the tail of the left-turn group. Figure 7 shows that total percentage of “running in front” and “cutting tail” actions substantially increased from 9% to 27% when the left-turn leader changed from the motorcycle to the auto. This finding may indicate that the increase in auto share may reduce the performance and safety at the intersections.

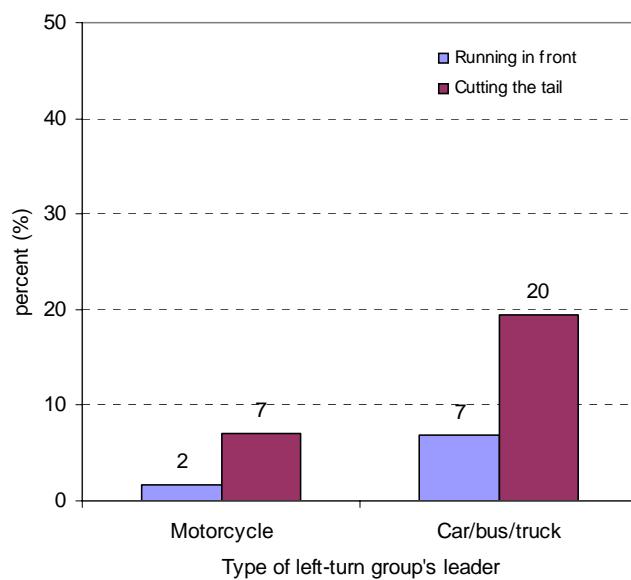


Figure 7 Percentages of “run in front” and “cut tail” actions by the type of the left-turn group leading vehicles

### **3.5. Initial Finding Summary**

The initial findings are useful for developing the gap acceptance model in the next section used to analyze the gap decision by the left-turn group. First, the straight-go group leading autos often keep their lanes while conflicting with the left-turn groups and thus it is possible to apply the traditional gap acceptance model to analyze the left-turn group gap acceptance behavior. Second, the determinants of gap acceptance behavior of the left-turn group may include gap size and the type of the two leaders. It is revealed that the relative size between

the two groups may be an important factor. Vehicles of different size or type would contribute differently to the “power” of the whole group. Of course, there would be other important factors to the interactions.

#### **4. THE LEFT-TURN GROUP GAP ACCEPTANCE BEHAVIOR MODEL**

As previously investigated, in case the leader of straight-go group does change the lane while interacting with the left-turn group, it is possible to apply the gap acceptance model to analyze the gap decision of the left-turn group in order to examine when and how the group decides to accept or reject the gap and what factors significantly influence the decision-making. Well understanding of the behavioral mechanism will be helpful in recommending some new concepts for managing the mixed traffics. The following section focuses on the development of such a group based gap acceptance behavior model.

##### **4.1.Assumptions**

**Assumption 1, “The left-turn group leading vehicle is treated as the decision maker for the whole group, so-called the left-turn leader”.** At the surveyed intersections, it is often observed that once the leading vehicles have decided the way to move, the other vehicles in the same group often follow the decision. Again, this phenomenon can be explained by the idea that by following the leader’s strategy to move the followers would feel safe and could avoid collisions with the vehicles of the opposing flows. However, if the leader sometime chooses an inappropriate way to move, some followers may decide to move in their own ways, not following the leader. In such a case, the group is more likely to be broken into smaller groups and the conflict becomes very complicated. It is required to apply the multi-player game theory to analyze the interaction. However, this paper did not take into account the conflicts of this kind and therefore it remains as the future research.

**Assumption 2, “The straight-go group leading vehicles do not change lane while negotiating intersection with the left-turn group”.** Generally, since autos always follow the lane disciplines, if the leader of the straight-go group is an auto the assumption holds true. In fact, in Vietnam the inner lanes are often occupied by autos and thus the left turning group finds it difficult to cross the inner lane(s) of the opposite direction.

Based on these assumptions, the logic of the conflict negation between the left-turn and straight-go groups is developed as illustrated in Figure 8. The left-turn leader has to decide whether to accept (or cross completely) or reject (or stop) the gap. In response, the straight-go leader will decide to stop (still keeping lane) or drive on. Among many factors of the

decision-making, this research pays special attention on the effect of the grouping behavior by checking if the following vehicles in the group (the number and type) significantly and indirectly influence the decision of the group leader through its direct effect on the behavioral change of the leader of the opponent group.

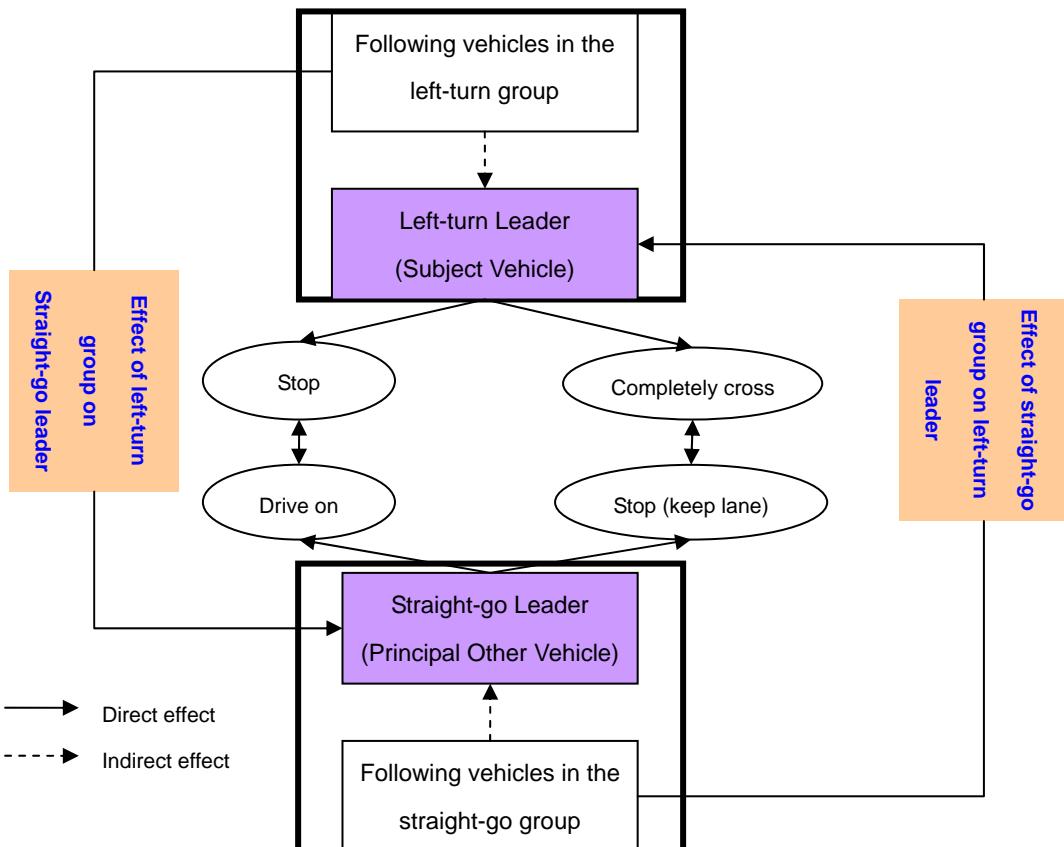
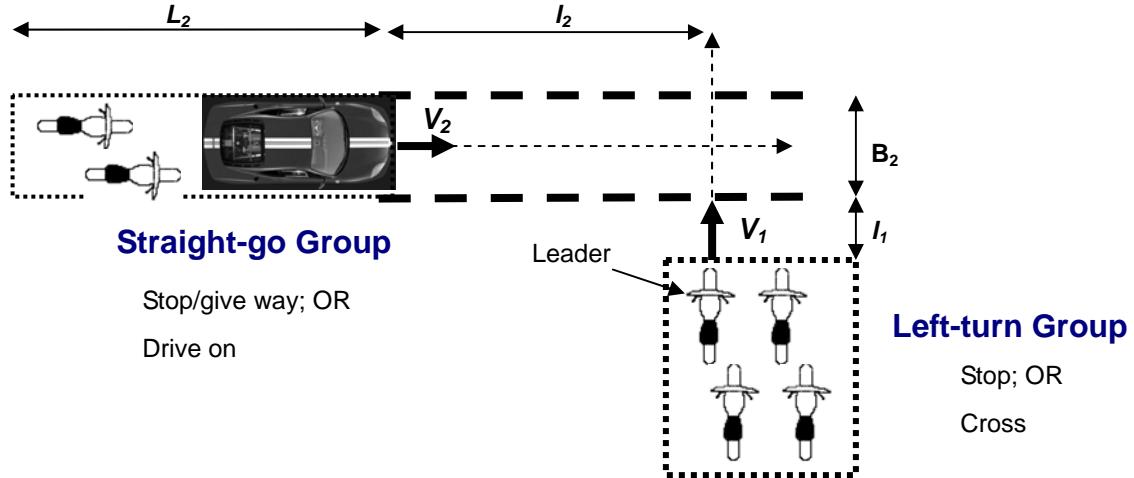


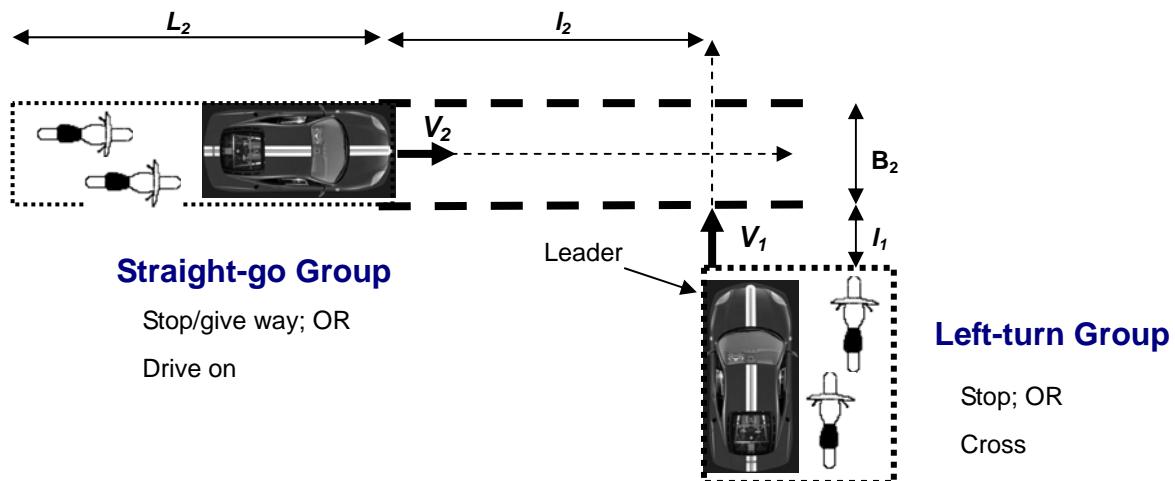
Figure 8 A logic of the inter-group conflict negotiation

#### 4.2. Model Development and Specifications

As shown in Figure 9, the leader of the left-turn group may be either a motorcycle or an auto. Given a gap created by the straight-go groups, the leading motorcycle and car of the left-turn group may make decision differently. Therefore, it is important to investigate the behavioral difference between the motorcycle driver and auto driver.



(a) The left-turn leader is a **motorcycle**



(b) The left-turn leader is an **automobile**

Figure 9 Scheme of the left-turn group gap acceptance model

Taylor et al (1998) used a discrete choice model to analyze gap acceptance behavior of the bicyclists when crossing a motor-traffic stream. This study applied the same method with the considerations of the grouping effect and other factors that are typical to the mixed traffics. The logit model was selected because of its mathematical simplicity. The model is specified as a binary logit model in which the utility of each alternative response, accept or reject the gap, is specified as follow:

$$U_i = V_i + \varepsilon_i \quad (1)$$

where,

$U_i$  is the utility of alternative response  $i$  for a given driver

$V_i$  is the systematic component of the utility, given below

$$V_i = \beta' X \quad (2)$$

$X_i$  is a vector of factors contributed to the gap decision

$\beta_i$  is a vector of coefficients to be estimated

$\varepsilon_i$  is random component

In the logit model (Ben-Akiva and Lerman, 1985), since  $\varepsilon_i$  is independently and identically Gumbel distributed and the utility function takes the linear form, the probability that alternative  $i$  will be chosen can be written as follow:

$$p(i) = \frac{\exp(V_i)}{\sum_{i \in L} \exp(V_i)} \quad (3)$$

where,  $L$  is the set of available alternative

#### 4.3.Factors to be Examined

**Total gap (s)** is introduced into the utility function. The total gap was calculated by subtracting the longitudinal gap by the lateral gap as below:

$$\text{Total\_gap} = LG - LaG \quad (4a)$$

$$\text{where, Longitudinal gap (s), } LG = \frac{l_2}{V_2} \quad (4b)$$

$$\text{Lateral gap (s), } LaG = \frac{l_1 + B_2}{V_1} \quad (4c)$$

$l_1$  = lateral distance between the two group leaders or lateral gap (m)

$l_2$  = longitudinal distance between the two leaders or longitudinal gap (m)

$B_2$  = width of current lane of the straight-go group (m)

$V_1$  = speed of the left-turn group leader (m/s)

$V_2$  = speed of the straight-go group leader (m/s)

**Expected waiting time, EWT (s)** is equal to the current waiting time plus an additional waiting time if the left-turn group ignores the current gap, calculated as follows:

$$EWT = (\text{current\_time\_frame} - 1) + \frac{(l_2 + L_2)}{V_2} \quad (5)$$

where,

$\text{current\_time\_frame} - 1$  = current waiting time (s)

$L_2$  = length of the straight-go group (m)

The **type of the left-turn group leader, SV**, was also examined. The value of this factor is given as followings:  $SV = 1$  if the leader is a motorcycle, 2 if a passenger car; 3 if a mini-bus or a mini-truck and 4 if a bus or a truck. Also, **the group composition** was examined by taking into account the numbers of motorcycles, passenger cars, mini-buses/minи-trucks, and buses/trucks in the group while estimating the models.

#### 4.4. Estimated Gap Acceptance Behavior Model of the Left-turn Motorcycle Drivers

Factors that significantly influence the motorcycle driver behavior were examined based on the analysis of the total 240 gap events, in which the left-turn group leaders were all motorcycles. Many combinations of the factors were considered while estimating the model and finally the best result was obtained as presented in Table 1.

Table 1 Model estimation results

Variable/Factor	The Motorcyclist		The Car Driver	
	Coeff.	p-value	Coeff.	p-value
Total gap	2.449	0.000	2.887	0.000
EWT (expected waiting time)	-0.045	0.132	0.127	0.072
MC1 (the number of motorcycles in the left-turn group)	0.198	0.048		
V1 (Speed of the left-turn group leading vehicle)			0.165	0.080
Constant	-2.257	0.000	-4.225	0.000
Samples	240		150	
-2 Log likelihood	91.417		87.513	
Cox & Snell R Square	0.648		0.551	
Nagelkerke R Square	0.869		0.717	

**Effect of the total gap:** It is shown in Figure 10 that about 10% of the left-turn group leading motorcyclists still accept zero gaps, more than half of them may accept 1-second gaps, and all would accept gaps that longer than 3s. It seems that taking into account both longitudinal and lateral gaps could realize how riskily the motorcycle drivers are accepting the gaps.

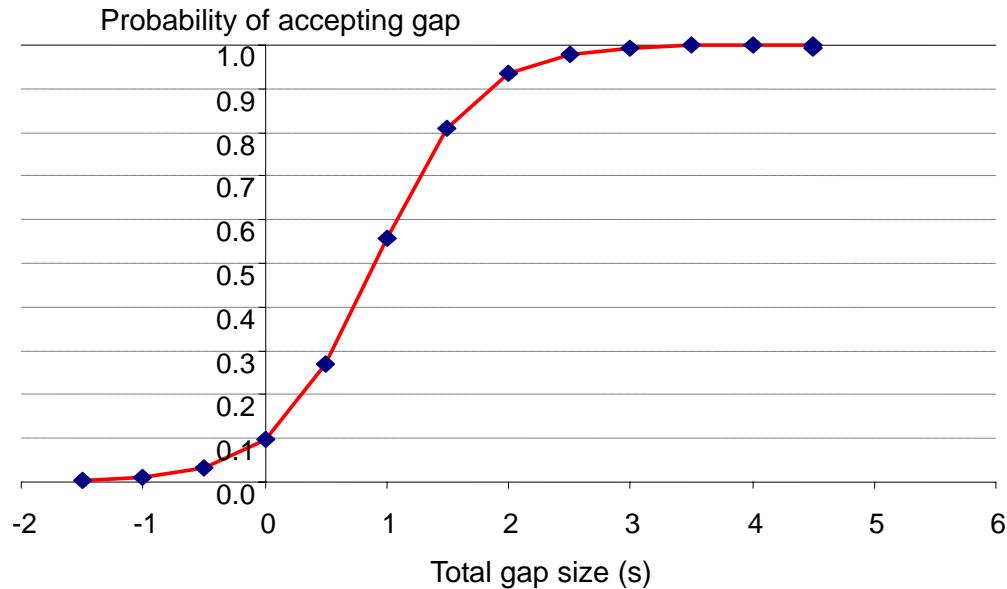


Figure 10 Cumulative probabilities of motorcyclists' gap acceptance by total gap

**Effect of expected waiting time:** As surprisingly seen in Figure 11, if the motorcyclist is expected to wait longer for the next gap, the probability of accepting the present gap decreases. Given the same gap of 1 second, the acceptance possibility decreases from 60% down to 30% if the expect waiting time increases from 5s to 40s. It is seemed that the motorcycle drivers are not sensitive to the expected waiting time due to some reasons.

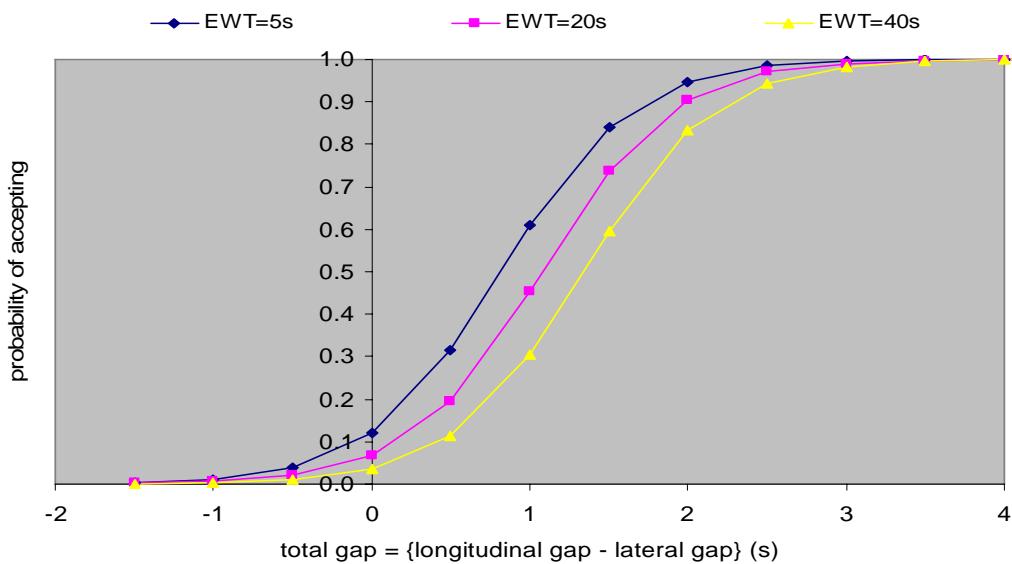


Figure 11 Effect of expected waiting time on the motorcyclist behavior

**Effect of the number of motorcycles in the left-turn group:** It is extremely interesting that the increased number of motorcycles strongly influenced the gap decision by the left-turn motorcyclists. Figure 12 shows that, given the zero gaps, the possibility to accept the gap

would increase from 0.08 to 0.25 and 0.60 if the number of motorcycles in the left-turn group increases from one to 10 and 20 motorcycles. Given the gap of 1 second, the acceptance possibility dramatically increases from 0.50 to 0.95 if the left-turn group increases from one to total 20 motorcycles. It is seemed that if the left-turn group becomes bigger the motorcycle drivers who lead the group may become over confident or even aggressive as they are likely to accept the very short gap without giving the way to the straight-go groups, thereby causing the traffic jammed. Also, it may help explain that the motorcycle drivers are not sensitive to the expected waiting time because, perhaps, they wait for the others to come until their group becomes big enough, then the whole group will cross the intersection.

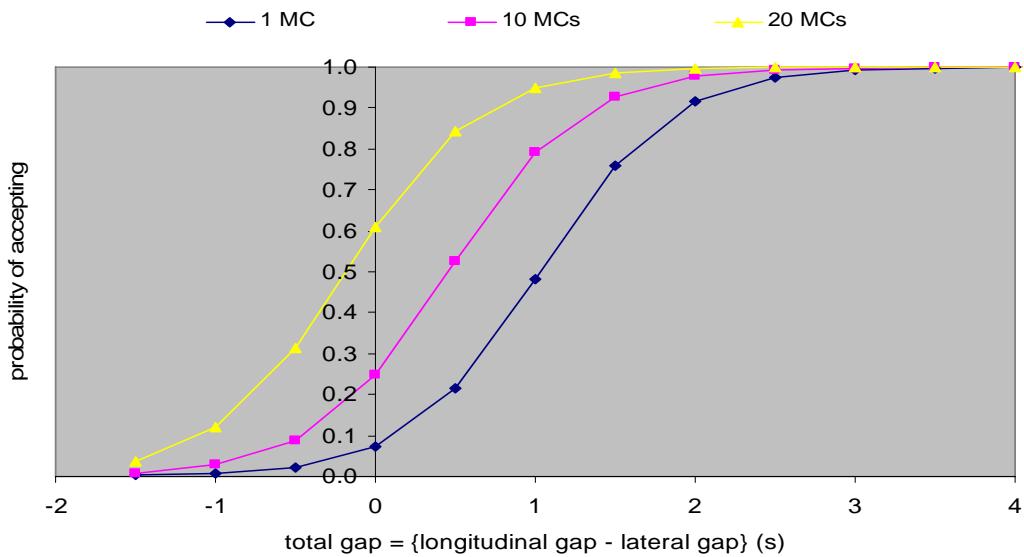


Figure 12 Effect of the number of motorcycles in the left-turn group on the gap decision by the leading motorcycle drivers

#### 4.5. Estimated Gap Acceptance Behavior Model of the Left-turn Automobile Drivers

Similarly, the gap acceptance behavior of the left-turn group leading car/auto driver was modeled based on a total of 150 gap events. The results are also given in Table 1 above. Interestingly, the model estimation shows that the number of motorcycles in the left-turn group probably has no effect on the gap decision of the leading auto driver because this factor is not significant and thus was removed from the table. However, the speed of the straight-go group leading vehicle is found to have significant impact on the decision.

**Effect of expected waiting time:** Clearly, the left-turn car or auto drivers behave differently from the motorcyclists. As shown in Figure 13, the car driver would become more aggressive as to accept the short gap if he or she is expected to wait longer at the intersection. For example, given the gap of one second, if the straight-go group is too long and hence the expected waiting time is, let's say, around 40s, there could be more than 95% of the cases in

which the car driver would accept the gap. This indicates that the auto drivers are very sensitive to the expected waiting time while the motorcycle drivers are not. In other words, the expected waiting time is an important factor of the aggressive behavior of the car drivers. Under the traffic conditions that the traffics are getting denser and the straight-go groups become much longer, the left-turn cars may have to wait for a long time; the car drivers will probably dare to cross the intersection dangerously by accepting very small gaps. This point must be kept in mind when proposing ways to manage the mixed traffics at the intersections.

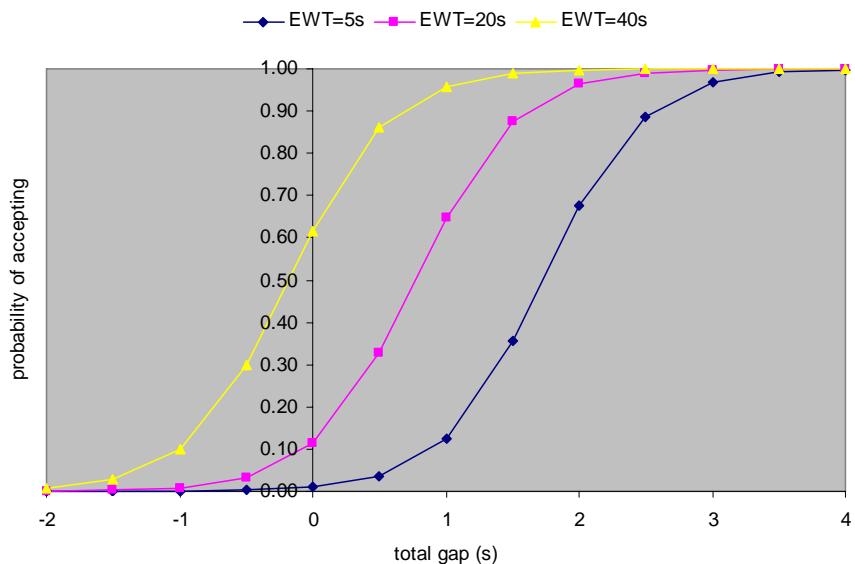


Figure 13 Effect of the expected waiting time on the gap decision by the leading auto driver

#### 4.6. Behavioral Differences between the Motorcyclists and the Car Drivers

From the previous analyses, the behavioral differences between the left-turn group leading motorcyclists and car drivers can be summarized as follows. First, car drivers are very sensitive to the expected waiting time whereas motorcyclists are not. This behavioral difference can be explained by the fact that the expected waiting time may be proportional to the length of the straight-go group, and the longer the straight-go group the more “power” the group would have. Actually, the left-turn motorcycles seem to be weaker than autos and thus they need to wait for the others to come and join their group until the group becomes strong enough. The expected waiting time can be seen as the “*power charging*” time for the motorcyclists. On the contrary, the left-turn autos may already be strong enough to fight against the straight-go groups and thus what the drivers care much is the expected waiting time. Second, the motorcycles who lead the left-turn groups feel more confident if there are many motorcycles in their groups, but the car drivers are not influenced by this factor at all.

## 5. CONCLUSIONS

In summary, this study has analyzed the interactions between the left-turn and the straight-go groups to realize the effects of the “grouping” behavior in the mixed traffics. The gap acceptance behavior model is developed to capture the significant factors of the gap decision made by groups of left-turn vehicles. The concept of “total” gap is introduced to combine the effects of the longitudinal and lateral gaps on the interactions; therefore the models can better explain the actual conflict negotiations at intersections.

Interestingly, the study found that the more number of motorcycles behind the left-turn leading motorcyclist the more confident he or she will be in making the gap decision. The motorcycle drivers might decide to wait for the others to come and join their group if they think the straight-go group is too big or too long, and they are not sensitive to the expected waiting time. What they concern most would be the “relative power” between their own group and the straight-go group. The auto drivers are found to be very sensitive to the expected waiting time. They might get frustrated if the waiting times are expected to be long and thus they may dare to accept the short gaps. These findings are helpful in understanding some aspects of the unexplored effects of the grouping behavior in the mixed traffics.

Now, the question is how to deal with the auto drivers’ aggressiveness which can be caused by the long expected waiting time and the motorcycle drivers’ over confidence due to the big number of motorcycles in the left-turn group. This study initially suggests two management measures or concepts. First, **multi-phased signal systems** would need to be installed to replace the existing two-phased signalized systems because such a system assigns an independent phase for the left-turn flows with high auto share. This measure is aimed to avoid the serious conflicts between the straight-go cars/autos and the left-turn cars/autos. This system also may help reduce the negative impact caused by the over confidence or aggressiveness of the left-turn motorcyclists if there are many motorcycles in their groups.

Alternatively, a new concept of **second stop line on the main road** should be developed and putted into trials. When the straight-go flow is so dense, the left-turn drivers may be not able to observe the whole traffic situation fully. They may not foresee how long they would have to wait for a safe gap. As the result, they are more likely to accept a very short gap presented to them at the beginning. The installment of a second stop line at a proper distance from (behind) the current stop line on the main road where the straight-go groups stop could proactively create a safe gap so that the left-turn groups can cross safely. In this case, the left-turn drivers would feel convenient while waiting for the gap and thus the traffic flows would be smooth.

Though this study could help us to understand some aspects of the unexplored inter-group interaction behaviors in the mixed traffic, there are quite many factors remained to be explored. It is worthwhile looking at some interactions, in which the straight-go vehicles change the lanes and many groups joining the conflict. Some game based analysis would be worthwhile being tried. Other factors such as traffic density and different auto share could influence the interactions. Lastly, management measures suggested in this study should be tried and examined in terms of feasibility and traffic performance enhancement.

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