論 文 の 内 容 の 要 旨

論文題目　　Interaction between Motorcycle and Automobiles in Mixed Traffic -The Case of Hanoi City
（オートバイと自動車の挙動の相互影響ーハノイ市を事例に）

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**Motivation and Objectives of the Research**

Group-riding is a unique behavioral phenomenon of mixed traffic at intersections. It is frequently observed that motorcycles move in groups while crossing intersections because they would feel safer and more confident in making decision. As the results, there are many interactions between groups of mixed vehicles, so-called inter-group interactions, inside intersection areas. Such interactions have critically influenced the mixed traffic performance as serious conflicts between groups have often caused unexpected congestions and accidents. Moreover, the increasing number of automobiles would have significant effects on the interactions and traffic performance as well. Therefore, this research is aimed to investigate "local traffic" rules that are governing mixed traffic at intersections, to find out behavioral mechanisms of the interactions, and to predict the effects of car share increase in the future. Based on the predicted car share effects, the policy objective of the research is to propose and discuss strategic management concepts for the mixed traffic in transitional periods prior to car-dominated traffic era.

**Case Study**

Hanoi City (Vietnam) is selected as a case study since motorcycles are the dominant mode in the city and management of mixed traffic in the City is also very critical. Video surveys were conducted at 2 signalized and 2 non-signalized intersections, which are typical in the City, in order to collect traffic date for the analyses. To extract data from the video clips, the computer software, named Vehicle Movement Tracking (VMT) is also developed in the research.

**Research Methodology**

To archive the research objectives, several behavioral analyses are carried out. Firstly, a gap acceptance behavior model (Model 1) is developed for analyzing gap decisions made by groups of left-turn vehicles at intersections. To construct the model, two assumptions are made. First, the vehicle leading the group can be treated as a group representative decision-maker because once he/she has decided the way to move, the others often follow him/her decision. Second, the group leader is assumed not to change lane. Then, a conventional gap acceptance model is applicable with some modifications. Among many factors, expected waiting time and the number of motorcycles in the left-turn group are especially taken into account. Scheme of the group based gap acceptance behavior is shown in Figure 1.

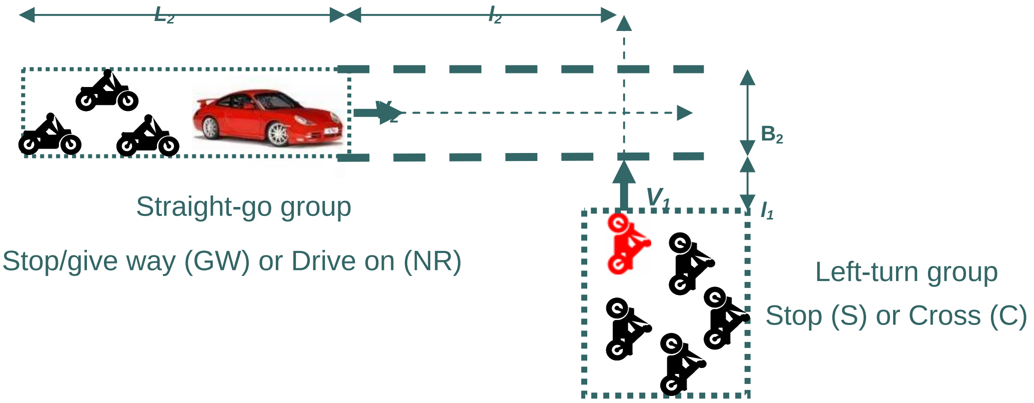



Figure 1 Scheme of group-based gap acceptance behavior

Secondly, a model of gap negotiations between left-turn and straight-go groups is developed (Model 2). Since the assumption of "no lane change" in Model 1 is relaxed, Model 2 can explain the real interactions better. In an interaction, the left-turn group leader may choose one from the three strategies: "stop/give way", "completely cross", and "incompletely cross". In response to the left-turn leader's decision, the straight-go groups can choose one from the four strategies: "drive on", "run in front", "cut tail", and "stop/give way". An outcome of the interaction can be one of the four strategy combinations: $SC_1$ {left-turn: stop, straight-go: drive on}, $SC_2$ {left-turn: incompletely cross, straight-go: run in front}, $SC_3$ {left-turn: completely cross, straight-go: cut tail}, and $SC_4$ {left-turn: completely cross, straight-go: stop}. Thus, the gap decision made by the left-turn leader is conditional on the straight-go leader's decision. If the straight-go leader does not change lane, the interaction become the gap acceptance behavior as described in Model 1. If the straight-go leader changes lane, several fuzzy logics developed are used to explain the reasons why he/she chooses to "run in front" or "cut tail" of the straight-go group.

Thirdly, once the straight-go leaders have decided to "run in front" or "cut tail", how do they change lateral positions overtime and under different conditions? To answer the question, a straight-go vehicle lateral maneuver behavior model (Model 3) is developed. Conceptually, lateral deviations made by a straight-go leader is assumed to be a function of determinant factors, such as, factors related to vehicle compositions and sizes of the two groups, group leaders' types, and the longitudinal movements of the two leaders (see Figure 2). Straight-go leaders' trajectories are then tracked and re-plotted in a two-dimensional plane in order to analyze relationships between lateral deviation and other factors.

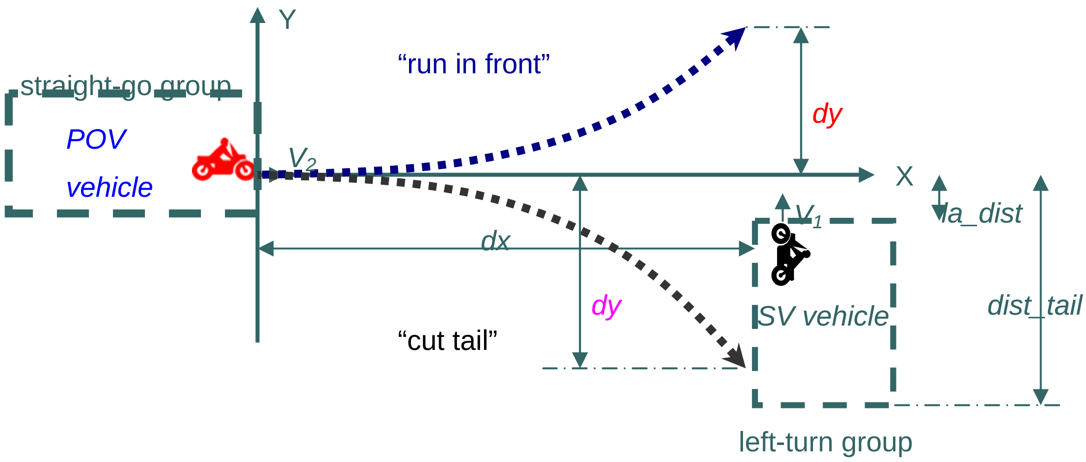



Figure 2 Conceptual movements of straight-go vehicles

Fourthly, my one theory, named Theory of Piggyback and Mirror, is developed based on the most interesting findings found in the first three behavioral analyses. The Theory is centered on the effects of group-riding phenomenon and the mechanism by which the group-riding effects take place. It is assumed that the other vehicle in the group also generate some "power", termed as "piggyback mass", imposing on the leader of the opposite group. Due to the piggyback mass, the opposite leader might be forced to change behavior as to decelerate or change lane. The subject leader may immediately realize this behavioral change because he used to be in the shoes of the opposite leader many times. Then, he might become more confident as to accelerate and cross the intersection. The behavioral change of the opposite leader is named as "Mirror of Behavior" because the subject leader looks into the mirror and changes his behavior upon the situation. A generalized mechanism of the inter-group interactions is shown in Figure 3. In conclusion, the Theory is aimed to realize and re-explain the effects of group-riding phenomenon and to investigate how a group of vehicles is subjectively defined drivers in the opposite group. These understandings are very valuable for planning and management of mixed traffic, especially at intersections.

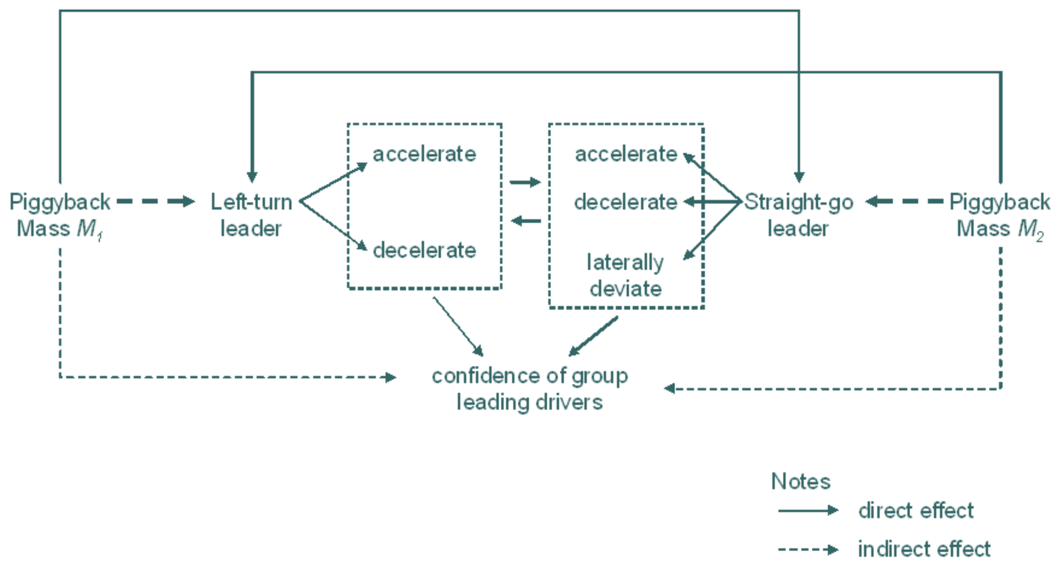



Figure 3 Generalized mechanism of inter-group interactions

**Findings**

**Model 1: Gap acceptance behavior of the left-turn group**

Amazingly, it has been found that the number of motorcycles in the left-turn group would make the leader more confident as he/she is more likely to accept a short gap if the number increases. As shown in Figure 4, considering the gap acceptance at 50 percentile, single motorcycle, 10-motorcycle, and 20-motorcycle groups would accept gaps of 1.0s, 0.5s, and -0.2s. Probably, the more number of motorcycles the more confident the group leader will be.

Another interesting finding is that "expected waiting time" factor has completely different impacts on motorcyclists and car drivers, as seen in Figure 5. For motorcyclists, the longer the waiting time the lower the probability of gap acceptance. In contrast, for car drivers, the longer they wait the more likelihood that they accept short gaps. The difference can be explained by the fact that the longer expected waiting time would coincide with the longer/bigger straight-go groups. The left-turn leading motorcycles would feel not so confident and decide to wait until others come and finally cross if they feel confident enough. However, the leading auto drivers would already feel confident and become very sensitive to the expected waiting time. These findings are very interesting and can be explained by the Theory of Piggyback and Mirror.

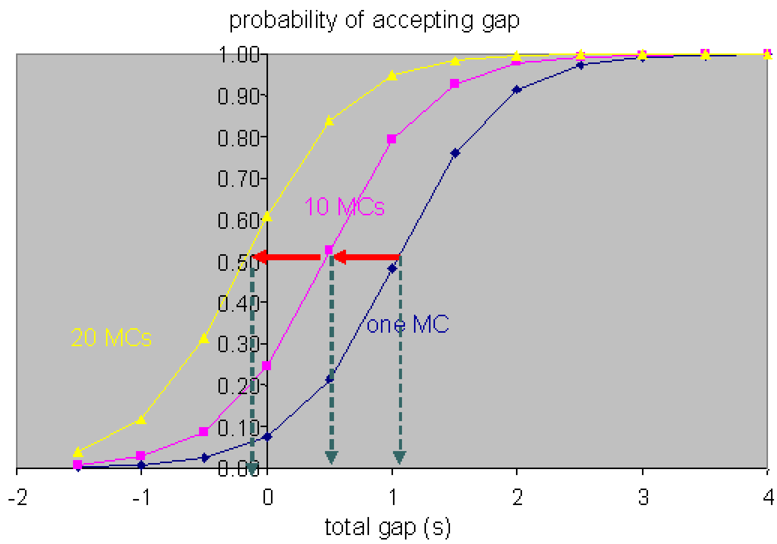



Figure 4 Impact of the number of motorcycles in the left-turn group on the left-turn leader's gap decision

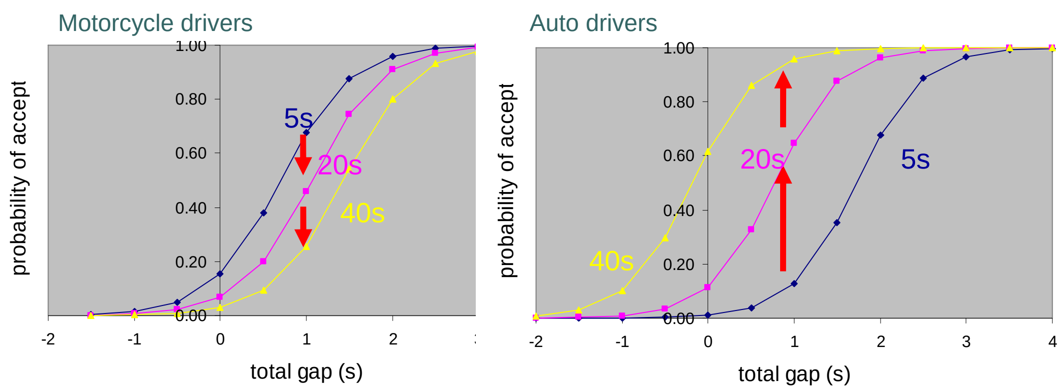



Figure 5 Behavioral difference between motorcyclists and auto drivers in term of sensitivity to expected waiting time

**Model 2: Gap negotiation behavior of the straight-go group**

The analysis on gap negotiation behavior has shown that the left-turn auto leaders may force the straight-go motorcycles to laterally deviate to the tails of the left-turn groups. As shown in Figure 6, two typical cases are compared, straight-go motorcycles versus left-turn motorcycles in case 1 and straight-go motorcycles versus left-turn autos in case 2. In the latter, percentage of due to the existence of auto leader, strategy combination {left-turn: completely cross, straight-go: cut tail} shares about 50 percent, while the number in the former is just 12 percent. It is meant that the left-turn autos have some advanced "power" compared to the motorcycles.

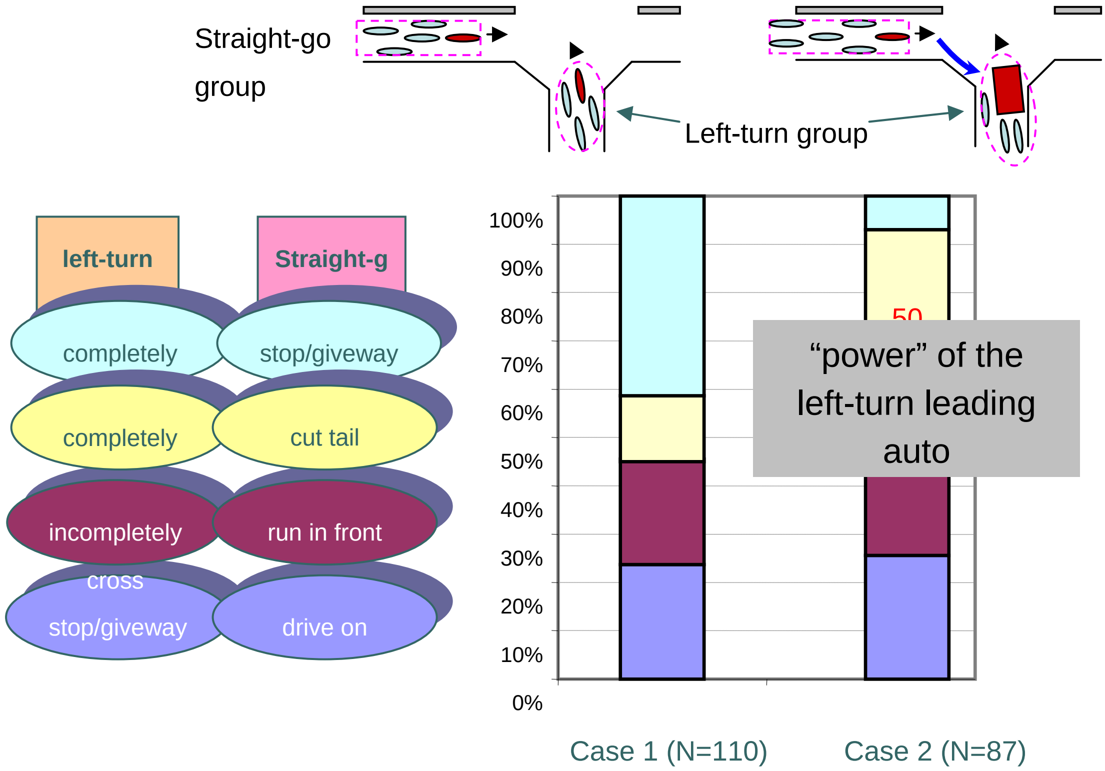



Figure 6 Impact of left-turn auto on straight-go motorcycle's decision

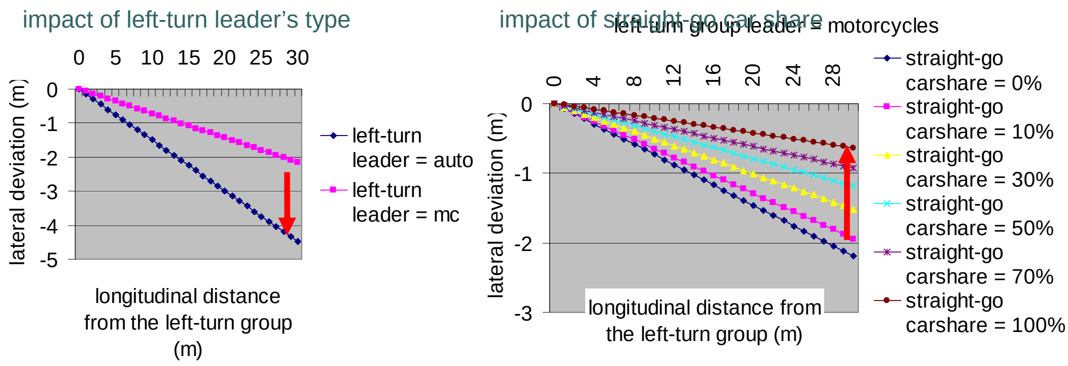


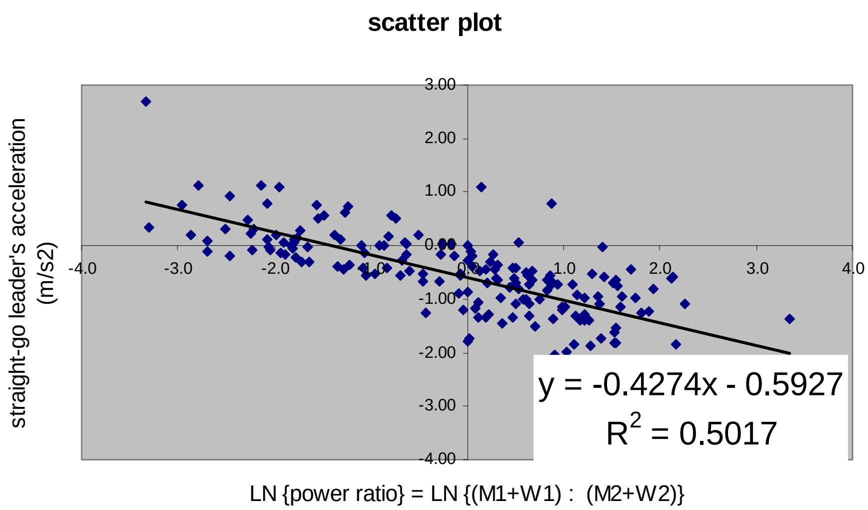

Figure 7 Impacts of left-turn leader type and straight-go car share on lateral deviations of straight-go motorcycles

**Model 3: Lateral maneuver behavior of straight-go vehicles**

In the third analysis, it has been found that left-turn autos would make straight-go motorcycles perform larger cut-tail deviations than the motorcycles do. However, in the mean time, the higher number of autos behind the straight-go motorcycles would encourage their confidences as the deviations decrease according to the increased straight-go auto shares. These contrary impacts are also considered as group-riding effects.

**Theory of Piggyback and Mirror**

In the Theory, the gap acceptance behavior comparisons have shown that the “weights” or powers of one passenger car, minibus, and bus are equivalent to 5, 12, and 24 motorcycles, respectively. It is also found that following vehicles that are 25m or longer far from the leader cannot generate piggyback mass because they are not taken into account by the drivers in the opposite group.




$$Power\_ratio = \frac{M_1 + W_1}{M_2 + W_2}$$

Figure 8 Straight-go leader acceleration and group power ratio

Following hypotheses which contribute to the inter-group interaction mechanism are tested and confirmed:

- Hypothesis 1: If left-turn piggyback mass behind the left-turn leader is bigger, the straight-go leader is more likely to decelerate. Thus, there is a significantly negative correlation coefficient between these two factors;
- Hypothesis 2: If the straight-go leader decreases speed due to the left-turn piggyback mass exceeds critical value ($M_{cr}$ = 6), the left-turn leader would be more confident as to increase speed, and vise versa. Therefore, there is a significantly negative correlation coefficient between these two accelerations;
- Hypothesis 3: If the power ratio between the left-turn group and the straight-go group increases, the straight-go leader would be less confident as to decrease speed. See Figure 8 below.

In conclusion, group leaders who become leader by chance (so-called deciding leaders) may not be confident enough to cross intersection if they move alone or in small groups. However, if there are many vehicles behind, they will be more confident in the battles because of the piggyback mass generated by some of the followers. Therefore, the leader's decision is inherently the group's will. Regardless of leader type, the winner in the game would be the group with significantly higher "power".

**Policy implications**

The behavioral models and the Theory are applied to forecast behavioral changes under scenarios of different car share. At present (car share $< 11\%$), percentages of "run in front" and "cut tail" are very high, totally 40% and the deviation max are ±3.0m. However, in the near future, keen attention must be paid on the case in which left-turn car share to be more than 50% because "cut tail" probability would be up to 50% with the deviation max of -5.0m. In the future, though "run in front" and "cut tail" would decrease but could be still high (20%). If so, actions should be taken from now on in order to eliminate the dangerous driving behaviors inherited from the "motorcycling culture". Based on the understandings of the interactive mechanisms and the behavioral change predictions, some management concepts are roughly proposed to cope with the mixed traffic in each transitional period. The proposed measures include motorcycle sub-lane system, car setback areas, road design, multi-phased signal systems, and driver education.