AN APPLICATION OF SOCIAL FORCE APPROACH TO THE DESCRIPTION OF THE MIXED TRAFFIC FLOW

by Long Xuan NGUYEN ** and Shinya HANAOKA***

1. Introduction

Although there are so many researches on the characteristics of car traffic flow, but we have little knowledge of mixed traffic flow which is very popular in developing country. The mixed traffic flow can be defined as a flow that includes many transport modes such as cars, motorcycles, buses and non-motorised transportation. Figure 1a shows that several big cities in Asia considered motorcycle as the main transportation in their transport system**.** Motorcycle has a high mobility of speed because it is smaller and easier to run than car in the mixed lane of urban road. Motorcycle also shows its high accessibility of door-to-door. This vehicle takes small parking space and people usually keep motorcycle in their houses. Figure 1b illustrates the high ownership of motorcycle in several cities. The main reason is related to the cost of motorcycle that is cheaper many times than car. Motorcycle is a best choice for a low or middle income family and each of working members can own one motorcycle. But this reason is not right for Taipei city. Taipei became a high income city but keep a high level of using motorcycle. In the past, Taiwan developed strongly motorcycle market and motorcycle users now are familiar with the high mobility and high accessibility of motorcycle.

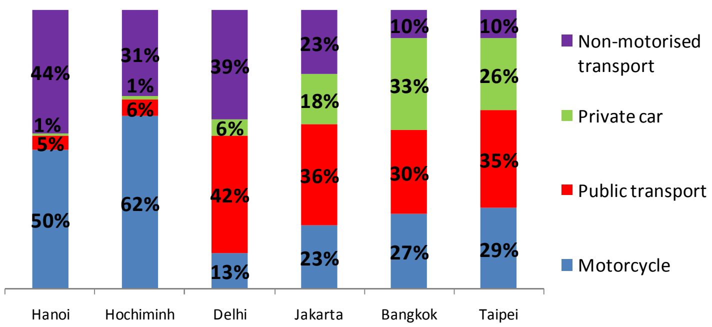

Figure 1a: Modal split in six Asian cities

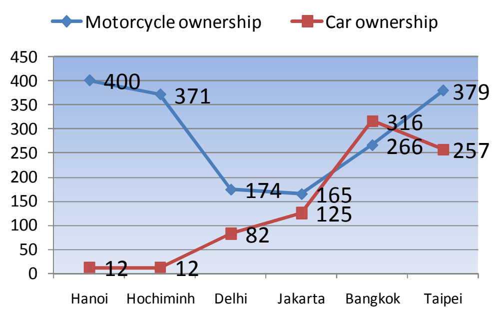

Figure 1b: Motorcycle and car ownership

As in the case of Taiwan, it is difficult to quit the habit of using motorcycle if people used motorcycle once. Therefore, the mixed traffic flow will exist for a long time in the future. It needs to be better understood the physical characteristics of the mixed flow and different properties between mixed flow and car flow. There are a series of empirical researches has been undertaken by Minh *et al*[5), 6), 10)] to understand some basic characteristics of motorcycle flow such as speed-flow relationship, distribution of headway. Motorcyclist has several behaviors which are the same as car driver. Motorcyclists follow their leader and decelerate to avoid a tail-head collision. Car-following model was applied for this movement (Van, 2009)[9)]. The behavior which a motorcycle with a higher speed overtakes a front vehicle is modeled by multinomial logit model (Lee, 2008)[8)]. Motorcyclist will decide randomly to change lane or not depending on the proposed utility function with affective factors like speed, gap acceptance and others. However, there are a number of different characteristics between car and motorcycle.

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**Master of Info. Sciences, Dept. of International Development Engineering, Tokyo Institute of Technology
(2-12-1-I4, O-okayama, Meguro-ku, Tokyo 152-8550, Japan, TEL/FAX: +81-3-5734-3468, Email: nguyen@tp.ide.titech.ac.jp)
*** Member of JSCE, Dr. of Info. Sciences, Dept. of International Development Engineering, Tokyo Institute of Technology

Due to big size and shape, a car needs more occupancy than motorcycle to move. Kov and Yai (2009)[1)] conducted the data survey on the mixed flow with high proportion of light vehicle in Phnom Penh, Cambodia. This study indicated that mean speed decrease tremendously when number of light vehicle increase. The speed of car in heavy traffic is smaller than motorcycle and motorcycles will be obstructed by a front car. The other different point between car and motorcycle is related to movement of cars and non-lane based movement of motorcycles. Car runs in lane, but motorcycle seems to change its direction very often. This causes the interactions between car and motorcycle in lateral distance and result in traffic congestion. Therefore, many researchers try to propose their approaches to explain non-lane based movement of motorcycle drivers. Some of them assume that motorcycles run on a virtual lane and change to next virtual lane randomly. This lane-changing behavior is modeled by using a multinomial logit model (Lee, 2008)[8)]. But they met difficulties to decide the width of virtual lane when collecting data and to differentiate lane-changing behavior with oblique following just by seeing traffic recording video.

The paper aims to propose firstly an approach to describe non-lane based movement of motorcycle which cannot be explained by previous approaches. This study also identifies that proposed approach can be applicable to lane based movement of car.

2. Formulation of social force approach for motorcycle

This is a first research that applies social force approach for motorcycle. Social force approach is used to describe the movement of pedestrian by Helbing[2), 3), 4)]. We assume that a motorcycle driver usually doesn't make complicated decisions to choose alternative behaviors, but he takes optimized behaviors that he has learned in his past experiences. For example, motorcycle drivers follow a leader in the oblique direction to avoid a tail collision. Sometimes they change their direction to move to wider space if they feel uncomfortable in a current position. Therefore, these psychological behaviors can be considered as social forces that make a driver to move**.** Social forces present effect of psychological behaviors on the motion of a driver. We can put social forces into an equation of motion to describe the changes of movement. Social forces for motorcycle are discussed as below.

(1) Acceleration force

A motorcycle driver α prefers to run with desired speed $\vec{v}_\alpha^0$ in a desired direction $\vec{e}_\alpha$ oriented towards his destination. He will change from actual speed $\vec{v}_\alpha$ to desired speed $v_\alpha^0\vec{e}_\alpha$ within a certain time T (or reaction time) if there is no obstacle in front of him. This behavior can be described by the acceleration forces $\vec{F}_\alpha^A$ as below.

$$\vec{F}_\alpha^A = \frac{1}{T}\left(v_\alpha^0\vec{e}_\alpha - \vec{v}_\alpha\right) \tag{1}$$

To considering the randomness of desired speed, it is assumed to be normally distributed, $v_\alpha^0 \sim N(0,\sigma_v^2)$.

(2) Repulsive force of other driver

A motorcycle driver α keeps a "private sphere" from other vehicle β to avoid a collision. When one motorcycle approaches close to another, he will decrease his speed. The closer they come, the lower motorcycle speed become. Consequently, private sphere can be assumed to vary depending on his speed. The effect of reduction in speed can be explained by the repulsive force $\vec{F}_{\alpha\beta}^R$ of other driver and is given by

$$\vec{F}_{\alpha\beta}^R = -\nabla_{\vec{r}_{\alpha\beta}} V_{\alpha\beta}(b(\vec{r}_{\alpha\beta})) \tag{2}$$

where $\vec{r}_{\alpha\beta}$ is distance vector between motorcycle α and motorcycle β. $V_{\alpha\beta}$ is assumed to be the repulsive potential illustrated as equipotential lines in Figure 2. These lines have the form of ellipse with semi-minor axis b. Repulsive potential $V_{\alpha\beta}(b)$ is monotonically decreasing function of b. The derivative of potential with respect to the distance expresses the repulsive force.

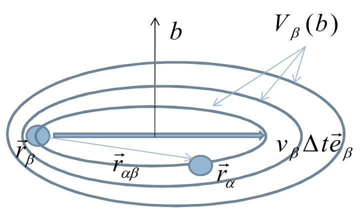

Figure 2: Repulsive potential of repulsive force

(3) Repulsive force of border

A motorcycle driver α keeps a distance from border B (median strip, guardrail) to avoid hitting them. If he runs close to the guardrail, he will decrease the speed and change his direction to go far from it. This behavior can be presented by repulsive force $\vec{F}_{\alpha}^{B}$ of the border.

$$\vec{F}_{\alpha}^{B} = -\nabla_{\vec{r}_{\alpha B}} U_{\alpha B}\left(\left\|\vec{r}_{\alpha B}\right\|\right) \tag{3}$$

Equation (3) has the same type as equation (2) does. $\left\|\vec{r}_{\alpha B}\right\|$ is distance from location of motorcycle to border B which is nearest to motorcycle. $U_{\alpha B}$ is assumed to be the repulsive potential function which is monotonically decreasing in distance $\left\|\vec{r}_{\alpha B}\right\|$.

(4) Angle of sight

A motorcycle driver can see objects in the angle of sight (Figure 3). If objects are out of his angle of sight, he cannot see them. Therefore, repulsive force should be hold for a situation in angle of sight and has a weaker influence c ($0 < c < 1$) for a situation located behind the driver.

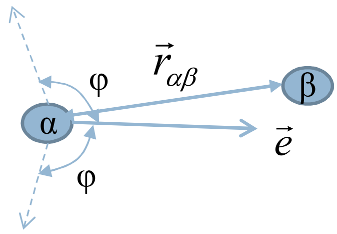

Figure 3: Angle of sight for motorcycle

The weight factor is introduced to capture this affect as below.

$$w = \begin{cases} 1 & if \quad \vec{r}_{\alpha\beta}\vec{e} \geq \left\|\vec{r}_{\alpha\beta}\right\| \cos\varphi \\ c & \text{otherwise} \end{cases} \tag{4}$$

Use the weight factor to modify equation (2) for calculating repulse force of other vehicle as follows.

$$\vec{F}_{\alpha\beta}^{R} = -w\nabla_{\vec{r}_{\alpha\beta}} V_{\alpha\beta}(b(\vec{r}_{\alpha\beta})) \tag{5}$$

After describing behavior of motorcycles by equations of social forces, now we can derive the equation of motion for one motorcycle here. Equation of motion is defined as the total of social forces which are equal to the change of actual speed $\vec{v}_{\alpha}$ within a certain time *dt*.

$$\frac{d\vec{v}_{\alpha}}{dt} = \vec{F}_{\alpha}^{A} + \sum_{\beta} \vec{F}_{\alpha\beta}^{R} + \sum_{B} \vec{F}_{\alpha}^{B} + \text{fluctuations} \tag{6}$$

Fluctuations term in the equation (6) captures other behaviors that cannot be measured. This is assumed to be normally distributed.

3. Formulation of social force approach for car

The basic difference in movement of car and motorcycle is that car runs in lane but motorcycle doesn't. In several Asian cities, all the roads are designed with several lanes for car to run. As a result, car driver often use the inner lane and middle lane to move and motorcycle driver can choose any lane that he feels comfortable to run. In chapter 2 we discussed the social force concept for non-lane based movement of motorcycle. This chapter shows that the social force approach is also capable of describing the lane based movement of car. In order to attain this purpose, we will identify connections between motorcycle model with social force approach and the car-following model.

The concept of social force for motorcycle model is used for car with some adjustments. Firstly, the car is assumed to run in line, following one leader. Therefore, car driver doesn't pay attention to the effects of collision with borders. Repulsive force of border will disappear and the equation of motion (6) for motorcycle can be modified as below.

$$\frac{d\vec{v}_\alpha}{dt} = \vec{F}_\alpha^A + \vec{F}_{\alpha\beta}^R + \text{fluctuations} \qquad (7)$$

Secondly, car-following behavior in the same lane can be considered as combination of two behaviors at the same time. The first behavior is to increase current speed v_α to reach a desired velocity v_α^0 in a reaction time *T*. It can be described by an acceleration force.

$$\vec{F}_\alpha^A = \frac{v_\alpha^0 - v_\alpha}{T} \qquad (8)$$

The second behavior is to decrease from desired velocity v_α^0 to the speed of leader *V* in a reaction time *T* in order to avoid a head-tail collision between them. It can be described by a repulsive force.

$$\vec{F}_{\alpha,\beta}^R = \frac{V - v_\alpha^0}{T} \qquad (9)$$

Thirdly, the assumption that fluctuation term is zero is enough to give the simplest car-following model. From the equation (7), (8), (9) we can derive the car-flowing model as follows.

$$\frac{d\vec{v}_\alpha}{dt} = \frac{1}{T}\left(V - v_\alpha\right)$$

4. Conclusion

The paper has proposed firstly social force approach to describe non-lane based movement of motorcycle which was not explained by previous approaches. This approach can be applicable to lane based movement of car. In the further research, a simulator will be developed based on the proposed model. It is expected that computer simulations can provide findings to understand the characteristics of the traffic mixed flow such as speed – flow relationship, interactions between car and motorcycle considering variations of car rate. These results can be used for geometric designs of intersection to improve problems of the traffic congestion in the intersections.

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