An Application of Social Force Approach for Describing Non-lane Based Movements in Mixed Flow Traffic

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Motorcycle is the main transportation mode in Vietnam because it has a cheap price and a higher mobility of speed than car's when running in congested city road. A better understanding in the characteristics of motorcycle traffic flow is very helpful to propose the traffic management policies. This paper focuses on the zigzag driving behaviors of motorcycle called as non-lane based movements. In a congested situation, motorcycles are observed to change their directions and speeds very often. Therefore, the research aims to investigate the mechanisms of non-lane based movements by considering two behaviors of motorcycles: route choice and collision avoidance. This paper develops a new approach to describe dynamic movements of motorcycles based on the social force approach for pedestrians. Calibration data for proposed model were extracted from video clips collected at a road intersection in Hanoi, Vietnam. By calculating the root-mean-square (RMS) error of estimated data and the field data, the study shows that proposed model can estimate velocity and moving direction of motorcycle with a high reliability.

Key Words : *motorcycle traffic flow, non-lane based movement, social force approach*

1. INTRODUCTION

There are many researches on the characteristics of car traffic flow. However, we have little knowledge of motorcycle traffic flow which is very common in developing countries. In Vietnam, motorcycle is used as the main transportation mode in the transport system including cars, buses and non-motorized transportation. The traffic flow is dominated by motorcycle with a high model split from 50% to 60% for Hanoi and Hochiminh respectively (Figure 1). There are two main reasons which explain why people prefer to use motorcycle. The first reason comes from a high mobility of motorcycle. It can run easier and faster than car or bus does in mixed traffic lanes of urban road due to its smaller size and shape. Because this vehicle takes small parking space, people usually keep motorcycles in their houses or the company's garage. Therefore, motorcycle is door-to-door transportation mode. The other reason is related to the cost of motorcycle that

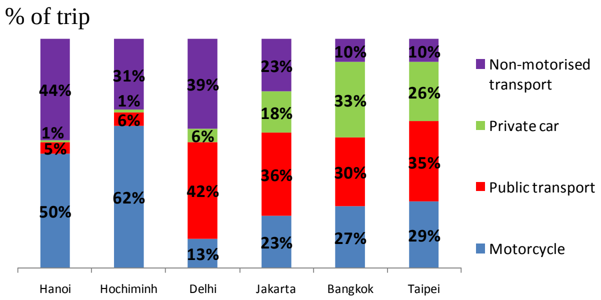

Fig.1 Motorcycle split in Asia cities[1)]

is cheaper many times than car's. Motorcycle is the best choice for a low or middle income family and each working member can own one motorcycle.

With the excellent characteristics of motorcycle such as high mobility and low cost, it is estimated that motorcycle traffic will exist for a long time in the future. A better understanding in different properties between motorcycle flow and car flow will help the policy makers propose useful traffic management policies. There has been a series of researches in this field. Minh *et al.*[2), 3)] looked at 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's. Motorcyclists follow their leader and decelerate to avoid a tail-head collision. Car-following model was applied for this movement[4)]. The behavior which a motorcycle with a higher speed overtakes a front vehicle is modeled by multinomial logit model[5)]. For motorcyclists, deciding randomly whether to change lane or not depends on the utility function with affective factors like speed, gap acceptance and others.

This research focuses on a basic different point between car and motorcycle that is related to the movement of cars and non-lane based movement of motorcycles. Car runs in lane, but motorcycle changes its direction very often. This causes the interactions between car and motorcycle in lateral distance and results 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[5)]. But they faced difficulties in deciding the width of virtual lane and in differentiating lane-changing behavior with oblique following just by seeing traffic recording video.

The study is an attempt to investigate the mechanisms of non-lane based movements by considering the two behaviors of motorcycles: route choice and collision avoidance. This paper develops a new approach to describe dynamic movements of motorcycles based on social force approach for pedestrians. Then, the proposed model is evaluated its reliability with empirical data from video clips collected at road intersection in Hanoi, Vietnam.

2. A SOCIAL FORCE APPROACH FOR MOTORCYCLE IN THE TRAFIC CONGESTED CONDITION

Many observations on the zigzag movements show that non-lane based movements can be explained by two behaviors. The first behavior is route choice. When a motorcycle runs in the traffic congested condition, it turns right or left very often to move to any space in front to pass the congestion district as soon as possible. We assume that the widest space or longest route is chosen by the motorcycle. The second behavior is related to collision avoidance. Motorcycle tries to keep a safety space to avoid hitting other vehicle in high density of traffic flow. As a result, it often slows down its speed and swerves to the right or left at the same time.

In order to describe these psychological behaviors of motorcyclists, this research applies the social force approach for motorcycle. The social force approach was used to describe the movement of pedestrian by Helbing[6)]. We assume that a motorcycle driver usually does not make complicated decisions to choose alternative behaviors, but simply takes optimized behaviors learned through past experiences. For example, motorcycle drivers keep a safety distance to avoid a tail collision. Sometimes they change their direction to move to wider space if they feel uncomfortable in a current position. These psychological behaviors can be assumed to be social forces that make interactions on the movements of a driver. Social force is different with physical forces. It comes from inside of a driver and shows the effects of psychological behaviors on movement**.** We can put social forces into an equation of motion to describe the changes of movement. Social forces for motorcycle are discussed next.

(1) Acceleration force to move in the direction of route choice

A motorcycle driver α prefers to run with desired speed v_α^0 in a desired direction $\vec{e}_\alpha$ ($\|\vec{e}_\alpha\| = 1$) oriented towards the destination. A driver will change from actual speed $\vec{v}_\alpha$ to desired speed $v_\alpha^0 \vec{e}_\alpha$ within a certain time τ_α (relaxation time) if there is no obstacle in front. This behavior of changing speed can be described by the acceleration forces $\vec{F}_\alpha^A$ as below:

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

To considering the randomness of desired speed and relaxation time, they are assumed to be normally distributed, $v_\alpha^0 \sim N(0, \sigma_v^2)$, $\tau_\alpha \sim N(0, \sigma_\tau^2)$ respectively.

In the Equation (1), desired direction $\vec{e}_\alpha$ shows the direction of route choice. In the light traffic condition, motorcycle chooses a destination to go straight. If the motorcycle turns right/left in the intersections, it has two destinations: the first one on the right/left lane of the running road and the second one on the lane of the next right/left-turn road. But in the heavy traffic, a subject motorcycle tends to move to a space in front. This space is made by a lead vehicle. Interestingly, it turns out that a subject motorcycle will follow its leader naturally. The zigzag movements can be interpreted as a change of the lead vehicle through the running time.

This research proposes a rule of route choice by determining who is a leader of a subject vehicle and the timing for changing an ex-leader to a new leader.

a) Conditions of becoming a leader

Figure 2 shows a case in which a subject motorcycle runs four vehicles numbered from 1 to 4. A leader at a certain time should satisfy all the conditions shown as follows:

1. There are no other vehicles on the route from a subject vehicle headed for a leader (No. 1,2,3). A subject vehicle can see a leader in the angle of view and can follow its leader without any obstructions from other vehicles.

2. The longest route is chosen (No. 3) because it provides a wider space for a subject vehicle to move further.

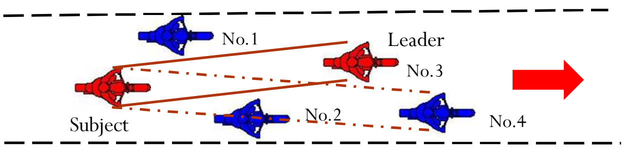

Fig. 2 Route choice of motorcycle

b) Timing for changing a leader

Obviously, the leader changes moving direction through the time to follow its leader. When it does not satisfy the conditions of becoming a leader, a subject will chose a new leader. The timing for changing a leader is a very important factor that can explain the right/left turning behaviors in the heavy traffic condition.

(2) Repulsive force for collision avoidance

One subject motorcycle α keeps a "safety sphere" from other vehicle β to avoid a collision. When a motorcycle approaches close to another, it will reduce its speed. The closer they come, the lower motorcycle speed become. Consequently, the effect of reduction in speed can be explained by the repulsive force $\vec{F}^{R}_{\alpha\beta}$ of other driver on target driver and is given by

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

where $\vec{r}_{\alpha\beta} = \vec{r}_{\alpha} - \vec{r}_{\beta}$ is a distance vector between motorcycle α and motorcycle β. $V_{\alpha\beta}$ is assumed to be as equipotential lines in Figure 3. These lines have the form of ellipse with semi-minor axis b. Repulsive function $V_{\alpha\beta}(b)$ is monotonically decreasing function of b. Based on these assumption, one safety sphere around a motorcycle driver can be drawn by a closed curve of ellipse. When other vehicle comes closer to a target vehicle, the semi-minor axis of the ellipse becomes smaller and as a result, repulsive force gets bigger.

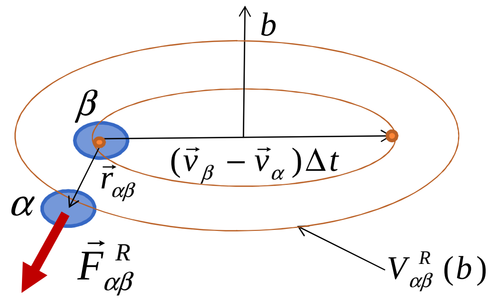

Fig. 3 Equipotential lines of repulsive force

Realistic observations show that target motorcycle estimates the movement of other motorcycles in next time step Δt (i.e. the reaction time) in advance. Therefore, it is reasonable to put an assumption that the distance between two focus points of an ellipse is equal to $(\vec{v}_{\beta} - \vec{v}_{\alpha})\Delta t$. This means that the semi-minor b axis of the ellipse is perpendicular to direction of relative speed vector between two drivers. Because the sum of the distances from any motorcycle on the ellipse to those two focus points is constant:

$$\|\vec{r}_{\alpha} - \vec{r}_{\beta}\| + \|\vec{r}_{\alpha} - \vec{r}_{\beta} - (\vec{v}_{\beta} - \vec{v}_{\alpha})\Delta t\| = 2\sqrt{b^{2} + \left(\frac{1}{2}\|\vec{v}_{\beta} - \vec{v}_{\alpha}\|\Delta t\right)^{2}} \qquad (3)$$

, then semi-minor b can be derived by

$$b = \frac{1}{2}\sqrt{\left(\|\vec{r}_{\alpha} - \vec{r}_{\beta}\| + \|\vec{r}_{\alpha} - \vec{r}_{\beta} - (\vec{v}_{\beta} - \vec{v}_{\alpha})\Delta t\|\right)^{2} - \left(\|\vec{v}_{\beta} - \vec{v}_{\alpha}\|\Delta t\right)^{2}} \qquad (4)$$

Motorcycle drivers can see objects in their angle of sight (Figure 4). If objects are out of its angle of sight, it cannot see them. Therefore, repulsive force should be hold for a situation in angle of sight φ and has a weaker influence c ($0<c<1$) for a situation located behind the driver.

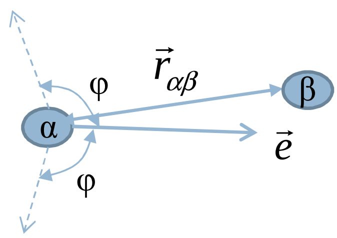

Fig. 4 Angle of sight for motorcycle

The weight factor is introduced here to capture this affect as below:

$$w = \begin{cases} 1 & \text{if} \quad \vec{r}_{\alpha\beta}\vec{e} \geq \|\vec{r}_{\alpha\beta}\|\cos\varphi \\ c & \text{otherwise} \end{cases} \qquad (5)$$

where $\vec{r}_{\alpha\beta}\vec{e} = \|\vec{r}_{\alpha\beta}\|\|\vec{e}\|\cos(\vec{r}_{\alpha\beta},\vec{e}) = \|\vec{r}_{\alpha\beta}\|\cos(\vec{r}_{\alpha\beta},\vec{e})$.

Therefore, the Equation (5) means that if motorcycle β is in angle of sight ($(\vec{r}_{\alpha\beta}, \vec{e}) \le \varphi$), weight factor is equal to 1. If motorcycle β is out of the angle sight ($(\vec{r}_{\alpha\beta}, \vec{e}) > \varphi$), weight factor become *c*. Use the weight factor to modify Equation (2) for calculating repulse force of other vehicle as follows.

$$\vec{F}^{R}_{\alpha\beta} = wV_{\alpha\beta}(b(\vec{r}_{\alpha\beta})) \qquad (6)$$

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*.

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

Fluctuations term in the Equation (7) captures other behaviors that cannot be measured. This is assumed to be normally distributed.

3. DATA COLLECTION

To analyze the dynamic movements of motorcycle, data on position of all vehicles over the time are necessary. Therefore, trajectory data of each vehicle on the time-series were collected. One sample contains information of a target motorcycle and other motorcycles in the interactions of motion between them. The next sample for the same target was taken after 0.5 second to capture sufficiently the change of speed and direction. Samples were also selected to exclude the conflicts of car on motorcycle behavior. The reason for this is that the interactions between car and motorcycle will not be the main part and should be discussed in another study.

(1) Survey location

Hanoi city in Vietnam with high population of motorcycles is the best location to conduct the survey. To understand the changes of dynamic motion in terms of traffic density, a two-phased signalized intersection with 3 lanes in each direction was selected. The width of each lane is 4.5 meter. When there are no cars or trucks on inner lane, motorcycle can run in any lane that they want.

A video recorder was set up on the high building near the intersection. Vehicle movements over 40 meters in length of one direction were captured in videotape at the pace of 5 frames per second. The survey was conducted from 6:30 am to 9:00 am to take in account the peak hours (7:30 am -8:00 am). An image video file with resolution 640x480 pixels was recorded to tracking the trajectories of vehicles.

(2) Data analysis

Computer software SEV was used to convert from video screen coordinates into roadway coordinates. The input is video file and the output is Excel file which contains the trajectory data of traffic. One trajectory data set (X-axis and Y-axis coordinate) for one vehicle is extracted by clicking on position of that vehicle in the monitor at every 0.5 second interval. The error of clicking by hand which was estimated around 20 cm can be accepted to estimate parameters. 298 observations for 69 motorcycles were used to estimate parameters of the model.

4. NUMERICAL RESULTS

(1) Parameter calibration

A data set which contains 298 observations of vehicle positions and speed over time is used for calibration. The method of non-linear regression analysis is applied to estimate parameters. To simplify non-linear function, the parameters of desired speed and reaction time for calibration are given as illustrated in Table 1. The desired speed is considered the maximum value of observed speed. The reaction time for motorcycle is referred to the study of Minh[2)].

Table 1 Given parameters

Parameters	Value
Desired speed v^0	10 m/s
Reaction time Δt	2s

The relaxation time in the formulation of acceleration force is the time during which a vehicle needs to reach the desired velocity. For simplicity, it was assumed to be a constant for all the motorcycles. The repulsive force of other motorcycle was assumed to decrease exponentially as follows:

$$V_{\alpha\beta} = V^0 (b - b^0)^{-\sigma} \qquad (8)$$

The software SPSS was used to estimate those parameter by solving the non-linear regression problem. We found the parameter values in Table 2.

Table 2 Parameter estimates

Parameter	Estimate	Std. Error	t-stat
V^0	0.320	0.188	1.702
b^0	0.600	0.450	1.333
σ	0.814	0.469	1.736
τ	5.000	0.876	5.708

The parameters are estimated with the t-test criteria which is used to test whether the parameter values to be near 0 or not. The signs of all parameters are positive. This makes intuitive sense since the repulsive force and relaxation time should have a positive value. Parameters of repulsive force are not at a high confidence level because the correlation coefficient between them is high. The relaxation time is obtained to be 5 second.

(2) Model validation

The estimated results are compared to field data for model validation. The study uses the statistical measures to calculate the value of errors as follows.

Root-mean-square (RMS) error is a derivation of the average estimated value from the field data.

$$\text{RMS error} = \sqrt{\frac{1}{N}\sum_{i=1,N}\left(V_i^E - V_i^F\right)^2} \qquad (9)$$

where,

V_i^E = estimated value of speed at the *i*th observation

V_i^F = field value of speed at the *i*th observation

N = number of observations

To measure the relative error, root-mean-square percent error is introduced as below:

$$\text{RMS percent error} = \sqrt{\frac{1}{N}\sum_{i=1,N}\left(\frac{V_i^E - V_i^F}{V_i^F}\right)^2} \qquad (10)$$

The mean error and mean percent error are other quantitative measures. If the value of error is positive, it means that the estimated value is over-predicted and if the error is negative, the estimated result is under-predicted.

$$\text{Mean error} = \frac{1}{N}\sum_{i=1,N}\left(V_i^E - V_i^F\right) \qquad (11)$$

$$\text{Mean percent error} = \frac{1}{N}\sum_{i=1,N}\left(\frac{V_i^E - V_i^F}{V_i^F}\right) \qquad (12)$$

The speed of motorcycle *V* and its components V_x, V_y on the x- axis and y-axis are chosen to calculate these errors (Table 3).

Table 3 Statistic measures for the speeds

Speed (m/s)	RMS error	RMS percent error	Mean error	Mean percent error
V_x	0.445	0.091	0.224	0.047
V_y	0.442	4.913	-0.018	-0.045
V	0.436	0.089	0.227	0.047

All the errors of speed *V* and its component on x-axis V_x are almost the same because the value of V_x (3.1 m/s - 10 m/s), is higher than that of V_y (0 m/s – 3.7 m/s). RMS error and RMS percent error of V_x and V_y are very small. V_x is over-predicted because the mean error is positive for V_x while the mean error of V_y is nearly 0. These indicators show that the proposed model replicated the actual speed well.

5. CONCLUSION

The paper outlines an application of the social force model to describe non-lane based movement of motorcycle in the congested traffic condition through a simple model with a few parameters. The two behaviors, route choice and collision avoidance, are modeled by using an application of social force model for motorcycle. With a small RMS error of speed, the actual speed can be predicted by the proposed model. However, for the simplicity of the non-linear regression analysis, a few parameters were assumed to be constant. Parameters were estimated at the low t-value of parameters when t-test is used for testing the parameters to be near 0 or not. Because the sample size of the survey is very low and the survey was conducted at only one place in a particular time period, the proposed model could not cover the overall characteristics of motorcycle behaviors. These limitations will be considered in the further research.

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