A Microscopic Simulation Model for Motorcycle Traffic Safety Assessment in Vietnam

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In Vietnam, commuters use the motorcycle as the main transport mode. However, motorcycle traffic safety is difficult to assess due to the lack of accident data as well as effective estimation models for motorcycle. This research introduces a microscopic model considering the non-lane-based movement of the motorcycle which is an important factor involving vehicle accidents in the congestion situation. The driver behavior model describes the changes of acceleration in response to safety level of the safety space whose boundary is determined by the influence of other motorcycle. Driver reaction time and motorcycle's physical size are essential factors to measure the safety space. Calibration data were extracted from video clips taken at road segments in Ho Chi Minh City. A simulation is developed to represent dynamic movements of the motorcycle in a road segment and assess the accident potential by calculating deceleration rate at each time step when the density of the motorcycle flow is assumed to be changed. The results from this research are expected to be very useful in understanding the characteristics of driving safety for the motorcycle traffic flow in the developing countries.

Key Words : *motorcycle traffic flow, non-lane-based movement, safety space, accident potential*

1. INTRODUCTION

In Viet Nam, motorcycle traffic safety is difficult to assess due to the lack of accident data as well as effective estimation models for motorcycle. Hence, the approaches to describe driving behaviors based on microscopic models are the important tools to address this problem. The results from microscopic simulations are expected to be very useful in understanding the characteristics of driving safety for the motorcycle traffic flow in the developing countries.

Different behavioral patterns of the motorcycle on a road vary according to road conditions (road segment or intersection) and traffic situations (non-congested or congested). This study focuses on zigzag movements on a road segment in the congested situations which have a high potential of traffic accident. The basic difference between the car and the motorcycle is that, the car runs in-lane to follow the leader (lane-based movements), whereas the motorcycle travels alongside other vehicles in the same line1). The motorcycle performs the non-lane-based movements. Related to the non-lane-based movements, the oblique following behavior was recognized in heavy traffic2). Oblique following behavior is observed when the motorcycle follows its preceding vehicle with a oblique angle.

Conventional models have the problems as (1) models' structures are complicated with a large number of parameters3), 4) (2) models are static6) or quasi-dynamic5) and (3) very few models consider the changes of driving behaviors in response to the different human factors such as angle of view, vehicles' physical size, swerving angle, perceived safety distances. Helbing7), 8), 9) introduced the social force approach to describe the non-lane-based movement of the pedestrian. His study assumed that pedestrians do not usually make complicated decisions between alternative behaviors, but rather follow optimized behaviors learned from experience. This model explained the influence of density on pedestrian movements. Nguyen.et.all10) investigated the mechanisms of non-lane based movements and proposed a concept of safety space to explain the non-lane based movements of the motorcycle.

This study develops new features of the safety space model to assess the accident potential for motorcycle by considering factors which access accident potential as motorcycle's physical size, critical swerving angle, maxmimum deceleration. As an model application, a computer simulator is developed to evaluate accident potential for motorcycle by calculating the probability of the sudden braking when the density of the motorcycle flow is assumed to be changed.

2. A MODEL FOR MOTORCYCLE TRAFFIC SAFETY ASSESSMENT

A model is developed to assess motocycle traffic safety based on the concept of safety space which was firstly introduced by Nguyen.et.all$^{10)}$.

(1) Concept of safety space

This concept includes 3 contents as follows:

a) Safety space

A single subject motorist is assumed to perceive safety space as an approximate half ellipse that surrounds it when running on a road (**Fig.1**). Safety space has the form of a physical space whose boundary is determined by the influence of other vehicles that affect the driving behaviors of the subject vehicle. The boundaries of safety spaces are equipotential lines, meaning that all the vehicles on the same boundary will offer the same level of safety V. The smaller safety space shows the lower level of safety. When an influential vehicle moves closer to or farther away from a subject vehicle, the safety space becomes smaller or larger; as a result, the perceived level of safety decreases or increases.

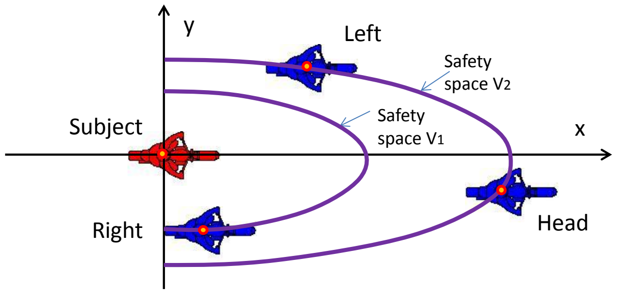


Fig.1 Equipotential lines of safety spaces

b) Threshold safety space

The safety level of a safety space varies according to physical traffic conditions, such as distances between vehicles, speeds, the sizes of the vehicles and the reaction time of drivers. Therefore, the "threshold" safety space is introduced to define the minimal safety level that the motorcyclist considers acceptable for avoiding a possible accident. The threshold safety space of a subject vehicle α is assumed to have an ellipsoidal shape, with the vehicle placed at the center and the direction of its velocity v_α determining the direction of the major axis (**Fig.2**). The physical size of a motorcycle on each axis is denoted by d_x, d_y. The length of the semi-major axis is the minimal safety distance on the x-axis, measured from the head of one motorist to that of another and expressed as $\tau_\alpha v_\alpha + d_x$, where τ_α is the relaxation time on the x-axis. Relaxation time τ_α is defined as the time needed to complete a series of actions to avoid a collision: perceive the leading vehicle braking suddenly, swerve left or right, and brake to reduce speed. The length of the semi-minor axis is the minimal safety distance on the y-axis, given by $W_\alpha + d_y$, where W_α is the lateral distance on the y-axis between two motorcycles. A motorcycle rider is assumed to control the speed and direction of motion so as to keep other motorcycles outside the vehicle's threshold safety space and avoid collisions.

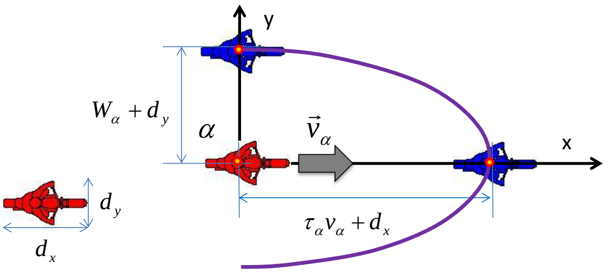


Fig.2 Threshold safety space of motorcycle

c) Acceleration equations

Suppose that a subject vehicle α travels at speeds v_α at time t. If an influential vehicle β increases or decreases its speed to v_β at time t, then vehicle α will adjust its acceleration a_α, with a lag of reaction time T_α, to be equal to a vector derivative of a level of safety V_β for the current position of β with respect to a relative speed vector $\vec{v}_{\alpha\beta} = \vec{v}_\beta - \vec{v}_\alpha$, as follows:

$$a_\alpha(t+T_\alpha) = -\nabla_{\vec{v}_{\alpha\beta}} V_\beta(t) \tag{1}$$

Equation (1) means that when influential vehicles run far from a subject vehicle, safety level become higher and a subject vehicle will accelerate speed. When influential vehicles come near to a subject vehicle, safety level will get lower and a subject vehicle will decelerate speed to avoid a collision. The level of safety V_β for vehicle β can be expressed by a function that decreases exponentially with the distance between two vehicles. Hence, the negative sign on the right-hand side of equation (1) means that a_α is negative or positive when β moves in or out of the safety space, respectively.

If V_β is assumed to be the equipotential curve of the ellipse, equation (1) can be rewritten as

$$a_\alpha(t+T_\alpha) = -\nabla_{\vec{v}_{\alpha\beta}}\left[A\exp\left(-\left(\frac{x^2}{(\tau_\alpha v_\alpha + d_x)^2} + \frac{y^2}{(W_\alpha + d_y)^2}\right)\Big/B\right)\right] \quad (2)$$

where A and B are parameters. Parameter A represents the magnitude of the safety level, while B represents the tendency of the safety level value to increase when two vehicles come near each other; x, y are the distances between vehicles α and β measured on the x-axis and y-axis, respectively.

The direction of the acceleration vector which shows the direction of motion, is related to the gradient direction of the safety space as:

$$\frac{\vec{a}_\alpha}{\|\vec{a}_\alpha\|} = \begin{cases} \dfrac{\nabla V_\beta}{\|\nabla V_\beta\|} & if\ a_\alpha \le 0 \\ \dfrac{-\nabla V_\beta}{\|\nabla V_\beta\|} & if\ a_\alpha > 0 \end{cases} \quad (3)$$

Equation (3) shows a simple assumption. When β moves closer to α, α will decelerate ($a_\alpha \le 0$) and keep farther away from β in the gradient direction to avoid a collision. When β moves farther away from α, α will accelerate ($a_\alpha > 0$) to follow β in the reverse gradient direction.

Under heavy traffic conditions, a motorcycle driver may not be able to respond to all the influential motorcycles. Hence, it is important to specify which motorcycle is the most influential. Suppose there are N influential motorcycles affecting the driving behavior of the subject motorcycle α and its acceleration for the influential vehicle i is denoted by $\vec{a}_{\alpha i}$. Then it can be assumed that the influential vehicle i is chosen to be the most influential if the subject vehicle responds to it with the maximum magnitude of the acceleration, as follows:

$$\max_i \left\{\|\vec{a}_{\alpha 1}\|, \|\vec{a}_{\alpha 2}\|, \dots, \|\vec{a}_{\alpha i}\|, \dots, \|\vec{a}_{\alpha N}\|\right\} \quad (4)$$

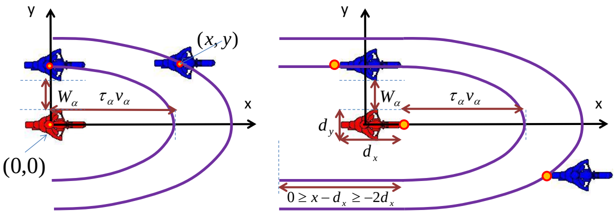
This assumption is reasonable because a rider cannot respond to many vehicles at the same time and will focus first on avoiding a collision with the most influential vehicle. Hence, the behavior of a motorcycle driver become simpler, consists simply of acceleration or deceleration in response to the most influential vehicle to achieve a higher safety level and run with a higher speed.

(2) Factors to access accident potential

The safety space approach has a good potential in the analysis of traffic safety. The paper makes an attempt to apply this approach to access motorcycle accident. Many factors related to evaluate whether accident possible happens or not, is integrated into the original approach.

a) Physical size of motorcycle

A rear-end collision happens when a preceding vehicle brakes suddenly and a following vehicle crashes into the preding vehicle. It is imposible to consider the rear-end collision if the motorcycle is assumed to be a point and a distance between two vehicles is measured from the head of one motorist to the head of the other. Therefore, it is assumed tha the motorcycle has a physical size of the rectangle and the distance is calculated from the rear of the preceding motorcycle to the front of the subject motorcycle (**Fig.3**).



(a) Point size (b) Physical size

Fig.3 Safety spaces for point size and physical size

A side collision is caused when a preceding motorcycle swerves left or right suddenly and is hit on the side by a following motorcycle. In order to consider this type of collision, the safety space Z with the sharp of approximate half ellipse in the case of point size shown in equation (5) is expanded to the both side of a vehicle in the case of physical size as illustrated in equation (6).

$$Z = \begin{cases} \dfrac{x^2}{(\tau_\alpha v_\alpha + d_x)^2} + \dfrac{y^2}{(W_\alpha + d_y)^2} & if\ x \ge 0 \\ 0 & if\ x < 0 \end{cases} \quad (5)$$

$$Z = \begin{cases} \dfrac{(x-d_x)^2}{(\tau_\alpha v_\alpha)^2} + \dfrac{y^2}{(W_\alpha + d_y)^2} & if\ x\text{-}d_x \ge 0 \\ \dfrac{y^2}{(W_\alpha + d_y)^2} & if\ 0 > x\text{-}d_x \ge \text{-}2d_x \\ 0 & if\ x\text{-}d_x \le -2d_x \end{cases} \quad (6)$$

By replacing equation (5) with equation (6), equation (2) of acceleration is rewritten as follows:

$$a_\alpha = \begin{cases} A\exp\left(-\left(\dfrac{(x-d_x)^2}{(\tau_\alpha v_\alpha)^2}+\dfrac{(y)^2}{(W_\alpha+d_y)^2}\right)\Big/ B\right)(v_{\alpha\beta})^{-1}\left(\dfrac{(x-d_x)v_x}{(\tau_\alpha v_\alpha)^2}+\dfrac{yv_y}{(W_\alpha+d_y)^2}\right) & if\ x\text{-}d_x \geq 0 \\ A\exp\left(-\left(\dfrac{(y)^2}{(W_\alpha+d_y)^2}\right)\Big/ B\right)(v_{\alpha\beta})^{-1}\left(\dfrac{yv_y}{(W_\alpha+d_y)^2}\right) & if\ 0 > x\text{-}d_x \geq -2d_x \\ 0 \quad if\ \text{-}2d_x > x\text{-}d_x \end{cases} \tag{7}$$

b) Acceleration and deceleration

To verify the difference of numerical values between acceleration and braking, the study distinguishes acceleration and deceleration by replacing the original parameters (A,B) in equation (2) with two new parameters (A_{acc},B_{acc}) and (A_{dec},B_{dec}). Equation (7) shows that acceleration will be zero when two motorcycle come near together. It is reasonable when a subject vehicle react to only one influential vehicle during the journey. However, a vehicle has to respond to many vehicles at the point of time under congested situation, it is assumed to achieve the maximum deceleration in the sudden braking situation. The maximum deceleration is easily derived from equation (7) by taking derivative of this function with respects to variables of x and y.

c) Conditions of choosing a lead vehicle to accelerate

A subject motorcycle needs to choose a lead motorcycle so as to accelerate its speed and follow the leader. The conditions of choosing a leader are as follows:

Critical following angle φ_0: a motorcycle feel safe and comfortable to accelerate and follow a leader with an angle φ which is smaller than the critical following angle φ_0 (**Fig.4**). The critical following angle is related to maximum swerving angle when a vehicle turn left or right to follow its leader.

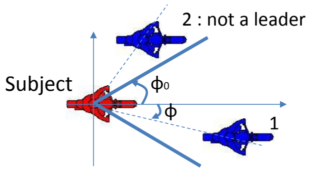


Fig.4 Critical following angle

Following route width RW_α: a subject motorcycle will accelerate and follow a lead vehicle if there are no other vehicles on the following route from a subject to a leader (**Fig.5**). The width RW_α of the following route decide whether a vehicle runs inside the route or not. The route width is only used for calibrating the parameters of the proposed model because calibration data were discrete based on trajectory observations in every 0.5s and it is necessary to choose a leader among many preceding vehicles after every 0.5s.

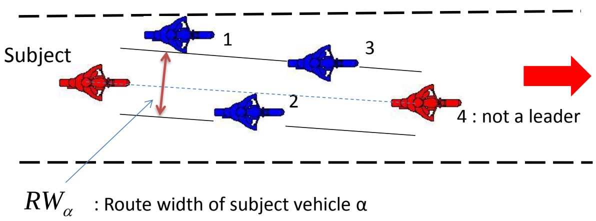


Fig.5 Following route to follow a leader

3. MODEL CALIBRATION

(1) Survey location

The survey was conducted in the period of December 30–31, 2010, from 6:00 am to 8:00 am and 3:30 pm to 5:30 pm, to record movements of motorcycles during peak hours. Two road segments on Phan Dang Luu Street and Cong Hoa Street were selected for data collection. The first road segment is near an intersection and is 8.4 m wide. This segment has only one lane in the observed direction. The one-lane segment has an average speed of 20 km/h. The second road segment has 3 lanes in each direction, each lane being 3.65 m wide. The three-lane segment is about 100 m from the nearest intersection with an higher everage speed of 30 km/h than one-lane street.

A video recorder was set up on a high building near the study location. Vehicle movements on a 40-m-long road segment in the study direction were captured on videotape at 30 frames/s.. Each site was surveyed on two different days and 4 h worth of video clips were obtained from each site to track the trajectories of vehicles.

(2) Data sets

The SEV computer software was used to convert video screen coordinates into roadway coordinates. The input was the video file and the output was an Excel file containing the trajectory data of traffic. A trajectory data set (X-axis and Y-axis coordinates) for one vehicle was extracted by clicking on the positions of that vehicle in the monitor at 0.5-s intervals, this being the average reaction time of a motorcyclist, according to Minh et al. [6].

Discrete observations for a target motorcycle and other influential motorcycles were recorded after every 0.5 second. There are 6 to 12 observations of one motorcycle. Observations in uncongested conditions or observations with cars, bicycles were excluded from data sample. As a result, 826 observations for 144 motorcycles in Phan Dang Luu Street and 579 observations for 152 motorcycles in Cong Hoa Street were used to estimate the parameters of the proposed model.

(3) Parameter calibration

The proposed non-lane-based model based on the concept of safety space was calibrated by the method of regression analysis. This model is formulated in equation (2). To simplify the calculation of the non-linear function, all drivers are assumed to be identical and a few parameters are assumed to be constant (see **Table 1**). The reaction time of a motorcycle is taken to be equal to the mean value of the reaction time distribution, i.e., 0.5 s. The lateral distance of the threshold safety space was measured to be 1.8 m from field data for two vehicles riding side by side. The physical size of a motorcycle is taken as the average size in reality. Critical following angle is set to be 30^0 and the width of following route is 2.0 meter to achieve a less error of the estimation result.

Table 1 Given parameters

Parameter	Value
Reaction time *T* (s)	0.5
Lateral distance *W* (m)	1.8 m
Vehicle size *dx* (m), *dy* (m)	length = 1.9, width = 0.8
Critical following angle(^{0})	30
Following route width (m)	2.0

SPSS software was used to derive the other parameters by solving the nonlinear regression problem (**Table 2**). All the parameters had a high level of statistical significance. The signs of the parameters A, B, and are positive because the magnitude of the safety space must have a positive value. The relaxation times at the two different locations observed were : 0.57 s and 0.68 s. As relaxation time is assumed to be the time required for the steering movement to change direction in combination with the braking movement to change speed, in order to avoid a possible collision, it does not differ in a large range between the two locations. The differences in the values of parameters *A* and *B* between the two locations show that drivers on Phan Dang Luu Street have a smaller rate of acceleration than those on Cong Hoa Street. Cong Hoa Street has three lanes and an average speed of 30 km/h, higher than the 20 km/h in Phan Dang Luu Street. A higher average speed implies a greater rate of acceleration.

Table 2 Estimated parameters

Parameter	Phan Dang Luu Street		Cong Hoa Street	
	Estimate	Std. Error	Estimate	Std. Error
A_{acc}	2.147	0.476	4.850	1.000
B_{acc}	3.046	1.242	3.005	2.461
A_{dec}	11.976	3.608	20.752	6.049
B_{dec}	0.142	0.039	0.131	0.034
τ (s)	0.573	0.052	0.678	0.065

(4) Model validation

The estimated results were compared to field data to validate the model. The study used statistical measures to calculate the value of errors. Root-mean-square (RMS) error is a derivation of the average estimated value from the field data as follows:

$$RMS\ error = \sqrt{\frac{1}{N}\sum_{i=1,N}\left(V_i^E - V_i^F\right)^2} \qquad (8)$$

where

= estimated value of speed at the ith observation

= field value of speed at the ith observation

= number of observations

To measure the relative error, RMS percent error is derived as

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

The mean error and mean percent error are other quantitative measures expressed as follows:

$$Mean\ error = \frac{1}{N}\sum_{i=1,N}\left(V_i^E - V_i^F\right) \qquad (10)$$

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

Positive and negative error values imply that the estimated value is over-predicted and under-predicted, respectively.

Table 3 Statistical measures of speed, ratio of swerving and acceleration modeled correctly

Parameter	Phan Dang Luu Street	Cong Hoa Street
RMS error (m/s)	0.481	0.576
RMS percent error	0.091	0.064
Mean error (m/s)	0.026	0.041
Mean percent error	0.010	0.007
Ratio of swerving modeled correctly (%)	63.0	63.7
Ratio of acceleration modeled correctly (%)	59.8	57.9

These errors were calculated for the speed of a motorcycle (see **Table 3**). RMS error and RMS percent error of speed are very small. These indicators show that the proposed model well replicates the actual speed. To validate the zigzag movements of motorcycles, the observed swerving maneuvers to the left or right from the current position were compared with the estimated swerving maneuvers based on all the observations. The results in **Table 3** show that 63.0% and 63.7% of the observed maneuvers in the two locations, respectively, could be reproduced by the proposed model. The rate of acceleration were also compared in the same way. 59.8% and 57.9% of the observed behaviors can be modeled correctly.

4. AN APPLICATION TO TRAFFIC SAFETY ASSESSMENT

(1) Conflict situations in a road segment

Situations with many conflicts have a higher probability than accidents. The research classified conflict situations in a road segment under congested conditions into three basic types:

Type 1: a preceding vehicle applies a brake suddenly (rear-end collision).

Type 2: a preceding vehicle swerves left or right suddenly (side collision).

Type 3: two side by side vehicles speed up to follow a leader at the same time (side collision).

(2) Safety index: Deceleration Rate (DR)

Safety index is used for measuring the frequency and severity of conflicts such as Gap Time, Time to Collision, Deceleration Rate. Here deceleration rate (DR) is adopted to be a safety index for motorcycle. DR is the value of deceleration taken by the subject vehicle when it applies a brake to avoid a possible collision with other influential vehicles. DR indicates an accident possibility and the severity linked to crash angle (types of collision) and crash speed. If DRs exceed a given critical value, "sudden braking" is assumed to happen. Because deceleration rates are available directly from the simulation model at each time step, the probability of "sudden braking" can be calculated easily from the simulation.

(3) Scenario settings for computer simulation

A simulator is developed on the basis of the proposed model. It can input the data on network information, such as the length and width a road segment, origin-destination points, time-series of traffic rate on each route, the estimated value of parameters of threshold safety space, and the free speed of a motorcycle. The output of the program can show coordinates, speed, and acceleration of all the vehicles on roads over time in the text data and calculate traffic volume and density of the traffic flow. In the calculation process, it combines two different models (1) a free acceleration model for describing the behavior of increasing speed to achieve free speed when no motorcycles are running in front of a subject motorcycle and (2) the proposed non-lane-based model for describing the behaviors of acceleration or deceleration when influential motorcycles appear.

The simulation conditions included a 100-m-long and 5.4-m-wide road segment (**Fig. 6**). All the vehicle are identical. The estimated parameters of the model for the case of Phan Dang Luu Street from **Table 2** and the other parameters shown in **Table 1** were used. The free speed was set to be the maximum speed of 25 km/h taken from the data sample. **Table 4** summarises the basic settings of the scenario.

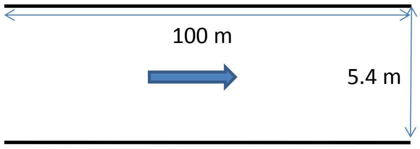


Fig.6 Non-lane-based road segment for simulation

(4) Effects of flow density on accident potential

The simulation is performed for two purpose: (1) to test whether types of collision in a congested traffic situation were reproduced or not, and (2) to verify effects of flow density on the probability of "sudden braking" to increase accident potential.

For the former purpose, 3 types of collision were confirmed when two vehicles overlapped each other. When vehicle brakes suddenly and its reaction time are not short enough to avoid an collision, overlap will happen. Because overlapped vehicles still keep their maximum deceleration during the overlap time, they will separate each other after a short time.

Table 4 Simulation parameters

Road size (length, width, in m)	(100.0, 5.4)
Free speed (km/h)	25.0
Aacc, Bacc	(2.147,3.046)
Adec, Bdec	(11.976,0.142)
Relaxation time τ (s)	0.573
Reaction time T (s)	0.5
Swerving angle (^{o})	30
Route width (m)	2.0
Lateral distance W (m)	1.8
Vehicle size (meter length, meter width)	(1.9, 0.8)

For the latter purpose, the higher flow density leaded to a greater increase in probability of “sudden braking” in 2 cases of the given critical deceleration rate, -0.4 m/s^2 and -0.6 m/s^2 as illustrated in **Fig.7**. This is clear, because the safety level decrease quickly as motorcycles run near together. When one motorcycle accelerates to turn left or right to follow its leader under congested conditions, a alongside motorcycle perceives its safety space smaller and push a brake to escape a side collision. As a result, a behind vehicle also apply a brake to avoid a rear-end accident.

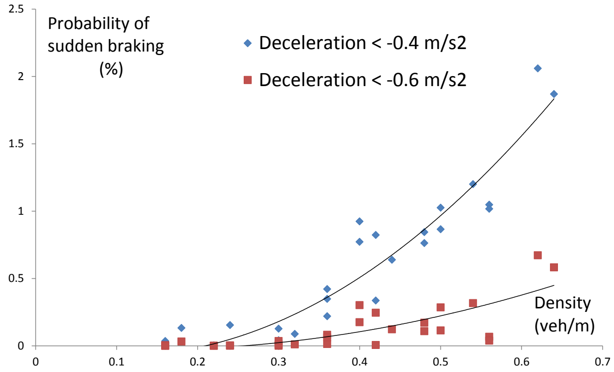


Fig.7 Effects of flow density on probability of sudden braking

5. CONCLUSIONS

This study proposed new features of the safety space model to assess the accident potential. Motorcycle's physical size is considered to make model more reliable when measuring the safety space. Parameters of deceleration and acceleration are estimated. The observed speed can be predicted by the proposed model with a small RMS error. The proposed model can reproduced correctly more than 63% of swerving behaviors to the left or right and about 58% of accelation behaviors. Conflict situations and an index of deceleration rate for the safety assessment are discussed. A simulation was developed to assess the accident potential by calculating deceleration rates at each time step when the density of the motorcycle flow is assumed to be changed. Simulation results reveal that 3 types of collision were confirmed and the higher flow density leaded to a greater increase in probability of “sudden braking”.

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