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Traffic conflict assessment for non-lane-based movements of motorcycles under congested conditions

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ABSTRACT

Traffic conflict under congested conditions is one of the main safety issues of motorcycle traffic in developing countries. Unlike cars, motorcycles often display non-lane-based movements such as swerving or oblique following of a lead vehicle when traffic becomes congested. Very few studies have quantitatively evaluated the effects of such non-lane-based movements on traffic conflict. Therefore, in this study we aim to develop an integrated model to assess the traffic conflict of motorcycles under congested conditions. The proposed model includes a concept of safety space to describe the non-lane-based movements unique to motorcycles, new features developed for traffic conflict assessment such as parameters of acceleration and deceleration, and the conditions for choosing a lead vehicle. Calibration data were extracted from video clips taken at two road segments in Ho Chi Minh City. A simulation based on the model was developed to verify the dynamic non-lane-based movements of motorcycles. Subsequently, the assessment of traffic conflict was validated by calculating the probability of sudden braking at each time interval according to the change in the density of motorcycle flow. Our findings underscore the fact that higher flow density may lead to conflicts associated with a greater probability of sudden breaking. Three types of motorcycle traffic conflicts were confirmed, and the proportions of each type were calculated and discussed.

1. Introduction

Motorcycles are the main mode of transportation in several developing Asian countries. The basic difference in the movement of a car and that of a motorcycle relates to lane-based and non-lane-based movements, respectively. A car runs in and seldom changes lanes. However, a motorcycle frequently changes direction, especially under congested conditions. When a road lacks a motorcycle lane, a motorcycle need not follow lane discipline. For example, a motorcycle may travel alongside other vehicles in the same lane [1] or obliquely follow a lead vehicle [2]. Such non-lane-based movements of motorcycles are unique and influence the likelihood of traffic accidents. Hence, in this study, we focus on the effects of such non-lane-based movements on traffic conflict under congested situations.

Many researchers have attempted to represent non-lane-based movements by separating them into longitudinal and lateral movements. Because longitudinal movement resembles car following, the traditional car-following model has been used to describe this movement. However, when modeling lateral movement, many different models have been developed on the basis of different assumptions regarding the relationship between longitudinal and lateral movements. Cho and Wu [3] assumed that the lateral position of a motorcycle was determined by the average lateral position of the surrounding vehicles weighted by their longitudinal positions. Minh et al. [4,5] supposed that a motorcycle runs on a “dynamic lane” to follow a lead motorcycle on the same dynamic lane or change lanes to overtake its leader. The width of the dynamic lane was calculated using the linear relationship between the distance separating two vehicles running side-by-side and the average speed. Lan and Chang [6] developed a cellular automation model to simulate two-dimensional motorcycle movements. They set the size of a cell unit to 1.25 m × 1.25 m to represent a motorcycle as 2 × 1 cell units. A motorcycle can then move from one cell to another based on simple moving rules developed for motorcycles, such as car-following, lane-changing, or overtaking. Moreover, most models do not consider safety factors such as reaction time, safety distance,

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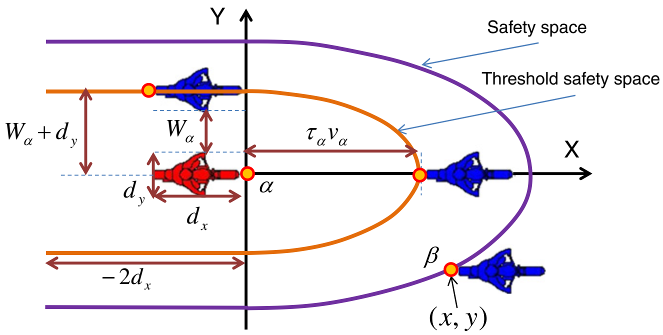

Fig. 1. Safety space and the threshold safety space.

or speed difference related to the description of collision avoidance behavior. Nguyen et al. [14] proposed the concept of a safety space in which longitudinal and lateral movements can be integrated. This model has the potential to evaluate the safety issues of non-lane based motorcycle movements.

The safety level of a vehicle is denoted by the number or rate of accidents involved with the vehicle. There are two popular approaches for estimating the safety level of a vehicle: (1) development of safety performance functions that relate the number or rate of accidents to the explanatory variables by using regression analysis, and (2) development of simulation models to calculate the safety level through measures for traffic safety assessment. In the former, correlations among variables are found by analyzing the dispersion and approximated by deriving regression formulas. Neuman and Glennon [7] found correlations among the road environment of road design, infrastructure, and accident causes. Warshawsky-Livne and Shinar [8] found relationships between the reaction time to a brake light and the driver's gender, age, level of expectancy for the brake light, as well as the number of times that a task was performed. However, this approach requires consensus data on traffic accidents, which are very difficult to collect in most developing Asian countries. In reality, the probability of a traffic accident is very low and varies across the time of day, day of week, location, and events. The latter approach has the potential to address the aforementioned lack of observation data. Simulation models were developed on the basis of behavioral modeling of the vehicles. Although these models cannot estimate the number of accidents, they can be used to assess the safety level or higher-than-average accident rates [9]. Simulation models can efficiently produce a larger amount of analysis data than observation data, with time savings. Moreover, these models cover many scenarios such as nighttime, weekends, and special locations, for which observers face difficulties in collecting data.

Conventional studies have focused on developing techniques for measuring traffic conflict [10–12] to evaluate the safety level of a vehicle. A traffic conflict is defined as an event that involves two or more road users, in which the action of one user causes another to make an evasive maneuver to avoid a collision [13]. The primary measures to determine a conflict by using microscopic simulation were summarized by Gettman and Head [9] as time-to-collision (TTC), post-encroachment time (PET), maximum of the speeds of two vehicles involved in the conflict event (MaxS), maximum relative speeds of two vehicles involved in the conflict event (DeltaS), and deceleration rate (DR). These values are available from the output of the simulation model at every time step. For this reason, here, we use DR as an efficient measure to assess the traffic conflict of motorcycles at a road segment.

In this study, we aim to develop a model to assess the traffic conflict of motorcycles. The proposed model consists of a concept of safety space to describe non-lane-based movements, which are unique to motorcycles in congested situations. New features are also developed for traffic conflict assessment, such as parameters of acceleration and deceleration as well as the following conditions for choosing a lead vehicle: (1) the following angle, and (2) the following route width. Calibration for parameter estimation is explained using the trajectory data of moving motorcycles observed from video images at two different road segments in Ho Chi Minh City. For model verification, a simulator is developed to verify the dynamic non-lane-based movements of motorcycles: swerving and oblique following. An assessment of traffic conflict caused by these movements is validated by calculating the DR at each time interval according to the change in density of the motorcycle flow.

2. Model development

2.1. Concept of safety space for depicting non-lane-based movements of motorcycles

The concept of safety space developed by Nguyen et al. [14] is used to describe the behaviors of increasing or decreasing speed for non-lane-based motorcycle movements. It consists of the following three assumptions:

Assumption 1. Safety space is the space that surrounds a single motorcycle running along a road. The boundary of the space, which is determined by the influence of other vehicles on the driving behaviors of the subject vehicle, is assumed to be the equipotential line; that is, all vehicles on the same line represent the same level of safety. In this study, the safety space for a subject motorcycle is assumed to be determined by the combination of a half-ellipsoidal boundary and two parallel lines, as illustrated in Fig. 1. The ellipsoidal boundary shows the space when a preceding motorcycle runs in front of the subject. Two parallel lines constitute the clearances on both sides of the subject when two vehicles run side-by-side.

The “threshold” safety space is introduced to define the minimal safety level that a motorcyclist considers acceptable for driving and avoiding a possible accident. As shown in Fig. 1, 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. The length of the semi-major axis, which is the safety distance on the x-axis measured from the front of one motorist to the rear of another, is expressed as $\tau_\alpha v_\alpha$, where τ_α is the relaxation time for α. *The relaxation time is defined as the time required to complete the following series of actions to avoid a collision: perceive a lead vehicle braking suddenly, swerve left or right, and brake to reduce speed.* The length of the semi-minor axis is the safety distance on the y-axis, given by $W_\alpha + d_y$, where W_α is the lateral distance on the y-axis between the subject motorcycle and another vehicle. The physical size of a motorcycle on each axis is denoted by d_x, d_y.

Assumption 2. When another vehicle moves closer to or farther away from a subject vehicle, the safety space becomes smaller or larger, respectively; as a result, the safety level decreases or increases. A motorcyclist is simply assumed to accelerate or decelerate in response to changes in the safety level with a view to achieving a higher safety level.

Suppose that a subject motorcycle α travels at speed v_α at time t. If an influential motorcycle β increases or decreases its speed to v_β at time t, then α will adjust its acceleration a_α, with a time lag T, to be equal to the rate of change in safety level V_β for the current position of β in the direction of the