MODELS OF MOTORCYCLE DECELERATION BEHAVIOR AT SIGNALIZED INTERSECTIONS*

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1. Introduction

Motorcycles as a means of mobility has been developed rapidly in most of urban transportation systems in developing countries. Many mega cities in Southeast Asian are suffering from a high degree of congestion, which is mostly caused by motorcycles. Especially at intersections, due to slender shape and small size, motorcycles do not follow "first in first out" rule, they slowly move to the front of the queue while other traffic modes must stop. In order to attain the desired position to have an advantage for traveling, motorcyclists may maneuver illegally in front of four-wheelers, reduce other modes' speed and therefore, they may cause congestion at that time. This behavior is very common at high proportion of motorcycle in traffic flows and at peak periods. In order to obtain a better understanding about behaviors of motorcycle at intersections, the present study aims to model motorcycle decelerations during red lights at signalized intersections. The general model captures the deceleration applied by motorcyclists while maneuvering in queues. The model incorporates both situations, deceleration of motorcycle with and without the constraint from other vehicles.

2. Methodology

The terminology "motorcycle" used in this research refers to fast-moving two-wheelers. In Hanoi, Vietnam, the engine capacity of motorcycles mostly ranges from 50cc to 150cc, including mopeds, scooters and normal motorcycles. Figure 1 presents the structure of the deceleration model in the present study.

(1) Dynamic Motorcycle's Lane

Different from four-wheelers, motorcycles do not follow lane disciplines. Even in the same lane, a motorcyclist would not experience being constrained in his maneuverability, if the neighboring or front vehicles are a little far from him. Therefore, in order to identify the leader of the subject motorcycle, the term "dynamic motorcycle's lane with respect to the subject motorcycle" should be introduced. This concept is used for only straight roads, not for curves. The dynamic motorcycle's lane is not stable on a roadway as a passenger car's lane but flexible according to the subject motorcycle's position. The width of motorcycle's lane may be defined as the width of the operating zone of the subject motorcycle. According to Hussain, H., *et al*[1], the physical witdth of a static motorcycle and the width of the operating space are 0.8 (m) and 1.3 (m), resepctively. However, the authors neglected the fact that those values mainly depend on speeds of motorcycle. In the other words, the width of the operating space is larger for the higher speed motorcycle. In the present study, to obtain the width of dynamic motorcycle's lane and to present the relationship between that value and speed, the minimum lateral distance between two motorcycles in paired riding was used. The paired riding of motorcycle is defined when a couple of motorcycles travels abreast together as a pair over 10 (m).

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(2) Longitudinal Threshold Distance of a Motorcycle

The longitudinal threshold distance of a motorcycle is defined as the threshold distance between the subject motorcycle and the leader or the stop line, at which a motorcyclist starts an action to change his direction or speed with the purpose of preventing collision or stopping safely at the stop line. That threshold determines the driving regime. If the distance between subject motorcycle and its leader is less than the longitudinal threshold distance, the constrained regime is applied. Otherwise, the motorcyclist is in the unconstrained regime.

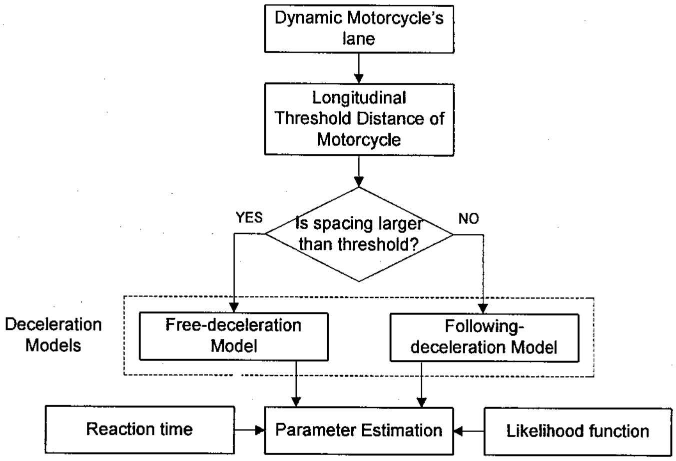

Figure 1: Structure of Deceleration Models

Previously, for passenger-car analysis, Leutzbach, W.[2] proposed the psycho-physical spacing model and introduced the term "perceptual threshold" to identify the relationship between the relative speed threshold and the space headway. The threshold is direct proportion to the space headway. At the certain large space headway, the threshold becomes infinity, implying that a driver no longer follows his leader. Leutzbach, however, didnot provide any mathematical formulation of the proposed model. Subramanian, H.3) assumed the distance threshold to be constant for a particular driver but varies across drivers according to a truncated shifted lognormal distribution. The distribution of the headway threshold is assumed to be skewed to the left since the probability of a driver being aggressive is much less than the probability of a driver being conservative. Unlike Subramanian, Ahmed, K.I.,[4] assumed that the time headway threshold follows a truncated normal distribution with truncation on both sides. The truncation is applied because time headway threshold must be positive and finite. Lemessi, M.[5] defined critical distance for a generic vehicle is a function of (i) braking space for that vehicle; (ii) leader advancement while the follower is braking; (iii) stochastic following distance; and (iv) leader's vehicle length. In this study, this threshold is assumed to vary from individual to individual but be constant for each one. It is computed based on the kinematic formula, which describes the correlation among distance, speed and acceleration.

$$S_n = \alpha \frac{V_n^{\beta}}{|a_n|^{\gamma}} \times \upsilon_p^{\delta_p} \times \upsilon_g^{\delta_g} + \varepsilon_n^{th} \quad (1)$$

where S_n (m): Longitudinal perceptual threshold of the motorcycle n;

V_n (m/sec): Speed of the motorcycle n;

a_n (m/sec^2): Deceleration of the motorcycle n;

$\alpha, \beta, \gamma, \upsilon_p, \upsilon_g$: Estimated parameters;

$$\delta_p = \begin{cases} 0 & \text{If only one person on a motorcycle} \\ 1 & \text{Otherwise} \end{cases} \quad (2)$$

$$\delta_g = \begin{cases} 0 & \text{If male motorcyclist} \\ 1 & \text{Otherwise} \end{cases} \quad (3)$$

ε_n^{th} : Random term of the motorcyclist n at time t, assumed to be distributed i.i.d normal across individuals,

$\varepsilon_n^{th} \sim N[0, (\sigma^{th})^2]$ (4)

(3) Reaction Time

Because the response of a motorcycle is a function of reaction time, the reaction time should be measured before estimating the parameters of models. The reaction time of a motorcyclist is expected to be a function of age, gender, number of people on a motorcycle, weather condition, traffic condition, speed, roadway geometry, vehicle's type, etc. For a particular motorcyclist, the reaction time tends to vary as the traffic condition or environment change. To quantify the parameter value for the reaction time, field experiments were conducted on the General Motors test track. The driver of the lead vehicle was instructed to follow pre-specified speed pattern, while the driver in the following vehicle was unaware of the pre-specified speed pattern and instructed to maintain a safe minimum distance behind the lead vehicle. (May, A.D.,)[6]. From the observed traffic data, Ozaki, H.[7] developed models, in which reaction time is the function of relative headway and subject vehicle's acceleration. However, in the definition of reaction time, Ozaki assumed that reaction time is the time taken to attain zero deceleration when relative velocity is zero but in reality it would be the time taken by the subject driver to realize that the relative velocity is zero and act (Subramanian, H.)[3].

In this research, reaction time is assumed to be a constant for a motorcyclist across observations and be varied over motorcyclists. From several set of historical data about speed, acceleration, distance, the reaction time value is estimated by matching distance with speed and acceleration. It means that for each person, among several assumed reaction times, the one with the highest correlation among distance, speed and acceleration is defined as the reaction time for that person.

(4) Deceleration Models

After the dynamic lane and the longitudinal threshold distance of a motorcycle are identified, the behaviors of motorcycle are modeled based on knowledge from passenger car. Generally, during the red light at a signalized intersection, all vehicles in the back of the queue decelerate slowly until they stop definitely. Intuitively, when the distance headway between the subject motorcycle and the leader is large (or no leading vehicle is case of some first coming motorcycles), the motorcyclist of the subject motorcycle would decelerate without any constrain from others. Thus, from the knowledge of passenger car, the deceleration applied by a motorcyclist depends on two cases (i) free deceleration or (ii) following the leader. The boundary between free-deceleration and following regime is determined based on the space headway between the subject motorcycle and the leading vehicle. The longitudinal threshold distance is used to determine the regime, to which a particular motorcycle belongs at a given instance.

$$a_n(t) = \begin{cases} a_n^{fd}(t) & \text{If } \; h_n(t-\tau_n) \geq S_n \\ a_n^{fm}(t) & \text{Otherwise} \end{cases} \tag{5}$$

where $a_n^{fm}(t)$, $a_n^{fd}(t)$ (m/s^2): The following deceleration and free deceleration, respectively.

τ_n(sec): The reaction time of the motorcyclist n.

S_n (m): The longitudinal threshold distance.

$h_n(t-\tau_n)$ (m): The space headway at time $(t-\tau_n)$.

a) Free-deceleration model

The subject motorcycle is in the free-deceleration regime if no leader or the leader space headway is larger than the longitudinal threshold distance, and so the subject is not affected by the leader's behavior. According to General Motors' theory (Gazis, D., *et al*)[8], the response of the subject vehicle is the function of the sensitivity and stimulus. In this study, the free-deceleration stimulus is assumed to be a constant and that constant is combined with the constant of the sesitivity term to be one parameter. The model assumes that the decelerations of a given motorcyclist over time are captured by the reaction time. The free-deceleration of a motorcyclist applies:

$$a_n^{fd}(t) = s^{fd}\left(X_n^{fd}(t-\tau_n)\right) + \varepsilon_{nt}^{fd} \tag{6}$$

where, $s^{fd}(X_n^{fd}(t-\tau_n))$ is the sensitivity function for free-deceleration. $X_n^{fd}(t-\tau_n)$ is the vector of explanatory variables describing the sensitivity function. ε_{nt}^{fd} is the random term associated with the free-deceleration of the motorcyclist n at time t. This term captures unobserved effects on free-deceleration model. It is assumed to follow an independent and identical normal distribution. It is independent for different motorcyclists and for the same motorcyclist over time: $\varepsilon_{nt}^{fd} \sim N[0, (\sigma^{fd})^2]$ (7)

where, $(\sigma^{fd})^2$ is the variance of the free-deceleration error term. Under these assumptions, the probability density function of the free-deceleration is given by:

$$f(a_n^{fd}(t)) = \frac{1}{\sigma^{fd}} \phi\left(\frac{a_n^{fd}(t) - s^{fd}\left(X_n^{fd}(t-\tau_n)\right)}{\sigma^{fd}} \right) \quad (8)$$

where ϕ is the probability density function of a normal distribution.

b) Following-deceleration model

When distance headway is less than the longitudinal threshold distance, the constrained driving regime is applied and the motorcyclist is assumed to follow the leader to decelerate until stopping at the back of the queue. Because the proportion of motorcycle prevails over other modes, therefore, in this research the leader is a motorcycle. The following deceleration model is given by:

$$a_n^{fm}(t) = s^{fm}\left(X_n^{fm}(t-\tau_n)\right) f^{fm}\left(\Delta V_n(t-\tau_n)\right) + \varepsilon_{nt}^{fm} \quad (9)$$

where, $X_n^{fm}(t - \tau_n)$ is the vector of explanatory variables describing the sensitivity function. $s^{fm}(X_n^{fm}(t - \tau_n))$ is the sensitivity function for following deceleration. $\Delta V_n (t - \tau_n)$ is the speed relative to the leader at time $(t - \tau_n)$. $f^{fm}(\Delta V_n(t - \tau_n))$ is the respective stimulus function. ε_{nt}^{fm} is the random term associated with the following deceleration of the motorcyclist n at time t. It is assumed to be i.i.d distributed and that it is independent for different motorcyclists, and for the same motorcyclist over time.

$$\varepsilon_{nt}^{fm} \sim N[0, (\sigma^{fm})^2] \quad (10)$$

where, $(\sigma^{fm})^2$ is the variance of the following error term.

Under these assumptions, the probability density function of the following deceleration is given by:

$$f(a_n^{fm}(t)) = \frac{1}{\sigma^{fm}} \phi\left(\frac{a_n^{fm}(t) - s^{fm}\left(X_n^{fm}(t-\tau_n)\right) f^{fm}\left(\Delta V_n(t-\tau_n)\right)}{\sigma^{fm}} \right) \quad (11)$$

where ϕ is the probability density function of a normal distribution.

(5) Likelihood Function

For passenger car analysis, according to Subramanian, H.[3], Ahmed, K.I,[4] and Toledo, T.,[9], all parameters of the car-following models and the distributions of reaction time, headway threshold were estimated jointly by using a maximum likelihood estimator and detailed vehicle trajectory data. In the present study, the model parameters are treated separately after obtaining the reaction time distribution and longitudinal threshold distance. The deceleration applied by a motorcyclist is given by formula (6) and (9), where error term is assumed to be distributed i.i.d normal. Therefore, the probability density function of the deceleration of motorcyclist n across I_n observations is expressed as:

$$f(a_{n1}, a_{n2}, .., a_{nIn}) = \prod_{t=1}^{I_n} \frac{1}{\sigma^r} \phi\left(\frac{\varepsilon_{nt}^r}{\sigma^r} \right) \quad (12)$$

Thus, the likelihood function is given by the product across all N motorcyclists:

$$L^* = \prod_{n=1}^{N} \left[\prod_{t=1}^{I_n} \frac{1}{\sigma^r} \phi\left(\frac{\varepsilon_{nt}^r}{\sigma^r} \right) \right] \quad (13)$$

The log-likelihood is given by:

$$L = \sum_{n=1}^{N}\left[\sum_{t=1}^{I_n}\ln\left(\frac{1}{\sigma^r}\phi\left(\frac{\varepsilon_{nt}^r}{\sigma^r}\right)\right)\right] \quad (14)$$

where a_{ni} is the deceleration of the motorcycle n at the observation i. ε_{nt}^r, σ^r are error term and its standard deviation for r = free-deceleration regime or following regime associated with the deceleration of the motorcyclist n at observation i. The maximum likelihood estimates of the model parameters are obtained by maximizing function L.

3. Data Collection

With high proportion and remarkable characteristics of motorcycle, Hanoi, Vietnam is a good representative to conduct this research. Several candidate signalized intersections were observed on-site for evaluation of traffic and environmental conditions. Finally, Daewoo intersection satisfied the criteria of data collection, that are (i) mixed traffic with sufficient motorcycle volumes; (ii) not near bus stop, petrol station, etc. to keep off modification maneuvers from road users and (iii) easy to observe motorcycles discretely. It should be noted that entire data was collected under conditions of clear weather, dry pavement, low magnitude of wind, and non-congested traffic environment.

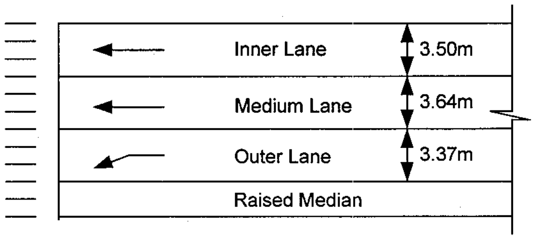

Figure 2: Outline of Study Area (Not to Scale)

The study area is located in Hanoi downtown and data were collected on November 2004. The observed approach has three lanes per each direction with the raise median. The lane widths are 3.50 (m), 3.64 (m), and 3.37 (m) for inner, medium and outer lane, respectively. The traffic is mixed among non-motorized vehicles, motorcycles, cars, vans, buses, etc., in which the motorcycle proportion is more than 85%. The fixed-time signalized control has been installed with 130 (sec) of cycle time, including 37 (sec), 3 (sec), and 90 (sec) for green, yellow, and red time, respectively. There is no all-red time for this signalized intersection. The average queue length is 30 (m).The outline of the study area is showed on Figure 2.

The digital video recorder was set up overhead at the study site, right angle to the direction of vehicle traffic. Motorcycle's positions were identified from image video file every one-tenth of a second interval. These positions regarding time events were calculated according screen coordinates then converted into roadway coordinates by using SEV software, developed in the traffic lab for specific purposes. A motorcycle was observed for over 5 seconds until it stopped. It is worth to note that the advantage of this research is it can capture the behavior of motorcycles according to both time series and motorcycle population. For each motorcycle entity, it is not only one observation but also 20 observations at different times were used for estimating model parameters. Because the proportion of motorcycle prevails over other modes, only interactions between motorcycles are considered in the present research.

4. Estimation Results

Estimation results of the proposed models are shown in Table 1.

(1) Dynamic Motorcycle's Lane

In the present study, the minimum lateral distance between two motorcycles riding abreast was applied to determine the width of dynamic motorcycle's lane. That value varies according to different traffic conditions, such as motorcycle's speed, number of people in the motorcycle, traffic density, etc. However, according to the purpose of this study, the width of dynamic motorcycle's lane of a given motorcycle is just used to identify the leader. Therefore, only the most significant variable affecting the dynamic lane-width, average speed, is considered. The relationship between motorcycle's average speed (V) (m/sec) and motorcycle's dynamic lane width (l_w) (m) may be expressed as:

$$l_w = 0.07V + 0.80 \tag{15}$$

Figure 3 shows the direct proportion between average speed and motorcycle's dynamic lane width. The sample size used to calibrate Equation 15 includes 150 motorcycle entities. Because the motorcycle speed limit is 11.11 (m/sec) (40 Km/h), the range of speeds in Figure 3 is from 0 (m/sec) to 11.11 (m/sec). The lane width is used to identify the leader of the subject motorcycle in the following regime.

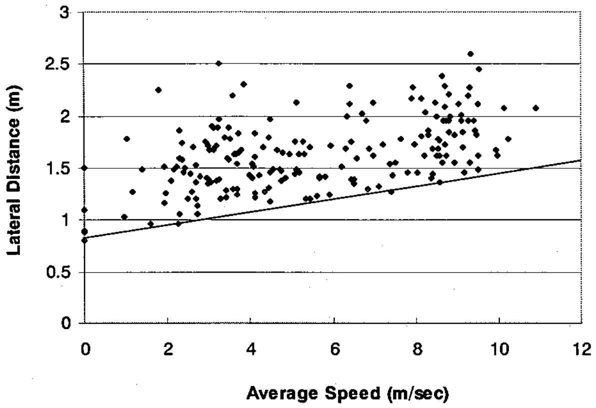

Figure 3: Dynamic Lane Width of Motorcycle

(2) Longitudinal Threshold Distance of Motorcycles

The longitudinal threshold distance of a motorcycle is computed when the motorcyclist starts the action to decelerate or to change the direction in order to avoid risks of collision or to stop safely at the stop line. From the trajectory data, the point when the motorcyclist starts decelerating is identified, then the speed and the deceleration at this point are also obtained. Those data are applied to estimate the longitudinal threshold distance according to the proposed model shown on Equation 1. The estimated coefficient α is expected to be positive due to the absolute sign of deceleration data. Motorcyclists need a long distance to start decelerating when running with a high speed. Therefore, the coefficient β is positive. In case of more than one person on the motorcycle, because the mobility of the motorcycle is reduced, the motorcyclist is likely to be more alert. Hence, the estimate coefficient υ_p is expected to be more than 1. Similarly, female motorcyclists seem to ride more carefully and alertly than men. The coefficient υ_g is therefore more than 1. The estimated longitudinal threshold distance is given by:

$$S_n = (4.590)\frac{V_n^{0.530}}{|a_n|^{0.092}} \times 1.118^{\delta_p} \times 1.018^{\delta_g} + \varepsilon_n^{th} \tag{16}$$

$$\varepsilon_n^{th} \sim N(0, 2.761^2). \tag{17}$$

(3) Reaction Time Distribution

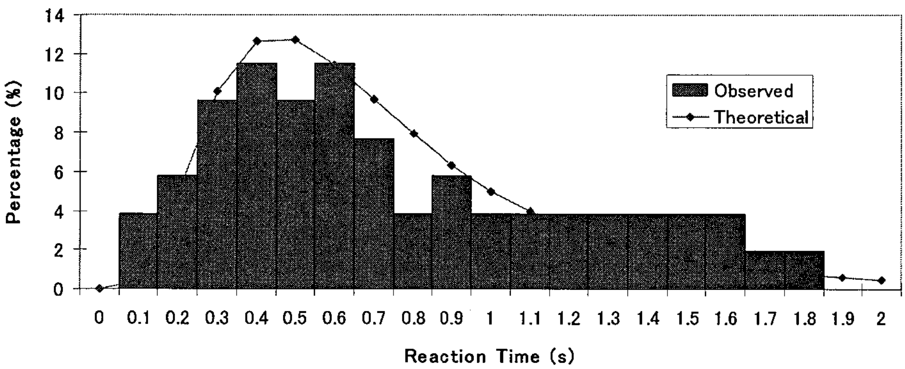

Figure 4: Reaction Time Distribution

Totally 53 samples of motorcycles are used to estimate the reaction time. The reaction time is followed lognormal distribution at the 5% significance level and shown on Figure 4. The density function of reaction time is:

$$f(x) = \frac{1}{\sqrt{2\pi}0.59x}\exp\left[-\frac{1}{2}\left(\frac{\ln x + 0.46}{0.59}\right)^2\right] \tag{18}$$

The mean and the standard deviation of the reaction time distribution are 0.74 (s) and 0.22 (s) respectively. The mean of reaction times of motorcycles is smaller than those of passenger cars which observed at General Motor test track. It may be explained by the fact that (i) motorcyclists have more advantages than drivers in observing ambient traffic environment; and (ii) drivers need time to lift the foot off of the accelerator pedal, move it laterally to the brake and then to depress the pedal; But for motorcyclists, they depress the brake pedal directly and instantly.

(4) Free-deceleration model

In case of free-deceleration regime, the deceleration rate of a motorcycle is free from the effect of the leader. The sensitivity part in this case may include the speed of the subject motorcycle, the spacing between the subject motorcycle and the leader or the stop line, the dummy variable of the number of people on the motorcycle, and the dummy variable of the motorcyclist's gender. The sensitivity part is given by:

$$s^{fd}\left(X_n^{fd}(t-\tau_n)\right) = \lambda \frac{V_n(t-\tau_n)^{\eta}}{\left(\Delta X_n(t-\tau_n)\right)^{\tau}} \times \nu_p^{\delta_p} \times \nu_g^{\delta_g} \quad (19)$$

A motorcycle decelerates freely until it reaches a complete stop at the stop line or at the end of the queue, thus the negative sign is applied. The constant parameter λ is therefore expected to be negative. Motorcyclists are likely to apply a higher deceleration at higher speeds compared to lower speeds, which implies that η should be positive. Moreover, the deceleration rate is also expected to be higher if the space headway is shorter and therefore, the corresponding parameter τ should be positive. In the other hand, different from passenger cars, motorcycles are affected by the weight they carry. Therefore, the number of people on a motorcycle contributes to the change of the deceleration rate. A dummy variable, δ_p, is used to capture this effect.

$$\delta_p = \begin{cases} 0 & \text{If only one person on a motorcycle} \\ 1 & \text{Otherwise} \end{cases} \quad (20)$$

The deceleration rate associated with more than one person on a motorcycle is decreased because the mobility of the motorcycle is reduced. As expected, the estimate coefficient ν is positive and less than 1. Moreover, in order to depict the difference between male and female motorcyclists, the dummy variable δ_g is introduced as follow:

$$\delta_g = \begin{cases} 0 & \text{If male motorcyclist} \\ 1 & \text{Otherwise} \end{cases} \quad (21)$$

Usually, ladies ride motorcycle more carefully than men do. Thus, the gender parameter is expected to be more than 1. After estimating the parameters, the free-deceleration model is given by:

$$a_n^{fd}(t) = (-0.924)\frac{V_n(t-\tau_n)^{2.021}}{\left(\Delta X_n(t-\tau_n)\right)^{1.256}} \times 0.899^{\delta_p} \times 1.045^{\delta_g} + \varepsilon_{nt}^{fd} \quad (22)$$

$\varepsilon_n^{fd} \sim N(0, 0.325^2)$.

(5) Following model

The sensitivity term is a non-linear function of explanatory variables that may include the speed of the subject vehicle, the spacing between the subject vehicle and its leader, and the dummy variable of the number of people on the motorcycle. The functional form for the sensitivity term is given by:

$$s^{fm}\left(X_n^{fm}(t-\tau_n)\right) = \xi \frac{V_n(t-\tau_n)^{\varphi}}{\left(\Delta X_n(t-\tau_n)\right)^{\psi}} \times \vartheta_p^{\delta_p} \times \vartheta_g^{\delta_g} \quad (23)$$

In this case, as the subject motorcycle decelerates its speed according to the deceleration of the leader, the corresponding parameter ξ is therefore expected to be negative. The deceleration at higher speeds is expected to be larger relative to lower speeds and therefore, speed parameter φ should be positive. Furthermore, motorcyclists are likely to apply a higher deceleration at short space headways compared to large space headways. The parameter ψ is therefore expected to be positive. On the other hand, in the present research, the respective stimulus function is assumed to be a non-linear function of the relative leader speed and shown as below:

$$f^{fm}(\Delta V_n(t-\tau_n)) = |\Delta V_n(t-\tau_n)|^{\omega} \quad (24)$$

In case of high relative speed between the subject motorcycle and the leader, the motorcyclist must highly decelerate. The sign of the corresponding parameter ω, therefore, should be positive. Different from a passenger car, the deceleration rate of a motorcycle is affected by the number of people on it. A dummy variable, δ_p, is used to capture this effect.

$$\delta_p = \begin{cases} 0 & \text{If only one person on a motorcycle} \\ 1 & \text{Otherwise} \end{cases} \quad (25)$$

Similar to the free-deceleration model, the estimate coefficient of this variable is positive and less than 1. The deceleration associated with more than one person on a motorcycle is reduced due to the reduction of the mobility of the motorcycle in that case. To depict the difference between male and female motorcyclists, the dummy variable δ_g is introduced as follow:

$$\delta_g = \begin{cases} 0 & \text{If male motorcyclist} \\ 1 & \text{Otherwise} \end{cases} \quad (26)$$

Usually, ladies ride motorcycle more carefully than men do. Therefore, the gender parameter is expected to be more than 1. In summary, the following deceleration model is given by:

$$a_n^{fm}(t) = (-1.515)\frac{V_n(t-\tau_n)^{0.414}}{(\Delta X_n(t-\tau_n))^{0.728}} \times \Delta V_n(t-\tau_n)^{0.520} \times 0.705^{\delta_p} \times 1.061^{\delta_g} + \varepsilon_{nt}^{fm} \quad (27)$$

$$\varepsilon_n^{fm} \sim N(0, 0.303^2). \quad (28)$$

Figure 5a and 5b are shown the difference between observed and estimated deceleration data in both the free-deceleration model and the following-deceleration model.

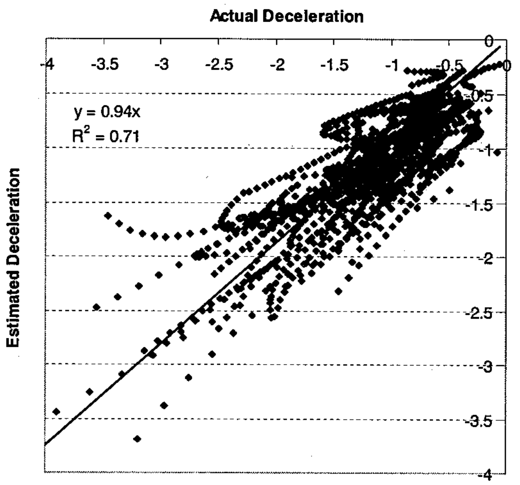

Figure 5a: Difference between Observed and Estimated Deceleration Data in the Free-deceleration Model

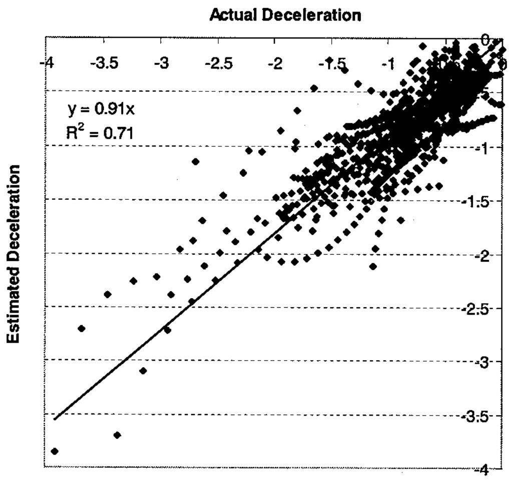

Figure 5b: Difference between Observed and Estimated Deceleration Data in the Following-deceleration Model

5. Conclusions

The paper proposes a rigorous framework for estimating deceleration behaviors of motorcycles during red-light time at the signalized intersection. Firstly, since a stream of motorcycles may not be assigned well-defined lanes as that of four-wheel vehicles may, the adapted definition of the dynamic motorcycle's lane has been introduced. The relationship between a motorcycle's lane width and its speed is constructed based on the minimum lateral distance between two motorcycles in paired riding. The lane width is applied to identify the leader of the subject motorcycle in proposed models.

The general deceleration framework of a motorcycle at a signalized intersection during red-light time is classified into two regimes: free-deceleration regime and following regime. In order to identify to which regime a motorcycle belongs, it is worth to introduce the longitudinal threshold distance. The model for estimating this threshold distance across the motorcyclist population is constructed based on the kinematic's formula.

Table 1: Parameter Estimates for Deceleration Models of Motorcycle

Parameter	*Estimate*	*t-statistic*
Longitudinal threshold distance		
Constant (α)	4.5901	7.482
Average speed (β)	0.5303	6.489
Average deceleration (γ)	0.0918	5.979
No of People dummy (υ_p)	1.1187	17.866
Gender dummy (υ_g)	1.0179	18.718
σ^{th}	2.7610	12.766
Number of samples = 79; L(0) = -7511.251; L(β) = -192.331; $\bar{\rho}^2 = 0.974$		
Free-deceleration model		
Constant (λ)	-0.9240	-25.331
Average speed (η)	2.0213	57.202
Spacing (τ)	1.2555	60.829
No of People dummy (ν_p)	0.8985	60.012
Gender dummy (ν_g)	1.0447	69.177
σ^{fd}	0.3252	-66.268
Number of motorcyclists = 87 ; Number of observations = 1740 L(0) = -3056.528; L(β) = -514.346; $\bar{\rho}^2 = 0.832$		
Following deceleration model		
Constant (ξ)	-1.5145	-29.151
Average speed (φ)	0.4138	10.047
Spacing (ψ)	0.7277	25.686
Relative speed (ω)	0.5199	36.650
No of People dummy (ϑ_p)	0.7049	33.168
Gender dummy (ϑ_g)	1.0613	45.234
σ^{fm}	0.3026	-53.456
Number of motorcyclists = 53; Number of observations = 1060 L(0) = -1423.997; L(β) = -223.645; $\bar{\rho}^2 = 0.843$		

Because the response of a motorcycle is a function of reaction time, the reaction time should be measured before estimating parameters of the models. Among several set of historical data about speed, acceleration and distance, the reaction time for each motorcyclist is estimated by matching distance with speed and acceleration values. Then, the reaction time distribution, capturing the variations in perceptions among motorcyclists, is developed. It is proved to follow the log-normal function at the 5% significance level, in which mean and the standard deviation are 0.74 (sec) and 0.22 (sec), respectively.

The deceleration framework is developed and then the parameters of the models are estimated. The framework captures the variation across the motorcyclist population. The effect of unobserved motorcyclist/ motorcycle characteristics is identified by a motorcyclist random term.

The proposed models are applied in the Hanoi case study. Because the microscopic data set comprised only position measurements of each motorcycle, a multinomial curve fit technique is employed in order to obtain the speed and deceleration data. From the trajectories, the speed, deceleration profiles are computed by taking first and second derivatives across time for each motorcycle. Then, all parameters of the deceleration models are estimated by using maximum likelihood method.

In further researches, data should be collected at various locations to distinguish site-specific effects. Moreover, the maneuver model of motorcycle should be concentrated in order to explain the motorcycles' maneuverability, especially at signalized intersections.

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Models of Motorcycle Deceleration Behavior at Signalized Intersections

By Chu Cong MINH, Kazushi SANO and Shoji MATSUMOTO

This research presents a model framework of motorcycle's behaviors at signalized intersections. The adapted definition of the motorcycle's lane has been introduced. Then, motorcycle's behaviors are treated as same as passenger car's by applying the free-deceleration model and the following-deceleration model with significant modifications. At every observed time interval, the longitudinal threshold distance is estimated to identify what model a motorcycle belongs to. The distribution of reaction time for the motorcycle population is also developed. Finally, a case study is introduced to estimate parameters of proposed models using microscopic traffic data collected at an intersection in Hanoi, Vietnam.

信号交差点における自動二輪車の停止挙動のモデル化

チュ　コン ミン・佐野可寸志・松本昌二

二輪車の挙動に関する研究はほとんど行われてこなかったが，本研究では，信号交差点での自動二輪車の停止時の運転挙動を表現するモデルの構築を試みる．仮想的な自動二輪車の走行レーンを想定することで，乗用車に適応されているのと類似の自由減速走行モデルと追従減速走行モデルを構築する．なお２つのモデルの適用範囲は先行車との車間距離の閾値により決定される．ベトナムのハノイ市におけるビデオ観測データを用いてモデルのパラメータの推定を行いモデルの適用性の確認を行うと同時に，自動二輪車の減速時の反応時間分布を得ることができた．