MOTORCYCLE TRAFFIC AT SIGNALIZED INTERSECTIONS*

by Chu Cong MINH**, Kazushi SANO***, Shoji MATSUMOTO****

1. Introduction

Transportation－involved matters are usual in most urban areas in the world. Many developed countries confront troubles, which relate to four-wheel vehicles. Besides, in the other parts of the world, developing countries are facing with small size motorized vehicles, such as motorcycles, mopeds, etc. Several cities in developing countries have been suffering from a high degree of the congestion problem, which is mostly caused by two-wheel vehicles. In Hanoi, Vietnam, for example, where two-wheelers are more than 80% of the total transportation means, motorcycle reduces the speed of other modes and makes the traffic more congested due to its shapes and behaviors. It is capable of zigzag maneuvers, creeps up slowly to the front of the queue when the signals are red, and impedes traffic flow by disturbing the start of other vehicles behind.

In order to obtain a better understanding about this mode, the present study aims (i) to draw the techniques applied for collecting and analyzing data, (ii) to develop models to describe the behaviors of motorcyclists, and (iii) to explain and discuss for better understanding this mode.

2. Literature Review

So far, very little empirical research has been conducted regarding the traffic operation of motorcycles. Some analyses have been undertaken by Nakatsuji *et al.*[1)] in order to carry out the effect of motorcycles on capacity at signalized intersections in Hanoi and Bangkok. These authors classified some patterns, which were different relative positions of motorcycle to passenger car, then used regression analysis to estimate how different among these patterns were in terms of headway and start-up lost time. Powell[2)] developed the model to describe motorcycle behavior at signalized intersections. An amended first order macroscopic model was used to represent motorcycle behavior and multiple regression analysis explained inaccuracies resulting from this technique. Other studies of motorcycle traffic have been conducted in developed countries[3)] but, for the most parts, the results of these studies have not been appropriate to apply in developing countries since the role of motorcycle, as a means of urban transportation characteristics, is not similar.

3. Data Collection and Analysis

With high proportion of motorcycle Hanoi, Vietnam, are good representatives to conduct this research. Several candidate signalized intersections were on-site observed for evaluation of traffic and environmental conditions. Finally, Daewoo intersection was satisfied the criteria of data collection (i) sufficient motorcycle volumes; (ii) not be near bus stop, petrol station… to keep off modification maneuvers from road users and (iii) easy to observer discrete motorcycles. Thus, that signalized intersection was select for data collection. The observed location is three-lane divided approach with raised median, separating two directions. The lane widths are 3.5m, 3.6m and 3.4m. The operation data determined the needs for this study include speed, acceleration/deceleration and road configuration and characteristics. The digital video recorder was set up overhead at the study sites, right angles to the direction of vehicle traffic. The filming traffic was converted into video file then replayed in a computer.

(1) Data Analysis by Using SEV Software

In order to analyze traffic data about trajectory, speed and acceleration/deceleration of traveling motorcycle, it is useful to apply the computer software, namely SEV.exe. The input file is a movie clip with 640 × 480 pixels resolution, which captures traffic at a candidate location. The output file is an Excel compatible file, which advances in analyzing trajectory data as well other necessary information about operation of motorcycle traffic.

* Keywords: Traffic Flow, Capacity Analysis, Motorcycle
** Graduate student at Dept of Civil and Environmental Eng., Nagaoka Univ. of Tech.,
(Kamitomiokamachi, 1603-1, Nagaoka, Niigata, Japan, TEL: 02–5847–6635, FAX: 02–5847–9650)
*** Member of JSCE, Dr. Eng., Dept of Environmental Eng., Nagaoka Univ. of Tech.,
(Kamitomiokamachi, 1603-1, Nagaoka, Niigata, Japan, TEL: 02–5847–9616, FAX: 02–5847–9650)
**** Member of JSCE, Prof., Dept of Environmental Eng., Nagaoka Univ. of Tech.,
(Kamitomiokamachi, 1603-1, Nagaoka, Niigata, Japan, TEL: 02–5847–9615, FAX: 02–5847–9650)

SEV has several advantages over conventional counting techniques as describing as below:

- The ability of measuring the trajectory, speed, and acceleration/deceleration of several vehicles simultaneously;
- The ability of measuring the of multi-position, speed, and acceleration/ deceleration of a vehicle over time interval as low as one thirtieth second;
- The ability to repeat several times to verify preceding results or recollect missing data as well as to skim unnecessary data;
- Less requirements in equipment and installation, few observers required in both on-site and laboratory;
- The user-friendly software. It is simple to learn as well as easy to operate.

(2) Coordinate Transformation Technique

In order to match the coordinate between screen and roadway, according Khan *et al.*[4], 2001, Coordinate Transformation Technique was applied. For every screen coordinate pair x_s, y_s and roadway coordinate pair x_r, y_r, the following expression may be derived:

$$x_r = \frac{C_1 + C_2 x_s + C_3 y_s}{C_4 x_s + C_5 y_s + 1} \quad (1)$$

$$y_r = \frac{C_6 + C_7 x_s + C_8 y_s}{C_4 x_s + C_5 y_s + 1} \quad (2)$$

where

x_r, y_r : Roadway x and y coordinates;
x_s, y_s : Screen x and y coordinates;
C_1, .., C_8: Coefficients.

In order to match the coordinate between screen and roadway, all coefficients will be computed by solving two types of equations above. This process required at least four points, so-call based points, in which, screen and roadway coordinates were determined. The trajectory data, speed and acceleration/ deceleration data for any vehicle is achieved by clicking on the same position at that vehicle over time intervals.

4. Methodology

Due to small size and shape, a motorcycle has maneuvers which are much more flexible than a passenger car does. To model the behaviors of motorcycle traffic, this research has applied the knowledge from passenger car with some modifications.

(1) Effective lane-width of motorcycle

For motorcycle traffic, since a stream of motorcycles may not be assigned well-defined lanes as that of four-wheel vehicles may, the adapted definition of the motorcycle's lane is necessary. The lateral distance between two motorcycles in paired riding is estimated and defined as effective lane width of a motorcycle. In this study, the paired riding is considered when motorcycle travel together as a group over a certain distance, while maintaining a minimum of a given distance of both longitudinal and lateral spacing. The concept of motorcycle lane introduced in the present research may be understood as a dynamic one. The lane of a given motorcycle does not fix on a roadway as a normal lane does, it may displace from a position to other positions depending on the position of that motorcycle. The width of a given motorcycle lane may change according to that motorcycle's speed. Based on the definition of effective lane width of a motorcycle, other vehicles in different lanes will have no any affect to the subject motorcycle.

(2) Effective Longitudinal Distance of Motorcycle

The effective longitudinal distance of motorcycle is defined as the distance between the subject motorcycle and the leader, at which a motorcycle starts an action to change its direction or speed with the purpose of preventing collision. That value is measured as the distance when a motorcyclist starts decelerating. The effective longitudinal distance may be modeled as below:

$$D(t) = \eta \frac{V_n(t)^{\rho}}{a_n^{\theta}(t)} \Delta V_n(t) + \varepsilon_{nt}^{th} \quad (3)$$

where D(t) : Longitudinal perceptual threshold at time t;
t : Current time period;

$a_n(t)$: Acceleration applied at time t of motorcycle n;
$V_n(t)$: Speed of subject motorcycle n at time t;
$\Delta V_n(t)$: Speed difference between leader and subject motorcycle;
η, ρ, θ: Estimated parameter;
ε_{nt}^{th} : Random term of motorcyclist n at time t, assumed to be distributed i.i.d normal.;
$\varepsilon_{nt}^{th} \sim N[0, (\sigma^{th})^2]$

$$\mathrm{cov}(\varepsilon_{nt}^{th}, \varepsilon_{n't}^{th}) = \begin{cases} (\sigma^{th})^2 & \text{if} \quad n = n' \\ 0 & \text{otherwise} \end{cases}$$

(3) Reaction Time Distribution

The reaction time of a motorcyclist is expected to be a function of age, gender, one or two people in 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 conditions or environment change. In this research, it is assumed to be a constant for a motorcyclist across observations and be varied over motorcyclists.

Among several set of panel data about speed, acceleration, distance, the reaction time for each motorcyclist is estimated by trial and error technique. For each person, among several assumed reaction times, the one corresponding with highest correlation among acceleration, speed and distance is defined as the reaction time for that person. Then, the distribution of the reaction time is constructed.

(4) Free-deceleration model

The subject motorcycle is in the free-deceleration regime if no leader or the leader time headway is larger than the effective longitudinal distance, and so the subject is not affected by the leaders' behavior. This model is applied for some first motorcycles traveling during red light. The free-deceleration the motorcyclist is given by:

$$a_n^{fd}(t) = \alpha \frac{V_n(t-\tau_n)^{\beta}}{(\Delta X_n(t-\tau_n))^{\gamma}} + \varepsilon_{nt}^{fd} \tag{4}$$

where,

$a_n^{fd}(t)$: Acceleration applied at time t of motorcycle n;
t : Current time period;
$V_n(t)$: Speed of subject motorcycle n at time t;
$\Delta X(t)$: Space headway at time t;
α, β, γ: Estimated parameters;
ε_{nt}^{fd} : Random term of motorcyclist n at time t, assumed to be distributed i.i.d normal.;
$\varepsilon_{nt}^{fd} \sim N[0, (\sigma^{fd})^2]$

$$\mathrm{cov}(\varepsilon_{nt}^{fd}, \varepsilon_{n't}^{fd}) = \begin{cases} (\sigma^{fd})^2 & \text{if} \quad n = n' \\ 0 & \text{otherwise} \end{cases}$$

(5) Car-Following Model

If the distance between the subject motorcycle and the vehicle ahead is less than the effective longitudinal distance, the motorcyclist will decide either change to another lane nearby or decelerate and follow the leader. In case he follows the leader, car-following model is applied with some adjustments for motorcycle traffic. From Subramanian[5)], the modified model is given as below:

$$a_n^{cf}(t) = \lambda \frac{V_n(t-\tau_n)^{\eta}}{(\Delta X_n(t-\tau_n))^{\upsilon}} (\Delta V_n(t-\tau_n)) + \varepsilon_{nt}^{cf} \tag{5}$$

where,

$a_n^{cf}(t)$: Acceleration applied at time t of motorcycle n;
t : Current time period;
$\Delta V_n(t)$: Speed difference between leader and subject motorcycle;
λ, η, υ: Estimated parameter;
ε_{nt}^{cf} : Random term of motorcyclist n at time t, assumed to be distributed i.i.d normal.;
$\varepsilon_{nt}^{cf} \sim N[0, (\sigma^{cf})^2]$

$$\mathrm{cov}(\varepsilon_{nt}^{cf}, \varepsilon_{n't}^{cf}) = \begin{cases} (\sigma^{cf})^2 & \text{if} \quad n = n' \\ 0 & \text{otherwise} \end{cases}$$

In order to estimate the parameters of the models above, log-likelihood technique is applied. Then, the model is calibrated and validated with on-site traffic data.

(6) Likelihood Function Formulation

The acceleration applied by a motorcyclist in free-deceleration or car-following regime is given by formula (4) and (5) where, error term is assumed to be distributed i.i.d normal. Therefore, the pdf of the acceleration of the n motorcyclist across I_n observations is expressed as:

$$f(a_{n1}, a_{n2}, .., a_{nI_n}) = \prod_{t=1}^{I_n} \frac{1}{\sigma}\phi\left(\frac{\varepsilon_{nt}}{\sigma}\right) \qquad (6)$$

where ε_{nt}, σ are random term and its' variance in free-deceleration or car-following models. Thus, the likelihood function is given by the product across all N motorcyclists:

$$L^* = \prod_{n=1}^{N}\left[\prod_{t=1}^{I_n} \frac{1}{\sigma}\phi\left(\frac{\varepsilon_{nt}}{\sigma}\right)\right] \qquad (7)$$

The maximum likelihood estimates of the model parameters are obtained by maximizing L = ln(L*) function. In this study, the statistical estimation software GAUSS was used in order to estimate parameters.

5. Estimation Results

Due to less space for writing, only results from free-deceleration model are presented. The estimated parameters are shown on Table 1.

Table 1: Parameter estimates for free-deceleration model

Parameter	*Estimate*	*Std. err.*	*t-stat*
α	-0.5476	0.0398	-13.757
β	1.4365	0.0744	19.309
γ	0.6410	0.0327	19.575
$\ln(\sigma^{fd})$	-0.5164	0.0219	-23.551

Final Log-likelihood value $L(\beta) = -938.65$; Initial Log-likelihood value $L(0) = -1913.71$; $\bar{\rho}^2 = 0.510$.

Number of motorcyclists N = 86; Total observations $I_n = 1720$.

6. Conclusion

No any adjustment factor for motorcycle has been made for 2000 Highway Capacity Manual[6)]. The procedures cannot be applied successfully in most of developing countries because of large differences in traffic composition, roadside facilities and driver behavior. The present paper provides a basic understanding of the traffic operation of motorcycle, which is necessary to conduct analytical models that serve the motorcycle traffic. The findings provide useful information that can be used to develop speed – flow relationship, to improve geometric designs of motorcycle facilities as well as to provide the data necessary to develop a motorcycle simulation model.

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