

Situational Factors of Influencing Drivers to Give Precedence to Jaywalking Pedestrians at Signalized Crosswalk

Xiaobei JIANG^{1,2}

¹*Department of Transportation Engineering, Beijing Institute of Technology, Beijing 100081, China*

²*Lehrstuhl für Ergonomie, Technische Universität München, München 85747, Germany*

Wuhong WANG*, Yan MAO

Department of Transportation Engineering, Beijing Institute of Technology, Beijing 100081, China

Klaus BENGLER, Heiner BUBB

Lehrstuhl für Ergonomie, Technische Universität München, München 85747, Germany

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Abstract

A large number of fatalities are caused by the vehicle-pedestrian accidents. Under a potential conflict between the vehicle and jaywalking pedestrian, giving precedence to the pedestrian will be a proper decision taken by the driver to avoid collision. Field traffic data has been collected by video recording and image processing at two signalized crosswalks. Vehicle speed performance in the single vehicle-pedestrian encounter and platoon vehicle-pedestrian encounter were analyzed for understanding the driver behavior in the conflict process. Binary logit model was proposed to estimate the drivers' giving precedence influenced by the situational factors and the model was validated to predict the drivers' choices accurately. The vehicle speed, pedestrian speed, pedestrian lateral distance and the vehicle longitudinal distance to the conflict point were proved to affect the drivers' choices in platoon driving. The research results would hopefully be helpful to the design of intelligent vehicles and pedestrian protection systems by the knowledge-based decision making process.

Key words: driver behavior; binary logit model; knowledge-based decision making; jaywalking pedestrian

1. Introduction

Motor vehicle-pedestrian accidents are a serious problem throughout the world²⁰. Pedestrian deaths alone cover about 11 percent of all motor vehicle deaths in the US¹ (2003), and about 14% in Germany² (2006–2009). In China, pedestrians make up of more than 20 percent of the traffic accident fatalities (MPSPRC Report³:

24.6% in 2003, 24.97% in 2004 and 25.85% in 2007), while most of that had resulted from the conflicts with motor vehicles. Considered the factors causing traffic accidents, the driver error accounts for 70%~80% and the pedestrian traffic violation accounts for 15%.³ The statistic shows that the proportion of pedestrian fatality in the urban area (67.93%) is significantly higher than that in the suburban area and rural area⁴. So how can we imagine such a situation that a driver conducts an

* Corresponding author: wuhwang@263.net

incorrect maneuver in response to a jaywalking pedestrian at urban crosswalk? Studies on the vehicle driver behavior and the factors of influencing the behavior with regard to giving precedence to pedestrian may provide information for the solution of pedestrian protection systems and promote the motor vehicle active safety^{23,24}.

While most of the traffic accidents to a certain extent depend on vehicle speed, vehicle speed also plays an important role on the description of pedestrian safety problems. Many studies on the motor vehicle–pedestrian conflict were centered drivers' speed performance and its effect on yielding safety. Pasanen⁵ indicated at a collision speed of 50km/h the risk of fatal injury for a pedestrian is almost eight times higher compared to a speed of 30km/h. High vehicle speed was proved to influence the pedestrian safety greatly according to the empirical evidence⁶ and field observation⁷. Further, the relationship between speed level and pedestrian death risk was analyzed⁸. Using a generalized ordered probit model, the research examines the impact of personal and environmental characteristics on severity of injuries sustained in pedestrian–vehicle crashes, the results suggest that the environmental conditions should be an important consideration when evaluating and planning for pedestrian safety²¹. The evaluation of crosswalk warning system was developed to increase the rate of giving way to pedestrians²². In addition, a microscopic traffic simulation model⁹ was proposed to examine the vehicle speed characteristics of interactions with pedestrians, cyclists and other road users. How the speed behavior influenced to give the precedence was investigated by the yielding frequency under different encounter situations related to pedestrian presence¹⁰ and speed limit⁸.

Although speed can be considered as an important parameter in yielding behavior, it is not the only factor that directly determines the driver's giving precedence to pedestrian because within the vehicle–pedestrian conflict process, other situational information would be interpreted by the driver from the environment. Some researches gave different considerations to describe the driver behavior in giving precedence. Persson¹¹ reviewed on communication between road users, and found that the likelihood of a driver giving precedence increased if information of the pedestrian's intention was increased by way of combination of various forms of

signs. Many other factors^{12–14} were presented to have an influence to the drivers to give way to crossing pedestrians: the type of crossing and lane, distance between oncoming vehicle and pedestrian, orientation of pedestrian, number of pedestrians, pedestrian distance from the curb, etc. Logit models^{13,15,16} were employed to analyze and evaluate the behavior of pedestrians and vehicle drivers at crosswalks, and it would be the first step for modeling the vehicle-pedestrian encounter process as well as the accident prediction.

However, in the developing countries, the drivers always scramble for the limited space with pedestrians and deter them from having the right of way. At signal controlled crosswalk (with both vehicle signal and pedestrian signal), the drivers may take it for granted that they just follow the traffic signal, focus on the vehicles in front and reduce the detection to the jaywalking pedestrian. As a result, the driver may not make an appropriate decision of giving priority to the jaywalking pedestrians, at the same time the pedestrians will easily be caught in an extremely dangerous situation which was investigated in this study and should be highlighted in the further vehicle-pedestrian conflict analysis.

2. Methodologies and Data Collection

2.1 Field observation

Two observation crosswalks without any roadside parking are selected for this study. The first one is a minor arterial crosswalk at a signalized X-intersection in Changchun city center. The conflicts between the straight-going vehicles entering the intersection and the jaywalking pedestrians are observed. The average flow rate of the straight-going vehicles (for each observation lane) is 297veh/h/ln within which the passenger cars are about 91.4% and the average pedestrian flow rate (for the observation crosswalk) is 123ped/h with 13.8% of jaywalking pedestrians. The second crosswalk is a mid-block crosswalk on a two-way undivided urban minor arterial road in Beijing. The average flow rate for each observation lane is 324veh/h/ln with 94.2% of passenger cars and the average pedestrian flow rate is 107ped/h with 26.2% of jaywalking pedestrians. The crossing markings were clearly visible in these crosswalks.

Two vehicle–pedestrian encounter situations are defined in this study:

- Situation I: A single vehicle encounters a jaywalking pedestrian;
- Situation II: Vehicle in platoon encounters a jaywalking pedestrian.

Considered the observed zebra crosswalks are perpendicular to the road lane and the evasive driving of the subject vehicle could be treated as a certain lane-based movement, the encounter situation is a right-angle encounter. Passenger cars both in single-driving and platoon-driving status are defined as subject vehicles in the study. Pedestrians who use the zebra crosswalk or very close to the zebra (less than 2m) to cross the road during the pedestrian red time are observed as sample jaywalking pedestrians. Some pedestrians who attempt to violate the signal and head toward the road but are forced to wait on the crosswalk could also be counted.

The driver would theoretically need to notice the mid-block crosswalk 38 m before reaching it at a speed of 11m/s, and have a clear view of both sides of crosswalk from that distance to effectively scan for pedestrians¹⁷. Considered the average speed of the vehicle at the two study sites is lower than 11m/s, a 35m lane length before the crosswalk is chosen for this study to estimate the drivers' giving precedence to pedestrian. The observation time is three successive hours on working day in the interval 14:00-22:00, it is just because the traffic fatality rate is higher than the others according to the Annual Report of the China Road Traffic Accidents Statistics³.

2.2 Video recording of driver and pedestrian behavior

Many available experiments have been conducted to get the real traffic data, and among the various methods for data collection, video observation is undoubtedly a cost-efficient one to reproduce the traffic event. In this study, the video recording and image processing are introduced as the major data collection methods for the analysis on the factors influencing drivers to give way to jaywalking pedestrians. Fig.1 is a sketch map taking an intersection in Beijing for instance and shows the location of the observation point with the camera view

covering the entire length of zebra crosswalk and a 35m approaching lane before the crosswalk.

The movement of the subject vehicle can reflect the driver's approaching behavior to an actual encounter situation. And this proximity can be defined by the distance in space or the distance in time between two road users. Fig. 2 illustrates the timeline of the yielding process by a vehicle B approaching a pedestrian A with the space to conflict point as its y-axis. From studying the trajectories of the subject vehicle, the jaywalking pedestrian and the kinematic equations of motion in relation to a fixed coordinate system, basic characteristics that describing the individual behavior can be derived.

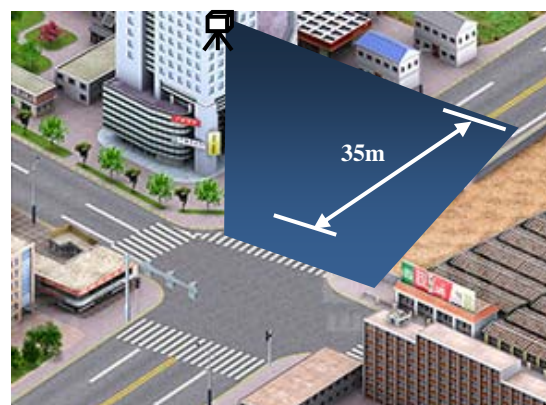


Fig.1 Location of the camera and the observation view

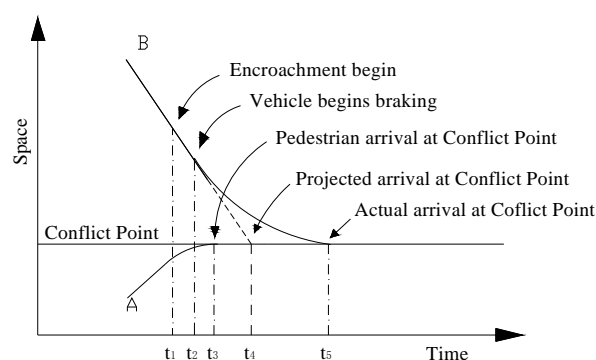


Fig.2 The yielding situation in a conflict

The global polynomial model was applied to transform the image coordinates to road coordinates with the below general equation:

$$x = p(X, Y) = \sum_{i=0}^n \sum_{j=0}^n a_{ij} X^i Y^j \quad (1)$$

$$y = q(X, Y) = \sum_{i=0}^n \sum_{j=0}^n b_{ij} X^i Y^j \quad (2)$$

Where, the (x, y) denotes the road coordinate and (X, Y) denotes the image coordinate. The value n will influence the accuracy of global polynomial method in the n -th power function. Generally, when n equals to 2, nine control points with their image coordinates and road coordinates were measured and substituted into the Eq. (1) and (2) for calculating the transformation coefficients a_{ij} and b_{ij} .

3. Data Analysis

3.1 Single vehicle encounter with jaywalking pedestrian

In naturalistic traffic environment, when a motorist

encounters a pedestrian, generally the decision made by a driver is decelerating before the conflict point to avoid a collision. The driver prefers to slow down rather than stop unless s/he is caught in a serious situation. This conflict event can be described as “pursuit — encounter — deceleration — undisturbed passage”. In the first observation site, 52 samples of drivers’ giving precedence to jaywalking pedestrians in Situation I are measured based on the trajectory data series of the encounter participants.

The approaching speed is one of the essential parts to describe the vehicle movement in the yielding process and it is also a basic parameter for the measures rating conflict severity. The analysis on the situational factors influencing approaching speed can reflect the driver’s maneuver to a certain traffic condition. Fig.3 plots the vehicle speed performance related to its longitudinal distance to the +. It describes a downward trend in vehicle speed with the decrease of the longitudinal distance to conflict point, and vehicle drivers brake from about 10m/s to a relatively low speed at about 4m/s before the conflict point then finally give precedence to

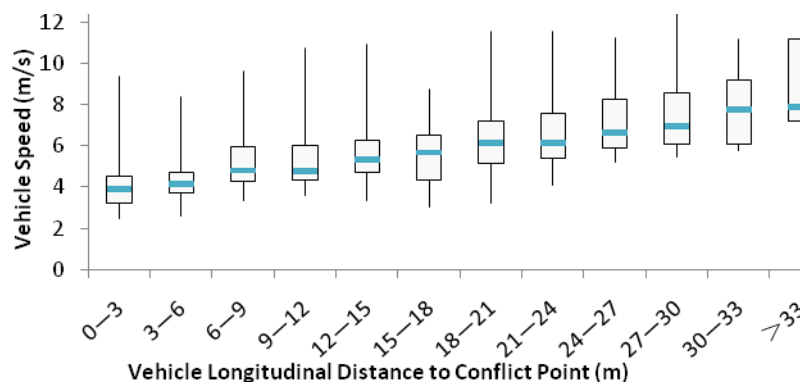


Fig.3 Box plot of relationship between vehicle speed and its longitudinal distance to conflict point in Situation I

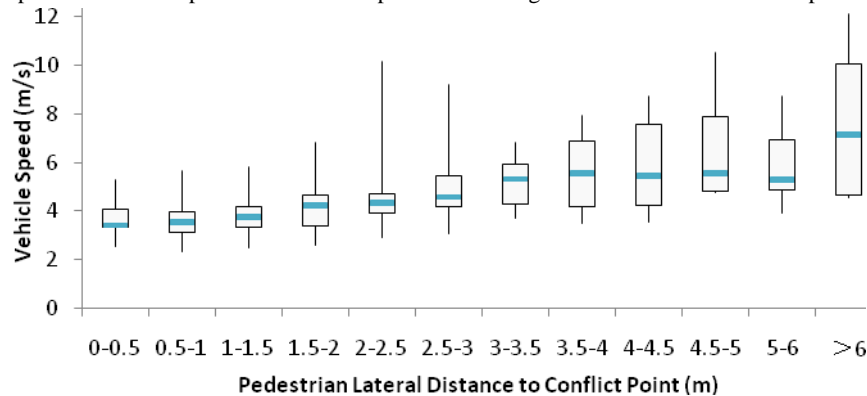


Fig.4 Box plot of relationship between vehicle speed and pedestrian lateral distance to conflict point in Situation I

the jaywalking pedestrians. Fig.4 gives the relationship between vehicle speed and pedestrian lateral distance to conflict point in Situation I. It shows obviously that the pedestrian lateral distance to the conflict point affects the drivers speed choice in yielding behavior. Pedestrian speed will also have an effect on the drivers' decision to a deceleration rate. In previous studies¹⁸, pedestrian speed could be conducted as input of the perceptive-cognitive driver systems in which the deceleration was the output and a pedestrian speed at 1.5m/s was elicited to be sensitive to the driver.

3.2 Vehicle in Platoon Encounter with Jaywalking Pedestrian

The interrelationship process between the jaywalking pedestrian and the vehicle in platoon is very complicated. The violation process of the pedestrian can be divided into several steps

- Arriving at the road side and attempts to violate;

- Forced to wait at the roadside curb;
- Entering the crosswalk and heads toward the road;
- Forced to stop by the vehicles and wait on the crosswalk;
- Crossing the road until a driver is willing to give precedence.

To a driver in the vehicle platoon, s/he has to face a combination influence by both the vehicle in front and the jaywalking pedestrian. 63 samples in Situation II are observed including 50 sample drivers in vehicle platoon don't give way to the jaywalking pedestrians and the other 13 drivers do; the yielding percentage is 20.6%. Compared with the speed performance in Situation I, the vehicle speed in this situation related to the longitudinal distance to conflict point and the pedestrian lateral distance to conflict point is relatively irregular. Fig.5 and Fig.6 illustrate these two relationships respectively.

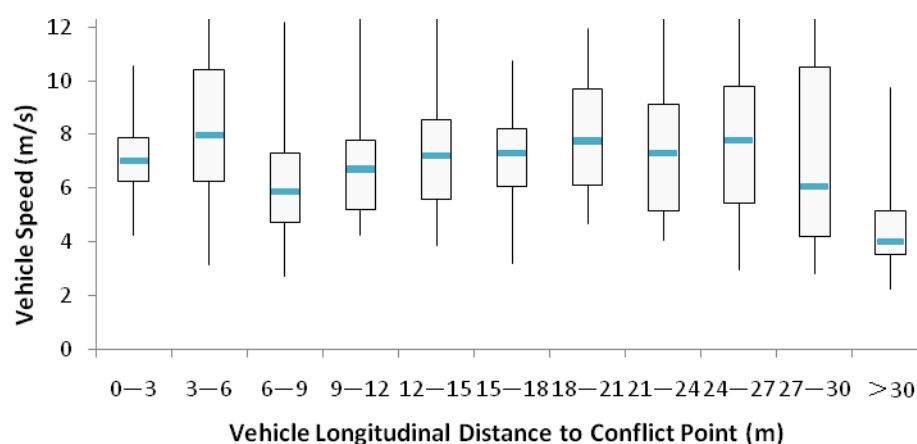


Fig.5 Box plot of relationship between vehicle speed and pedestrian lateral distance to conflict point in Situation II

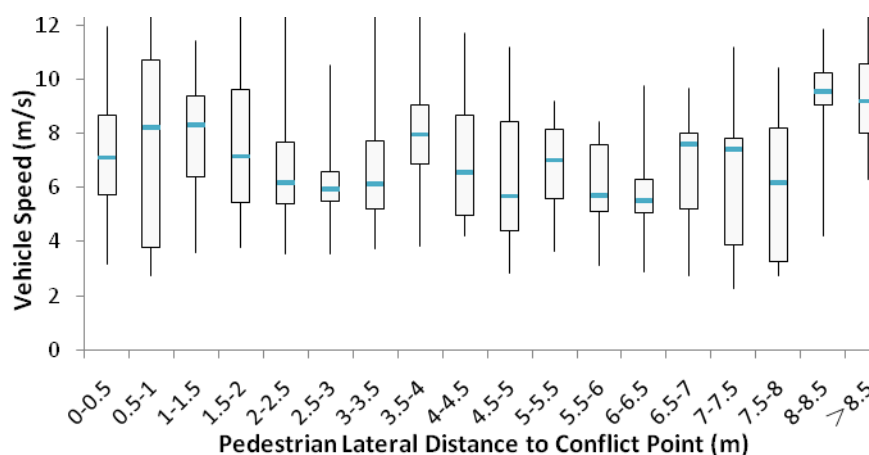


Fig.6 Box plot of relationship between vehicle speed and longitudinal distance to conflict point in Situation II

Normally, in the car-following phase, the driver in platoon will be influenced by the vehicle in front continuously until the rear bumper of the front vehicle reaches the conflict point on the crosswalk, then the major conflict turns to the conflict between the subject vehicle and the pedestrian. Some parameters characterized this situation have been measured.

- Gap in Distance is defined as when the rear bumper of the vehicle in front reaches the conflict point (complete passing the conflict point), the distance from the rear bumper of the front vehicle to the rear bumper of the subject vehicle (in meter).
- Gap in Time expressed as the time it will take for the subject vehicle to cover the Gap in Distance (in seconds).

Tab.1 gives a statistically description of these parameters assorted by “accept” (the drivers give precedence to the jaywalking pedestrian) and “reject” (the drivers don’t give precedence to the jaywalking pedestrian). It can be deduced that if the Gap in Time is larger than 3.5s, the drivers will prefer to give precedence. Other parameters as the pedestrian speed were calculated according to the trajectories.

4. Situational Factors Influencing Driver Behavior Based on Logit Model

It is necessary to the human operator controls the hazardous process work with interpretation of the situation and decision making¹⁹. For analyzing drivers’ giving precedence to jaywalking pedestrian, the flow chart in Fig. 7 illustrates the situational factors as inputs for the driver decision to give precedence during platoon driving.

Firstly when a jaywalking pedestrian presents on the crosswalk, the driver in platoon should determine his/her position in the platoon, and if the vehicle in front is just safely passing the pedestrian that means the subject driver encounters the pedestrian directly. In this case, the situational factors have to be detected, characterized and processed for decision-making. The final decision made by the driver can only be the binary choice: giving precedence or not. The binary logit model which has two discrete choices (generally 1 and 0) as its dependent variable can be applied in the study. The probability of choosing either choice is based on a utility function:

$$U_i = \beta_0 + \beta_{11}x_1 + \beta_{12}x_2 + \dots + \beta_{1n}x_n \quad (3)$$

Where, U_i is the utility of choosing alternative i ; β_{in} is the coefficient; i is the number of alternatives, and n is the number of the independent variables.

Then the model in terms of odds can be written as:

$$P(i = 1)/(1 - P(i = 1)) = e^{U_i} \quad (4)$$

Or in term of the probability of the outcome:

$$P(i = 1) = \frac{1}{1 + e^{-U_i}} \quad (5)$$

In this study, five situational factors as model attributes have been conducted in the binary logit model for predicting the drivers’ yielding behavior:

- Vehicle Speed (VS): the speed of the subject vehicle, m/s;
- Lateral Distance of the Jaywalking Pedestrian to the Conflict Point (LDP), m;
- Pedestrian Jaywalking Speed (PS), m/s;
- Position of the Subject Vehicle in Platoon (PSV): when the pedestrian jaywalks from the roadside

Tab.1 Statistics of Gap in Time and Gap in Distance

		Gap in Time(s)		Gap in Distance(m)	
		Reject	Accept	Reject	Accept
Mean		2.25	4.1	18.56	26.45
Std. Error of Mean		0.11	0.26	1.06	2.63
Median		2.14	3.52	16.84	24.36
Std. Deviation		0.75	0.93	0.52	9.49
Percentiles	5	1.21	3	8.15	14.61
	25	1.78	3.34	11.97	19.1
	75	2.6	5.16	24.03	33.93
	95	3.68	5.24	34.04	48.53

curb, the vehicle which is the first to encounter the pedestrian is considered as 1st Position;

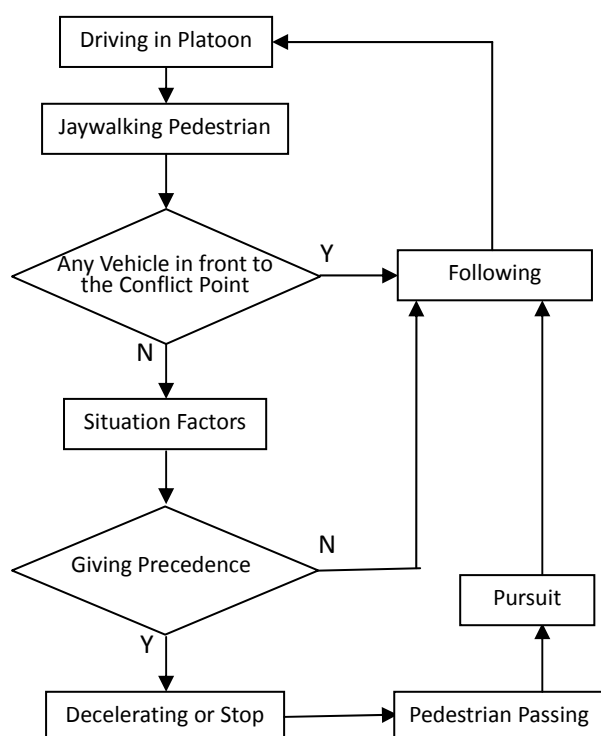


Fig.7 Flow Chart of Platoon Driving

- Gap in Distance (*GD*): compared with Gap in Time, the distance-centered parameter Gap in Distance can be intuitively perceived by the driver and these two parameters have a linear relationship to a certain extent, so the Gap in Distance is determined as the independent variable in the model, *m*.

The discrete choice set (1, 0) is defined as the output of the model, 1 for the decision of giving precedence to the jaywalking pedestrian and 0 for not giving precedence. The utility function for this model is:

$$U_1 = \beta_0 + \beta_1 \cdot VS + \beta_2 \cdot LDP + \beta_3 \cdot PS + \beta_4 \cdot PSV + \beta_5 \cdot GD \quad (6)$$

After logistic regression and variable test, the four independent variables *VS*, *LDP*, *PS* and *GD* are significant ($p < 0.05$), so we remove the non-significant situational factor *PSV* from the model. The probability of the drivers' giving precedent can be predicted by:

$$P(1=1) = \frac{1}{1 + e^{-(0.1678 - 1.9722 \cdot VS - 24.934 \cdot LDP + 0.125 \cdot PS + 0.395 \cdot GD)}} \quad (7)$$

55 sample data series were used for estimating the coefficients of the model by regression and the other 8 samples for prediction. The result showed that the binary logit model could predict the drivers' yielding behavior accurately (the predicted value were all fit the observed data). The model also specified the vehicle speed, the lateral distance of the jaywalking pedestrian to the conflict point, the pedestrian speed and the gap in distance as the situational factors had an influence to the driver behavior in giving precedence to jaywalking pedestrian while the vehicle position in the platoon didn't significantly affect such behavior.

5. Concluding remarks and future works

The driver behavior centered encounters with jaywalking pedestrians at signalized crosswalk has been observed and measured in this paper. By analysis on the trajectories of both the vehicles and the jaywalking pedestrians, the characteristics of road user behavior can be derived. Drivers' speed performance has been studied related to the lateral distance of the jaywalking pedestrian to the conflict point and the vehicle longitudinal distance to the conflict point. The speed performance between Situation I and Situation II are significantly different due to the complexity of the traffic conditions. The box plots implied a linear decrease of the vehicle speed in approaching process in the former situation versus irregular way in the latter one. Two definitions, Gap in Distance and Gap in Time have been introduced and statistically estimated for drivers' decision of giving precedence. In this study, binary logit model is applied to estimate the drivers' yielding behavior influenced by the situational factors. Four factors: *VS*, *LDP*, *PS* and *GD* are demonstrated to have great effect to the driver decision in giving precedence in platoon driving and the probability function can predict the drivers' choices accurately. However, lack of detection and taxonomies to the individual characters of pedestrians like the gender, age, assertiveness, disability, etc., and the feature parameters of the roadway, the situational factors proposed here cannot describe the entire conflict condition comprehensively. More

situational information needs to be gathered in the further work and the model proposed in this study could hopefully be the groundwork in the target of modeling driver behavior in vehicle–pedestrian conflicts.

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