Gap Acceptance Decision Model for U-turn Movement at Midblock Median Opening

Thakonlaphat JENJIWATTANAKUL[1] and Kazushi SANO[2]

[1]Graduate Student, Dept. of Civil and Environmental Eng., Nagaoka University of Technology
(1603-1 Kamitomioka, Nagaoka, Niigata 940-2188, Japan)
E-mail: s107017@stn.nagaokaut.ac.jp
[2]Associate Professor, Dept. of Civil and Environmental Eng., Nagaoka University of Technology
(1603-1 Kamitomioka, Nagaoka, Niigata 940-2188, Japan)
E-mail: sano@nagaokaut.ac.jp

U-turn movement at the midblock median opening was based on gap acceptance process. This research investigated the factors affecting the u-turn decision of the driver and evaluated the significance and influence levels of each factor. The u-turn decision model had also been developed after knowing the significant factors. The u-turning vehicles in the study included car, taxi, and pick-up, which the passenger car equivalent equal to 1. The binary logistic regression technique was employed in the data analysis and model development. The gap size, speed of conflicting vehicle, wait time at stop line, and conflicting vehicle type were statistically significant at the confidence interval of 90%. Unlike the gap acceptance process of two-way stop-controlled intersection, queue time of the u-turning vehicle did not significantly affect the gap acceptance decision. The developed decision model, which explanatory variables included gap size, speed, and wait time, could predict the u-turn decision well with the percentage correct of more than 90%.

Key Words : *u-turn, gap acceptance, logistic regression, decision model*

1. INTRODUCTION

U-turn movement at an unsignalized midblock median opening is based on the gap acceptance behavior. When the vehicle arrives the median opening, its driver faces the gaps of the conflicting through traffic, waits for an acceptable gap, and then makes a u-turn. Since the u-turn movement is complex and may lead to safety concerns, the factors affecting the u-turn decision were investigated.

The objectives of this research were as follows:

(i) to evaluate the factors affecting the u-turn decision in terms of their significance and influence;

(ii) to develop a u-turn decision model, in order to predict the decision under variety of factors.

Eight factors were considered; five related to the u-turning vehicle (age, gender, vehicle type, queue time, and wait time), three related to the conflicting traffic (gap size, speed, and vehicle type). The binary logistic regression technique was employed in the data analysis process.

The results showed that those factors had effect on the decision in the following descending order: gap size, speed, wait time, conflicting vehicle type, queue time, gender, u-turning vehicle type, and age. The significant factors included gap size, speed, and wait time at the confidence interval of 95%. The conflicting vehicle type could also be significant at the confidence interval of 90%. It could be noticeable that the queue time of the u-turning vehicle did not significantly affect the gap acceptance decision, but the wait time did.

The u-turning vehicles in this study focused only on passenger car, which included all kinds of vehicle with passenger car equivalent (PCE) of 1.

2. LITERATURE REVIEW

The gap acceptance behavior can be observed at the unsignalized intersection, especially the two-way stop-controlled (TWSC) intersection and the roundabout[1)]. The capacity estimation methods providing for TWSC can be applied to estimating u-turn capacity at unsignalized median openings[2)].

The different conditions (combination of driver, vehicle, traffic, and environment conditions) result in the different gap acceptance behavior. The difference in driver age group affects the gap acceptance capabilities[3]. For gender, the male drivers tend to accept smaller gaps than female drivers[4].

A decision model for gap acceptance at intersections has been developed based on a risk-reward loop process. The result shows that the entry onto the main road occurs when the benefit from entry is greater than the associated risk[5].

The study at a u-turn section shows that the combination of gap size and acceleration of priority vehicle gives the best and most consistent definition of the probability of gap acceptance of u-turning vehicles[6]. The speed, wait time, and vehicle type of the priority vehicle are among the insignificant factors.

In the gap acceptance process at unsignalized intersections, there might be some aggressive drivers who force their vehicles into the major stream, making the conflicting vehicles to slow down or stop. Three major factors that affect the probability of such a forcing maneuver include driver age, car performance, and average speed on the major road[7]. In addition, the driver's total waiting time, while waiting for an acceptable gap, is not contributable to the aggressive behavior occurrence.

3. METHODOLOGY

The gap acceptance decision is the dichotomous problem, of which the possible solution will be either "yes" or "no". The binary logistic regression is widely used to model the occurrence of the event. The output of the model is the probability of the event occurrence. In addition, the logistic regression also gives the statistical significance level of each variable.

The probability of the u-turn decision based on the explanatory variables $x_1, x_2, \ldots, x_n$ can be modeled as:

$$\text{P(accept)} = \frac{e^z}{1+e^z} = \frac{1}{1+e^{-z}} \quad (1a)$$

$$z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n \quad (1b)$$

where $\beta_0, \beta_1, \beta_2, \ldots, \beta_n$ are the parameters estimating from the logistic regression analysis.

The analysis started with all variables to determine the significance of each variable. The forward and backward stepwise analyses, based on likelihood ratio, were also conducted to validate the level of influence of variables. The level of significance was set at 0.05 for the variable entry and 0.10 for the variable removal in the stepwise analysis. The cutting value for the decision of accepting the gap was set at the probability of 0.5.

4. DATA COLLECTION

(1) Site characteristics

The selected midblock median opening is located on a six-lane divided street with three lanes in each direction. There is an exclusive u-turn bay for both directions. Most u-turning vehicles encroach to the middle lane when they make a u-turn. Therefore, the vehicles on the middle and median lanes were treated as the conflicting vehicles.

(2) Collected data

Two kinds of data were collected in the field, i.e. video data and sound data. A video camera was set at the nearby pedestrian bridge to record the traffic movement. The video data was reviewed to collect useful information in the laboratory, i.e. vehicle type, queue time, wait time, gap size, and speed.

The sound data was recorded by another observer, who was near the u-turn location. The observer recorded the u-turn driver age and gender of some random vehicles. The follow-up u-turning vehicles were not considered because they did not perform the real gap acceptance behavior. Since the driver age information was based on the observer's perception, the age data was divided into rough three groups to minimize the human error.

The total of 154 u-turning vehicles was analyzed. Each vehicle faced some or many rejected gaps and accepted only one gap. The largest rejected gap of each vehicle was selected. The analysis included a total of 308 cases of the u-turn decision, of which 280 cases were used for model development and the remaining 28 cases were used for model evaluation.

(3) Considered factors

Eight variables were included in this study:

(i) u-turn driver age group, dividing into three groups as young, middle, and old;

(ii) u-turn driver gender;

(iii) u-turn vehicle type, dividing into car (sedan, sport utility vehicle, and van), taxi, and pick-up;

(iv) queue time, which is the time duration that the u-turning vehicle starts to queue until it reaches the stop line;

(v) wait time at the stop line;

(vi) gap size, referring to time headway of conflicting traffic in this study;

(vii) speed of the conflicting vehicle; and

(viii) conflicting vehicle type, dividing into car (sedan, sport utility vehicle, and van), taxi, pick-up truck, and heavy vehicle (bus and large truck).

The variables (i) - (v) related to the u-turn traffic while the remaining related to the conflicting traffic.

5. RESULTS

(1) Variable selection

The p-value of each variable was shown in **Table 1**. When the p-value is less than the significance level, the null hypothesis is rejected. The result is said to be statistically significant. In the analysis, the null hypothesis is no difference on having the variable in model. On the other words, the variable with higher p-value has less effect on the u-turn decision. Therefore, the influence of variables to the decision in the descending order was as following: gap size > speed > wait time > conflicting vehicle type > queue time > gender > u-turning vehicle type > age.

Table 1 p-value of all variables

Variable	p-value
Gender	0.7780
Age	0.9374
U-turn Veh. Type	0.8978
Queue Time	0.3603
Wait Time	0.0002
Gap Size	0.0000 (6.03×10^{-12})
Speed	0.0000 (1.24×10^{-7})
Conflict Veh. Type	0.0819

Only three variables were statistically significant, at the significance level of 0.05, including gap size, speed, and wait time. The conflicting vehicle type could be statistically significant at the significance level of 0.10.

(2) Effect of significant variables

Base on the forward stepwise logistic regression analysis, each significant variable was entered into the model according to its p-value. The effect of each variable was described in the following sub-sections.

a) Gap size

The relationship between the gap size and probability of accepting the gap was shown in **Fig. 1**. At the P(accept) of 0.5, the gap size was 5.1 seconds. This implied that when a u-turning vehicle faced a gap size of greater than or equal to 5.1 seconds, the vehicle would accept the gap and make u-turn.

b) Speed of conflicting vehicle

The speed of the conflicting vehicle affected the gap acceptance behavior. As shown in **Fig. 2**, the higher speed, the less probability of accepting the gap for the same gap size. At the P(accept) of 0.5, the gap size was 3.1, 4.1, and 5.0 seconds for the conflicting vehicle's speed of 30, 45, and 60 km/hr, respectively.

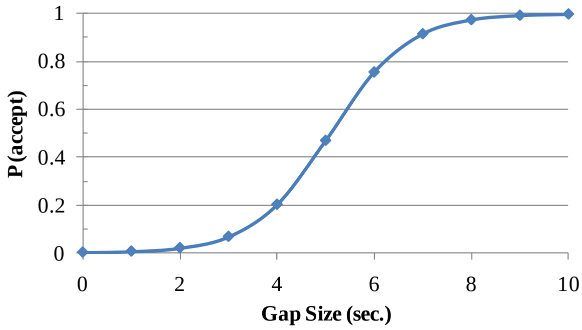

Fig. 1 Effect of gap size on u-turn decision

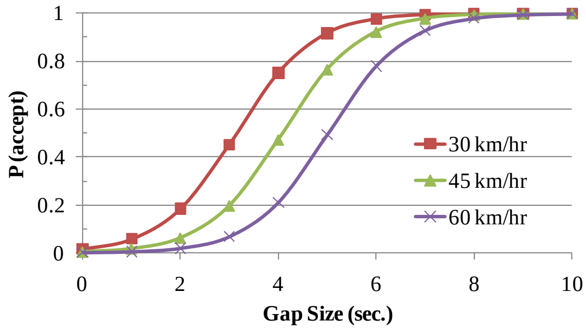

Fig. 2 Effect of conflicting vehicle speed on u-turn decision

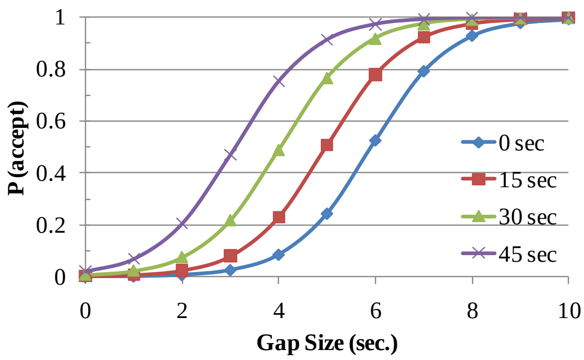

Fig. 3 Effect of wait time on u-turn decision

c) Wait time

The wait time of the u-turning vehicle affected the gap acceptance behavior. As shown in **Fig. 3**, the longer wait time, the higher probability of accepting the gap for the same gap size. At the P(accept) of 0.5, the gap size was 5.9, 5.0, 4.0 and 3.1 seconds for the wait time of 0, 15, 30, and 45 seconds, respectively. This was based on the conflicting speed of 60 km/hr.

d) Conflicting vehicle type

The conflicting vehicle type affected the u-turn decision, at the significance level of 0.10. As shown in **Fig. 4**, the conflicting vehicle of car and taxi provided the highest probability, followed by pick-up, and then heavy vehicle (HV). At the P(accept) of 0.5, the gap size was 4.6, 5.4, and 6.1 seconds for car & taxi, pick-up, and HV, respectively. This was based on the conflicting speed of 60 km/hr and wait time of 15 seconds.

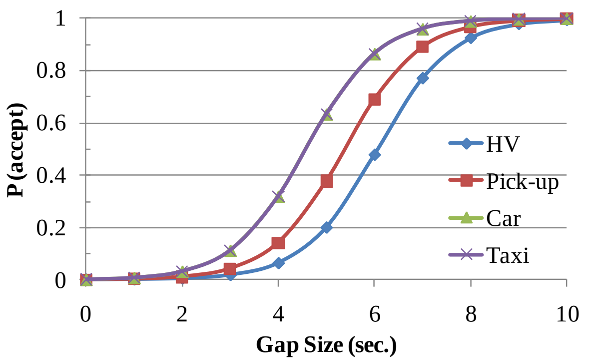

Fig. 4 Effect of conflicting vehicle type on u-turn decision

(3) Decision model

To predict the u-turn decision at the confidence interval of 95%, three variables were included in the model formulation. The developed u-turn decision model was shown as follows:

$$P(\text{accept}) = \frac{e^z}{1+e^z} = \frac{1}{1+e^{-z}} \qquad (2a)$$

$$z = -1.950 + 1.235\ \text{Gap} - 0.089\ \text{Speed} + 0.077\ \text{Wait} \qquad (2b)$$

The model yielded the Nagelkerke R^2 of 0.800. The Hosmer and Lemeshow test also indicated the goodness-of-fit of the observed and predicted events.

The classification table showing the percentage correct of the model prediction was shown in **Table 2** for both the cases that were used and not used in the model development process.

Table 2 Classification table showing the prediction result

		Predicted		
		Cases for model development		
		Rejected	Accepted	% Correct
Observed	Rejected	125	15	89.3
	Accepted	13	127	90.7
		Overall Percentage		90.0
		Cases for model validation		
		Rejected	Accepted	% Correct
	Rejected	14	0	100.0
	Accepted	1	13	92.9
		Overall Percentage		96.4

6. DISCUSSIONS AND CONCLUSIONS

The findings from this research could illustrate the distinctive characteristics of u-turn gap acceptance behavior. For TWSC intersection, the mean accepted gap tends to decrease as the queue time or wait time increases[8]. From the result of this research, the queue time is not statistically significant for the u-turn gap acceptance. The u-turn vehicle, when staying in queue, could see the conflicting traffic stream and realize the traffic situation. Therefore, the u-turn drivers would not take the delay in queue to decide whether or not accepting the gap. Nevertheless, it also depended on the nature of the driver population in the area.

Unlike the past research[6), 7)], the speed, wait time, and conflicting vehicle type also influenced the u-turn decision. When the wait time was as high as 45 seconds, the driver would accept the gap as low as 3.1 seconds. Thus, the longer waiting time would contribute to the aggressive behavior of u-turning drivers.

The conclusions could be listed as follows:

- gap size, speed, wait time, and conflicting vehicle type significantly affected the u-turn decision;
- u-turn driver age, gender, vehicle type and queue time did not significantly influence the decision;
- driver facing the heavy vehicle need a large gap to make u-turn;
- u-turn decision model based on gap size, speed and wait time could predict well.

Since the analysis was based on the collected data, the more sample data might give the better representative results for practical future usage.

REFERENCES

1) Transportation Research Board, *Highway Capacity Manual*, 4th Edition, National Research Council, USA, 2000.
2) Liu, P., Lu, J. J., and Cao, B. : Capacity of u-turns at unsignalized median openings on six-lane streets, *Transportation Research Record*, No. 2130, pp. 59-65, 2009.
3) Dissanayake, S., Lu, J. J., and Yi, P. : Driver age differences in day and night gap acceptance capabilities, *IATSS Research*, Vol. 26, No. 1, pp. 71-79, 2002.
4) Yan, X., Radwan, E., and Guo, D. : Effects of major-road vehicle speed and driver age and gender on left-turn gap acceptance, *Accident Analysis and Prevention*, No. 39, pp. 843-852, 2007.
5) Pollatschek, M. A., Polus, A., and Livneh, M. : A decision model for gap acceptance and capacity at intersections, *Transportation Research Part B 36*, pp. 649-663, 2002.
6) Ebisawa, R., Espada, I. C., Nakatsuji, T., and Tanaboriboon, Y. : Gap acceptance characteristics at a u-turn section in Bangkok, *J. of the Eastern Asia Society for Transportation Studies*, Vol. 4, No. 2, pp. 63-74, 2001.
7) Kaysi, I. A., and Abbany, A. S. : Modeling aggressive driver behavior at unsignalized intersections, *Accident Analysis and Prevention 39*, pp. 671-678, 2007.
8) Kyte, M., Clemow, C., Mahfood, N., Lall, B. K., and Khisty, C. J. : Capacity and Delay Characteristics of Two-Way Stop-Controlled Intersections, *Transportation Research Record*, No. 1320, pp. 160-167, 1991.

(Received August 5, 2011)