TURNING GAP ACCEPTANCE ON CROSSWALK:
IMPACT OF DIFFERENCE ON PAVEMENT

Hasina IASMIN¹, Aya KOJIMA² and Hisashi KUBOTA³

¹PhD Candidate, Graduate School of Science and Eng., Saitama University
(255 shimo okubo, Sakura-ku, Saitama 338-8570, Japan)
E-mail: hasina_iasmin@yahoo.com

²Member of JSCE, Associate Professor, Graduate School of Science and Eng., Saitama University
(255 shimo okubo, Sakura-ku, Saitama 338-8570, Japan)
E-mail: kojima@dp.civil.saitama-u.ac.jp

³Fellow of JSCE, Professor, Graduate School of Science and Eng., Saitama University
(255 shimo okubo, Sakura-ku, Saitama 338-8570, Japan)
E-mail: hisashi@dp.civil.saitama-u.ac.jp

It is very common practice for turning vehicle to share the crosswalk with pedestrian to complete their turning maneuver at signalized intersection. During this sharing it is expected that turning vehicle will yield pedestrian first. But accident data reveals that pedestrian are not yielded properly by turning vehicle at signalized intersection. This study objectives to analyze the likelihood of left and right turning vehicles accepting gaps towards pedestrian considering difference on pavement using logistic regression. Speed of turning vehicle on conflict area during accepting gap is also analyzed to address the severity of interaction occurred by accepting gap. The results show that driver on crosswalk with brick pavement shows more yielding behavior by rejecting smaller gap compared to baseline condition and red colored pavement.

Key Words : turning vehicle, gap acceptance, pedestrian safety, crosswalk, pavement design

1. INTRODUCTION

Traffic signal is operated to control competing flows of traffic. For traffic operation efficiency it is not always possible to give separate signal phase for all types of road users. Separate traffic signal for pedestrian is operated only if the conflicting road user volume is heavy on the pedestrian crossing. For moderate traffic volume it is hard to provide an isolated traffic signal for all road users. In that case turning vehicle have to share the same signal phase with pedestrians. As turning vehicle has to use the pedestrian crossing to complete their maneuver, pedestrian-turning vehicle conflict is a very common phenomenon at signalized intersection. At crosswalks pedestrians are given prioritized right of way. It means that turning vehicle has to yield pedestrian first when they interact with pedestrians at crosswalks. But accident data reveal that Pedestrians have a danger with turning vehicles at pedestrian crossings. In Japan, 49% pedestrian accidents occurred at signalized intersection during 2008 to 2012. Among which 41.6% fatalities took place with right turning vehicle and 7.8% pedestrian fatalities occurred with left turning vehicle. One of the main reason for this type of accidents is inappropriate gap selection by turning driver.

Drivers are constantly searching the correct opportunity to cross the intersections by themselves. This opportunity is named “gap” and the behavior is called “Gap acceptance”. Incorrect gap acceptance may cause accidents between road users. If drivers tend to accept small gap it may increase the probability of occurring collision between road users. Gap acceptance is well known to study the way in which drivers move into a priority area where they must give way to other road users. Many researchers have modelled driver’s gap acceptance behaviors towards pedestrian or cyclist in priority area. Sun et al. have applied logit and probit model to analyze driver’s yielding patterns at an unsignalized pedestrian crosswalk. A logistic-regression model has been developed to predict driver’s yielding or gap acceptance behavior considering different factors, including the presence of pedestrian crossing treatments. Alhajyaseen et al. have modelled left turn driver’s gap acceptance behavior to predict how driver considers the position of pedestrian. A gap
acceptance study has been conducted to interpret driver’s overlooked behavior towards cyclist at roundabout. Different population and the place had different critical gaps. The Gap acceptance study is appropriate for analysis driver’s behavior.

Some researchers have found that there is a close relationship between road features and road user behavior (i.e. intersection angle, curve radius, intersection area, colored pavement, pavement marking etc.). Keeping this point (road features) in mind the main objective of this study is to evaluate how left and right turn driver move into the crosswalk with different pavement design in the presence of pedestrian on a crosswalk or near the crosswalk. The Gap acceptance study is used to interpret driver’s changes behavior due to different pavement design on crosswalk in this study. The purpose was to examine the gap size what driver choose in the course of interaction. Driver’s approach speed has an effect on his gap acceptance behavior. Driver accepts small gap with high speed. Due to this reason driver’s speed on crosswalk during accepting small gap was also analyzed in this study. Since this study based on observational data, it was impossible to assess driver characteristics in depth.

2. METHODOLOGY

(1) Data collection

The first criteria of intersection selection were two-two lane (without right turn lane) 4 legged signalized intersection where it is not possible to provide separate signal phase for left and right turning vehicles. In that case turning driver has to share the crosswalk with a pedestrian at same signal phase. How driver interact with pedestrian on crosswalk by accepting/rejecting different gap size was motivated to analyze. The second criteria of intersection selection were geometric difference of a crosswalk or intersection area. The purpose was to observe the effect of these differences on turning driver’s yielding behaviors. Considering these two criteria, a selection has been made for potential locations based upon google street view information. After that on site location, visit was also done to observe the real features of the locations. There are three impending locations were found to conduct the study. The study area is located near Nishikawaguchi station, Japan. All of these intersections are situated in a residential area. In these intersections one urban road is intersected by three local residential roads. All these three sites are situated along a major road one by one (Fig.1). As the area purpose and dimension of these intersections are same, it was hypothesized that the traffic volume would same. From data collection it was found that almost all characteristics except pavement design are similar in these three intersections (Table 1). There is no separate signal phase for pedestrians at three intersections. Pedestrian follow the same signal time with the through vehicle. Left and right turn vehicle also share the same signal phase for completing their maneuver. Table 1 presents the geometric characteristics of observed sites which is illustrated in Fig.2 - 4. The average demands of turning vehicle, pedestrian, cyclist on observed crosswalk and through traffic volume, signal cycle time on major road leg A-leg C (urban road) are presented in Table 1. The traffic demand is very low in these intersections.

In Fig.2 - 4 it is found that the setback of a crosswalk on urban road is different for each intersection i.e. 4.04m (corner cutoff 2.31m) for baseline condition, 5m (corner cutoff 1.05m) for red colored and 3m (corner cutoff 2.03m) for brick pavement. As corner cutoff is small for red colored intersection, it makes the intersection corner less compact than others. Data were collected during December, 2014- January, 2015, during the daylight from 9:00 a.m. to 4:00 p.m. by video recording. It was winter season and the weather was sunny and clear. There are total four crosswalks at each intersection. Crosswalk on leg D (baseline condition, brick pavement), B (Red colored) was studied to observe gap acceptance behavior of turning driver’s. Car from leg A to leg D (baseline condition, brick pavement), leg C to leg B (Red colored) was considered for left turn movement. For Right turn car it was con-
considered from leg C to leg D (baseline condition, brick pavement), leg A to leg B.

(2) Data extraction
The total 30hrs video was observed from all three intersections. All interaction is observed from the video. Required data like speed of vehicle, time duration, distance are extracted from video by using video analyzing software Kinovea. Kinovea is a free and open source (GPL2) French software created in 2009 as a tool for movement analysis\(^1\). This software is mainly used for sport analysis. With parameters, calibration of the geometric data of the marking lines, Kinovea is able to calculate motion parameters including position, speed, and acceleration etc. of sports car, athletes, and player. So it can be possible to use Kinovea for traffic study. A low pass filter is used for filtering data in Kinovea. The filter does two passes of a second-order Butterworth filter. The two passes (one forward, one backward) are used to reset the phase shift\(^2\). To initialize the filter the trajectory is extrapolated for 10 data points each side using reflected values around the end points. The extrapolated points are then removed from the filtered results\(^3\). Kinovea allowed to export filtered data in Excel form automatically. Fig.5 shows an outline of detailed description of video analyzing procedure.

<table>
<thead>
<tr>
<th>Pavement type</th>
<th>Avg. left turning car on crosswalk (veh./hr)</th>
<th>Avg. right turning car on crosswalk (veh./hr)</th>
<th>Average Through vehicle On urban road (veh./hr)</th>
<th>Avg. pedestrian /cyclist on crosswalk Ped./hr</th>
<th>Cyc./hr</th>
<th>Green signal time of urban road (Total cycle) (sec)</th>
<th>Intersection corner angle</th>
<th>Corner cutoff for left turn (m)</th>
<th>Width of Major road (Carriage way) (m)</th>
<th>Width of Minor road (Carriage way) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline condition</td>
<td>6</td>
<td>3</td>
<td>58</td>
<td>44</td>
<td>12</td>
<td>17</td>
<td>46 (80)</td>
<td>90°</td>
<td>2.31</td>
<td>8.5 (6)</td>
</tr>
<tr>
<td>Red colored pavement</td>
<td>8</td>
<td>5</td>
<td>55</td>
<td>42</td>
<td>9</td>
<td>13</td>
<td>41 (80)</td>
<td>90°</td>
<td>1.05</td>
<td>8.5 (6)</td>
</tr>
<tr>
<td>Brick pavement</td>
<td>5</td>
<td>2</td>
<td>57</td>
<td>41</td>
<td>7</td>
<td>13</td>
<td>42 (80)</td>
<td>90°</td>
<td>2.03</td>
<td>8.5 (6)</td>
</tr>
</tbody>
</table>

Table 1 Traffic conditions and geometric characteristics at observational crosswalk of local residential road B-D.

Fig.2 Geometric sketch of baseline condition.

Fig.3 Geometric sketch of red colored intersection.

Fig.4 Geometric sketch of brick pavement intersection.
(3) Data analysis

Gap acceptance is well known to study the way in which drivers move into a priority area where they must give way to other road users. In this study to understand the driver’s tendency to give priority to pedestrian or cyclist on the crosswalk gap acceptance study is used.

In this study gap is considered as an opportunity for a turning car to cross the pedestrian crosswalk when they interact with pedestrians. The definition of term is given below:

“A lag is the required time for a single pedestrian to reach the conflict area.”

“A gap is the time difference between two successive pedestrian to reach the conflict area.”

If pedestrian came single than the definition of lag is used. But if pedestrians came in a group than for first pedestrian it was lag and for next pedestrian it became gap. But for result both lag and gap are treated as gap.

“Conflict area is defined as the area which is covered by car on crosswalk of outflow road”. Since all potential conflicts with pedestrian or cyclist occur within this area.

Gap is recorded at the point in time where the turning car driver decides whether he accepts or rejects the gap. Since precise determination of this point is very difficult to get, in this study decision point is assumed that when the driver reach near the crosswalk of the inflow road. From Fig.2 - 4 it has been found that the position of the crosswalk in the inflow road from the intersection corner is different for each intersection (baseline condition = 4m; brick pavement = 3m; red coloured = 5m). To keep consistent with data collection the decision point was trying to keep on the same distance from intersection corner. For brick pavement intersection this point is assumed on exit point of the crosswalk (3m from intersection corner), for red coloured intersection it is assumed 1m, far from the exit point of the crosswalk (3m far from the intersection corner) and for baseline condition it is assumed 2m far from the exit point of the crosswalk (3m far from the intersection corner) (Fig.6). Right turn vehicles use the opposite inflow road where setback distance is also different for each intersection (baseline condition = 4m; brick pavement = 2m; red coloured = 1m). Considering decision point same methodology for left turning vehicles has also been used for right turning vehicles. According to the definition of lag and gap, measurements are made of the number of seconds which are available for turning car before the pedestrian arrive the conflict area (Fig.6).

To estimate the gap acceptance probability distribution empirical data are collected. After collecting the required data, gap/lags are divided into several bins of 1.0s size, due to the limited sample size. The acceptance probability for each bin can be calculated by using Eq. (1).

\[
P(x) = \frac{\text{No. of observed accepted gaps/lags}}{\text{No. of observed accepted and rejected gaps/lags}}
\]  

To analyse left turn gap acceptance logistic regression method was used. It was found that logistic regression is appropriate for modelling a situation in which drivers a lot of opportunities where the driver has to take yes/no decision. The logistic regression model is Eq. (2).
\[ P(x) = \frac{1}{1 + e^{-b_0 - b_1 x}} \]  \hspace{1cm} (2)

Where \( P(x) \) is the probability of accepted a gap/lag \( x \); \( b_0 \) and \( b_1 \) are intercept parameter and slope parameter. As an indicator of model fit the mean values of Nagelkerke’s \( R^2 \) for each individual regression model is reported for each analysis\(^{20}\). For measuring critical gap Raff method has been used in this study\(^{21}\). By using graphical method, two cumulative distribution curves are drawn: one of them relates gap lengths \( t \) with the number of accepted gaps less than \( t \) and the other relates \( t \) with the number of rejected gaps greater than \( t \). The intersection of these two curves gives the value of \( t \) for the critical gap\(^{22}, 23\).

3. RESULTS AND DISCUSSIONS

(1) Left turn gap acceptance

A total 110 individual gap decision at three intersections were recorded (details are given in Table 2). As stated by methodology, observed lag/gaps are divided into 1.0 sec size bin (0-1 sec, 1.1-2 sec, 2.1-3 sec, 3.1-4 sec, 4.1-5 sec, 5.1-6 sec, 6.1-7 sec, 7.1-8 sec, 8.1-9 sec). The acceptance probability can be calculated by using Eq. (1).

Fig.7 shows the percentage of drivers who accepted each gap at studied intersections with different type pavement design. None of the drivers at brick pavement accepted gap less than 4 sec. Drivers at baseline condition accept gap in the range of 1.1-2 sec. Critical gap measured for left turning vehicle was 3.32 sec using raff method (Fig.8). It can be understood that driver at baseline condition accept small gap which is unsafe for pedestrian. Fig.9 shows the effect of different pavement design on left turn driver’s gap acceptance behavior. In the graph solid vertical line indicates critical gap size 3.32 sec. As can be clearly seen, driver at brick pavement has low tendency to accept gap less than the critical gap. Driver at red coloured pavement also reject gap smaller than critical gap 3.32 sec. The estimated values of regression parameter for three pavement design are shown in Table 3. Parameter \( b_0 \) is also indicated the lower value for red coloured and brick pavement.

(2) Right turn gap acceptance

For right turning car 51 (16 with baseline condition, 22 on red colored pavement and 13 on crosswalk brick pavement) were used for gap acceptance analysis of right turn car (Table 2).
different pavement design on left turn driver’s gap acceptance probability. There is a solid line drawn through the $x=3.09$ point. This line specifies the critical gap location. As can be clearly seen, driver at brick pavement has low Probability ($<0.2$) to accept gap less than the critical gap. From Fig. 12 it is revealed that right turn driver at red coloured pavement has almost same probability to accept smaller gap than 3.09 sec. The summary of logistic regression results are described in Table 3.

(3) Speed at conflict area

A crosswalk is a place which is shared by turning vehicle and pedestrian. Pedestrians are very vulnerable road user. They have more danger than automobile user. The risk of the causality of crashes increases with increasing free travelling speed$^{24, 25}$. It is rational to use the vehicle speed in the conflict area as an indicator of the severity of the conflict. For three different intersections the cumulative distributions of observed turning vehicle speed at the conflict area after accepting a specific lag/gap are shown in Fig. 13. The cumulative distributions are developed by dividing the speeds into 2.0 km/h size bin (0-2 km/h, 2.1-4 km/h, 4.1-6 km/h, 6.1-8 km/h, 8.1-10 km/h, 10.1-12 km/h, 12.1-14 km/h, 14.1-16 km/h, 16.1-18 km/h, 18.1-20 km/h, 20.1-22 km/h, 22.1-24 km/h, 24.1-26 km/h).

From gap acceptance study it is found that left turn drivers at the crosswalk of red colored and brick pavement tend to accept larger gaps than baseline conditions. Fig. 13 shows clearly that the speed of left turn car on conflict area of crosswalk at baseline condition is significantly higher than the provision of red color and brick pavement when accepting gaps/lags. The 85th percentile speed of left turn car on crosswalk with red colored and brick pavement is lower than the speed at crosswalk without any pavement design. From t-test it is found that the difference between the speeds at the baseline condition crosswalk and red color and brick pavement is significant. It also found that 7.6% drivers at a crosswalk with red color and 21.4% drivers at a crosswalk with brick pavement were travelling the conflict area with speed less than 10km/h when they found pedestrian near the crosswalk. But Fig. 13 illustrates that for right turn car speed at red colored was higher than brick pavement. The 85th percentile speed of right turn car at baseline condition was more

<table>
<thead>
<tr>
<th>Pavement type</th>
<th>Left turn</th>
<th>Right turn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gap accept</td>
<td>Gap reject</td>
</tr>
<tr>
<td>Baseline condition</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>Red coloured</td>
<td>26</td>
<td>18</td>
</tr>
<tr>
<td>Brick pavement</td>
<td>14</td>
<td>16</td>
</tr>
</tbody>
</table>

Fig. 10 Percentage of drivers accept each gaps to make right turn.

Fig. 11 The critical gap estimation by Raff’s method: right turn car on crosswalk$^{21}$.

Fig. 12 Predicted probability that drivers accept gaps to make right turn through crosswalk. Solid vertical line indicates critical gap size 3.09 sec.

Table 2 Left and right turn vehicle’s gap acceptance data.
than 20 km/hr. On red colored intersection and brick pavement, it was >15 km/h and <15 km/h respectively. It can be said that brick is more efficient to reduce right turn vehicle speed on crosswalk than red colored pavement. In the case of red colored and baseline condition, Fig. 2 - 4 showed that the setback distance of a crosswalk is long compared to brick pavement intersections. This distance may influence the driver’s speed in the conflict area at baseline condition intersection (Fig. 13).

Table 1 also showed that a corner cutoff of red colored intersection is relatively lower than other two intersections which make this intersection more compact. From Fig. 1 it also found that there are some bollards are installed along to corner of brick pavement intersection. This compactness may make left turn driver’s speed lower at red colored intersection. Though these bollards do not narrow the road width, may give some tight feelings to turning vehicle. The effect of intersection corner cut off, setback distance, the presence of bollards on turning driver’s speed will be considered for future study.

4. CONCLUSIONS

A crosswalk is a very crucial area, for road users, especially for pedestrian. Pedestrians are more vulnerable road user than the vehicle. So the safety of pedestrian at an intersection should be ensured proper. Pedestrian safety on crosswalk greatly depends on driver’s gap acceptance behaviour. This study investigated the effect of difference of pavement on gap acceptance behaviour of turning vehicle on crosswalk when they interact with pedestrians. Two intersections with provisions of red colour, brick pavement and one typical intersection without any design on crosswalk (Baseline condition) were selected for conducting the research. The summarization of the key conclusion of this study is presented below:

There is a positive effect has been found for application of brick pavement on crosswalk. Turning driver when approached near the crosswalk and found differences in pavement due to application of brick became more careful. This carefulness made driver’s speed, low which we can see from Fig. 13. Due to this reason he intended to give away pedestrian who near the crosswalk. Gap acceptance behaviour also reflects this circumspection. The percentage of left-right turn driver to accept a larger gap than critical gap was high at the brick pavement crosswalk.

For left turn manoeuvres it has been found that speed of the car at red colour was not significantly higher than that at brick pavement, but for right turn manoeuvre speed was comparatively higher (Fig. 13). From Table 1 it is given that the corner cut-off is smaller at a red coloured intersection. This small corner cut-off makes the intersection corner compact. Due to this compactness left turn car could not increase his speed during a left turn. But for the right turn car driver increased his speed as much as he can. Due to the compactness of the intersection corner the speed was not high like baseline condition. Driver’s gap acceptance at red coloured specified that driver tends to accept a smaller gap than brick pavement. It gives a meaning that driver at red coloured intersections were not so influenced by the red colour. The left turn driver reached at intersection with red coloured pavement intended to accept small gap. But due to the compactness of the intersection corner he did not get the confidence to increase his speed. For
this reason he rejected the gap smaller than 2 sec. Right turn driver had not to face this difficulty too much and some drivers accepted gap smaller than the critical gap 3.09 sec.

Finally, this study concluded that driver at a typical crosswalk with baseline condition show non-yielding behaviour by accepting smaller gap with high speed at conflict area. But with the same geometric characteristics other intersection with brick pavement, reduce driver’s non-yielding behaviour by reducing speed and increasing the “stop and look around”13) behaviour. Effect of other pavement design (i.e. Yellow colour, green colour, etc.) will be examined as a further analysis. Besides this, effect of intersection corner cut off, setback distance, the presence of bollards or other elements will also be considered for future study.

ACKNOWLEDGMENT: This study was conducted under the project “Communication Promoting Cooperative Behavior for Other Road Users and Traffic Safety” (Principal Investigator: Ayako Taniguchi, Tsukuba University) supported by The General Insurance Association of Japan.

REFERENCES
1) Institute for Traffic Accident Research and Data Analysis, ITARDA information, Japan, 2013, http://www.itarda.or.jp/itardainformation/english/info100_e.pdf
17) Kinovea, 0.8.23 Experimental version; Joan Charmant and Contrib, http://www.kinovea.org/

(Received February 26, 2016)