Yielding behavior of left turning driver towards pedestrian/cyclist: Impact of intersection angle

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Abstract: It is a common practice for left turning vehicles (left hand traffic system) to share the same traffic signal phase with pedestrian at signalized intersection. Although signalized crosswalk are operated to give pedestrians prioritized right of way, accident data reveal that left turning vehicles are not always being able to give pedestrians their right of way. As such, it is important to find the reasons for why the left turning vehicle driver fails to grant a legally-crossing the pedestrian right of way. To investigate the effect of intersection angle on the yielding behavior of the left turning vehicle driver with pedestrians, this study used data from an observational study, conducted at nine signalized intersections in Japan in 2013. In this study events related with sudden brake and acceleration for avoiding collision is considered as “non-yielding” behavior. The results show that driver’s behavior at obtuse angled intersections is more “non-yielding” than other typed intersections.

Keywords: Pedestrian safety, Intersection angle, Left turn, Signalized Intersection, Yielding behavior, Conflict Analysis

1. INTRODUCTION

Pedestrian safety in urban areas is an issue of growing concern. Pedestrians are exposed to motorized traffic and are the most vulnerable road user. Intersections are the most critical roadway elements with high concentration of vehicle-pedestrian crashes. To control competing flows of traffic at intersection, traffic signal is operated. Usually at signalized intersection pedestrian and cyclist have a separate signal phase. But for traffic operational efficiency right- and/or left-turning vehicles are often allowed to perform their maneuvers during the pedestrian “WALK” signal indication at signalized intersections. Although signalized crosswalks are operated to give pedestrians prioritized right of way, accident data reveal that turning vehicles are involved in most of the accidents at signalized intersections. Approximately one out of five accidents at signalized intersections involves a turning vehicle hitting a pedestrian (Federal Highway Administration, 2003). The split between left-turning and right-turning accidents is about 60/40 (right hand traffic system) (Robertson et al. 1984; Zegeer et al. 1982). In Japan 49% pedestrian accidents were occurring at signalized intersection during 2008 to 2012. Among which 7.8% fatalities were took place between left turning vehicle and pedestrian (ITARDA, 2013).
Several studies have identified that these types of accidents may result from driver’s failing to yield right of way to pedestrians (Al-Ghamdi, 2002; Preusser et al. 2002; Hatfield et al. 2007). To improve the safety of signalized intersections, it is important to find the reasons for why the left turning vehicle driver fails to grant a legal-crossing the pedestrian right of way. Some researchers have identified several factors influencing yielding behavior, including speed limits and number of lanes (Turner et al. 2007), pedestrian’s distance from the curb (Himanen et al. 1988), pedestrian’s clothes (Harrell, 1993) and also the number of pedestrians waiting to cross (Sun et al. 2003). Leden, L. (2002) studied the effect of number of pedestrian on pedestrian risk. Several studies have empirically modelled the yielding behavior of vehicles. Sun et al. (2003) applied logit and probit model for motorist’s choice to yield pedestrian at an uncontrolled midblock crosswalk. The Gap acceptance model is studied frequently by researchers to represent driver’s yielding decision (Ragland, et al. 2005; Gattis & Low, 1998; Davis and Swenson, 2004; Harrell and Spaulding, 2001). Alhajyaseen et al. (2013) studied the effect of position of the pedestrian on the gap acceptance of left turn vehicle driver.

As left turning vehicle makes a turn along the intersection corner, so the intersection corner has a great influence on the behavior of turning driver. Considering the position of pedestrian it is found that pedestrian who are crossing from the left side of a left turning driver are at higher risk (Alhajyaseen et al. 2013; Hagita et al. 2011). However, as contributory factor intersection corner geometry was not fully investigated by previous studies. Some previous studies identified some issues considering intersection geometry for which a considerable variance in the turning path of the vehicle was found (Stover, 2008; Stover et al. 2008). Nevertheless, these studies did not provide any information about the effect of such variation on pedestrian safety. The Manual on Intersection Accident Countermeasures of Japan (Japan Society of Traffic Engineers, 2002) suggests modifying intersection corner geometry to improve safety performance regarding accidents between left turning vehicles (left hand traffic) and pedestrians. These measures clearly indicate that understanding the effects of intersection corner design elements on the turning maneuvers of vehicles is essential, as the left turning vehicle has to turn along the corner of an intersection.

Intersection angle is a very important design element of intersection corner. Due to different intersection angle drivers view of sight is also changed (Gattis & Low, 1998). So it may influence driver’s behavior. Previous research showed the effect of skewed intersection on traffic safety (Gattis & Low, 1998; McCoy et al. 1994). However the effect of different intersection angle on pedestrian safety was not so clear from these studies. Because of different intersection angle trajectory of turning vehicle varied significantly (Alhajyaseen et al. 2013). Does this difference make any change in the yielding behavior of left turning vehicle drivers? The main objective of this study is to find the answer of this question. The definition of turning movements throughout this study is based on left-hand traffic system.

Gathering data on the actual traffic situation is perquisite for understanding the pedestrian accidents at signalized crosswalks. It is also of interest to study left turner’s behavior at crosswalk, e.g. stopping behavior, manner of entering the crosswalk and interaction with pedestrians at crosswalks. This study recorded left turn driver’s involvement (at the crosswalk) in serious traffic conflicts. Due to scarcity and less information of accident data, the concept of traffic conflicts was first proposed by Perkins and Harris as an alternative to collision data (Perkins & Harris, 1968). A formalized definition of a traffic conflict was later adopted as “an observable situation in which two or more road users approach each other in space and time for such an extent that there is a risk of collision if their movements remain unchanged.” (Amudson & Hyden, 1977). Various conflict indicators have been developed to measure the severity of an interaction by quantifying the spatial and temporal proximity of
two or more road user (Tarko et al. 2009). In this study yielding behavior is evaluated by using traffic conflict techniques. In methodology section it has been discussed in details.

2. METHODOLOGY

The paper aims to evaluate the effect of different intersection angle on the yielding behavior of the left turning driver. For this purpose left turn vehicle and pedestrian interaction was observed by using video data. When there is an interaction occurs between left turning vehicle and pedestrian near the crosswalk, a driver can show two types of behavior: yielding behavior or non-yielding behavior. For getting a clear view of methodology definition of interaction, yielding behavior and non-yielding behavior in this study has been discussed.

**Interaction:**
Interactions are considered as events when a left turning vehicle driver reaches at the crosswalk of inflow road and at the same time a pedestrian/cyclist reach at the crosswalk of the outflow road where they have to share the same traffic signal phase with left turning vehicle (Figure 1). In this study it is assumed that crosswalk of the inflow road is the decision area of left turning vehicle driver, as it is very difficult to precise this decision point.

![Figure 1. Interaction between turning vehicle and pedestrian](image)

**Yielding behavior:**
When there is an interaction between a left turn vehicle and pedestrian occurred, then time gap is an opportunity for him to make a turn. Gap means time duration before a pedestrian or cyclist reach to the conflict area (Figure 2).

\[
Gap, t = t_2 - t_1
\]

Where,
\[
\begin{align*}
t_1 & = \text{The time when car reach near the crosswalk of inflow road (sec)}, \\
t_2 & = \text{The time when pedestrian reach the conflict area (sec)}.
\end{align*}
\]

If the gap is large enough he can make a turn safely and for a small gap he must show yielding behavior. In this study yielding behavior is considered when a driver rejects any small gap.
**Non yielding behavior:**
From literature review it is found that a left turning vehicle driver shows non-yielding behavior when he accepts a small gap or makes a sudden brake to avoid a collision. In this study it is assumed that if a driver tries to show non-yielding behavior he may

- Accept that small gap with high velocity (Alhajyaseen *et al.* 2013) or
- Make a sudden brake to avoid collision with pedestrian or cyclist

Sometimes driver comes with a very low velocity and if he found any pedestrian or cyclist on the crosswalk he make a sudden brake, which may not be so dangerous. To select the most severe situations created by sudden brake, the approach of the Swedish Traffic Conflict Technique is used (Hydén, C., 1987). This technique is developed at Lund University. In the Swedish traffic conflict study they use TA-CS graph (Figure 3) to show the severity of each sudden brake event. The blue line is created from curve based on emergency braking on dry asphalt and are then moved to intersect the TA-axis at different values.

![Figure 2. Gap definition](image)

**TA (Time to Accident)** is the time that remains from one of the road users have started an evasive action, until a collision would have occurred if the road users had continued with unchanged speeds and directions.

The TA value can be calculated based on the estimates of distances $d$ and conflicting speed $CS$.

**Example:**

- $CS = 20 \text{ km/h}$
- $TA = 0.5 \text{ seconds}$

![Figure 3. Severity of Swedish traffic conflict technique (Hydén, C.,1987).](image)
Where, \( d = \text{Distance to collision point} \) = is the remaining distance between the point where car takes evasive action (sudden brake) and the potential point of collision. The conflicting speed (CS) is the speed of the involved road user at the moment when the evasive action (sudden brake) starts.

2.1 Observation site description:

Intersection angle is a very important design element of intersection corner. Intersection angle means the angle at which two roads are intersecting to each other. The "normal" intersection (Figure 5) consists of two streets intersecting and crossing at near-90° angles. However, there are many instances where the intersection angle of crossing streets is not close to 90°. These intersections are termed "skewed intersections". Skewed intersections can be grouped into two categories shown in the figure, (Figure- 4, 6), the "right skewed" intersection and the “left skewed” intersection. The left skewed intersection is skewed such that the obtuse angle created is to the left of a driver on the minor road approach. But the intersection angle itself is less than 90°. The right skewed intersection is skewed such that the acute angle created is to the left of a driver on the minor road approach and the intersection angle between the two roads is greater than 90°.

For observing non-yielding behavior of the left turn driver nine signalized intersections in Japan was chosen. The main point of this selection is three type of intersection angle (Figure 7). From each type, three intersections are chosen for taking video of left turn vehicle and pedestrian/cyclist interaction. In all intersection left turn vehicle is permitted to make turns through the crosswalk when the pedestrian signal is green. Other characteristics are trying to keep similar. Table 1 represents the geometric characteristics of observed sites.
### Table 1 Characteristics of all intersections

<table>
<thead>
<tr>
<th>Angle</th>
<th>Sl. No</th>
<th>Name of intersection</th>
<th>Intersection angle</th>
<th>(major road) No of lane</th>
<th>(major road) Road width (m)</th>
<th>(minor road) No of lane</th>
<th>(minor road) Road width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;90°</td>
<td>1</td>
<td>Kamiochiai</td>
<td>60 °</td>
<td>3</td>
<td>8</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Myamachi</td>
<td>75 °</td>
<td>3</td>
<td>8</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Minamimae kawa</td>
<td>70 °</td>
<td>3</td>
<td>8</td>
<td>2</td>
<td>6.5</td>
</tr>
<tr>
<td>=90°</td>
<td>4</td>
<td>Near kitaurawa station</td>
<td>90 °</td>
<td>3</td>
<td>9</td>
<td>2</td>
<td>5.25</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Rokukenmon dori</td>
<td>90 °</td>
<td>3</td>
<td>9</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Homachi icchome</td>
<td>90 °</td>
<td>3</td>
<td>8.5</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>&gt;90°</td>
<td>7</td>
<td>Sasame sanchoume</td>
<td>120 °</td>
<td>3</td>
<td>10</td>
<td>2</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Suzuya intersection</td>
<td>113 °</td>
<td>3</td>
<td>10.5</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Omiya keisatsusho Iriguchi</td>
<td>110 °</td>
<td>3</td>
<td>9.25</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

### 2.2 Data collection and processing:

For conflict analysis, empirical observations are essential. To obtain data for analysis, one video camera with 3 meter camera stand was used during the permissive left turn phase. Nine approaches at nine intersections were videotaped. Data were collected in one weekday during 7.30am to 1.00pm from each intersection. Total 49 hours 30 min video was taken from all intersections. The weather during the survey day was sunny; so the observation site had satisfactory visibility. One example of the traffic scenario can be seen in a screenshot from recorded video (Figure 8).

To avoid the interference of other vehicles to a driver’s yielding decision, following left turn vehicles is not considered in the data processing. Events related to accepting small gap with high velocity and sudden brake was observed from the video. For extracting gap acceptance data it is important to know where and when a driver decides to accept or reject an available gap. Since a precise determination of this decision point is very difficult. When a driver reaches near the crosswalk of minor road he should give a look on the crosswalk of major road, it is assumed that when a left turn driver reaches the crosswalk of minor road he takes decision to go or not to go (Figure 8).

![Figure 8. Observation view for data collection](image-url)
For measuring the severity of this type of event speed of vehicle at conflict area was extracted from video. To select the most severe situations created by sudden brake, the approach of the Swedish Traffic Conflict Technique is used. For using this technique, Distance to collision point \(d\) and Conflicting speed (CS) was extracted from video.

\[
d_1 = (x_2 - x_1)^2 + (y_2 - y_1)^2
\]

\[
d = d_1 + d_2 + \cdots + d_{n-1}
\]

Where,

\(d\) = Distance to collision point (meter)

\(d_1\) = First distance between the point \((x_1, y_1)\) where car takes evasive action (sudden brake) and next point \((x_2, y_2)\) of the trajectory of car.

\(d_{n-1}\) = Last distance between the point \((x_{n-1}, y_{n-1})\) and collision point \((x_n, y_n)\)

Distances, speed and timings of left turning vehicles as well as pedestrians and cyclists are extracted from video data by using Kinovea video analysis software (Figure 11). Kinovea is a free software application for the observation, measurement, analysis and comparison of videos. To able to make measurements on the perspective grid, calibration is required. To do this real world length of four points at an intersection was measured which are visible on the image. After laying down the grid and aligning its corners on these four points, corresponding measures were entered in calibration dialog (figure 9).

![Real field data from Google maps](image)

![Plane calibration using real field data](image)

Figure 9. Camera calibration for extracting data (Kinovea Homepage)
After calibration was done, the accuracy of the estimated parameters was tested using the crosswalk strip length estimated from google map (Figure 10). The percentage of error is about 1-2%.

![Figure 10. Comparing real field distance and extracting distance for accuracy check](image)

Total five parameters (accepted gap size, speed of vehicle when accepting gap, rejected gap size, conflicting speed of vehicle, remaining distance for occurring accident) were finally selected for the conflict analysis in this study. Details of data extracting shows in figure 11.

![Figure 11. Data extraction by using video analyzing software](image)

3. RESULTS

According to the definition of interaction, yielding behavior and non-yielding behavior, Table 2 shows the sample of observation of left turn vehicle driver and pedestrian/cyclist interaction.

**Table 2 Observation samples of left turn vehicle driver and pedestrian interaction**

<table>
<thead>
<tr>
<th>Observation</th>
<th>Acute angled intersection</th>
<th>Right angled intersection</th>
<th>Obtuse angled intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of total interaction</td>
<td>38</td>
<td>52</td>
<td>78</td>
</tr>
<tr>
<td>Accepted gap</td>
<td>18</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>Reject gap</td>
<td>20</td>
<td>27</td>
<td>32</td>
</tr>
<tr>
<td>No of sudden brake</td>
<td>0</td>
<td>6</td>
<td>16</td>
</tr>
</tbody>
</table>
3.1 Gap Acceptance:

Figure 12 shows the percentage of drivers who accepted different gap at different type intersection angled intersection. All drivers in each typed intersection accepted gap greater than 5 Sec. None of the drivers accepted gap smaller than 1 Sec. Gap size less than 2 Sec and less than 3 Sec was considered small in this study. For differentiating yielding and non-yielding behavior this gap size was used as a boundary. Figure 10 indicates that percentage of accepting small gap is higher at obtuse angled intersection than at acute angled and right angled intersection. 61.11% driver at obtuse angled intersections accept small gap less than 3 sec gap. 33.33% drivers at right angled intersections and 6.67% driver at an acute angled intersection accept small gap less than 3 Sec. But all events accepting small gap are not always risky. For getting the risky events speed of the vehicle at the conflict point was used as an indicator of the severity of the conflict, assuming that the clearing speed would be very close to the crash speed if the conflict becomes a real crash. The distribution of left turn vehicle speed at conflict area when accepting gap are shown in Figure 13.

Figure 12. Percentage of Gap acceptance by left turn driver

Figure 13 shows that only one driver at an acute angled intersection accepted small gap less than 2 Sec and one driver at right angled intersection accepted small gap less than 3 Sec. When they accepted this small gap their speed is relatively low. It indicates that when these drivers accepted this gap they saw the pedestrian and they became slow. Expect them no one accepted small gap less than 3 secs in these intersections. Average speed in conflict areas in acute and right angled intersection was less than 20km/hr when they accept any gap. So the results of gap acceptance highly supports that drivers at acute and right angled intersection show more yielding behavior towards pedestrian and cyclists.

Figure 13 confirmations that driver at obtuse angled intersection were more likely to accept a small gap with high velocity (20km/h to 30km/h) comparing other typed intersection. Left turn driver’s average speed at obtuse angled intersection is 25km/hr. Due to this high speed driver’s tendency to accept small gap is relatively more on these types of intersection. The ANOVA result shows that significant effect of intersection angle (p<.001) on driver speed at conflict point when driver accept small gap less than 3 sec. So the results of gap acceptance greatly support that drivers at obtuse angled intersection shows more non-yielding behavior towards pedestrian and cyclists than another typed intersection.
3.2 Sudden brake events:

There are total 22 sudden brake occurred in all intersections. Whereas 16 sudden brakes are occurred at obtuse (greater than 90 degree) angled intersection and 6 are at 90 degree angles intersection. No sudden brake was found at less than 90 degree angled intersection (see table 2).

Figure 14 shows the severity of each sudden brake event by using TA-CS graph. In the graph it is clear that sudden brake event at 90 degree angled intersection are in non-serious conflict zone and 10 out of 16 sudden brake at greater than 90 degree angled intersection are in serious zone. So the results of TA-CS graph greatly supports that drivers at obtuse angled intersection shows more non-yielding behavior towards pedestrian and cyclists than other typed intersection.
For traffic operational efficiency it is difficult to provide separate traffic signal phase for left turn vehicle and pedestrians. In this type of mixed situation pedestrian has first priority according to rule. A left turn driver must have to show yielding attitudes towards pedestrian, who are going to cross the road. But accident data reveals that pedestrians have danger with left turning vehicle. Literature review showed that driver’s non-yielding behavior is one of the causes of this type of accident. It seems very important to understand the fact for which left turning vehicle driver tends to show non-yielding behavior. As left turning vehicle turns along the intersection corner, it was hypothesized that intersection angle may influence left turning vehicle driver’s attitude towards pedestrians. A field study was done to find the effect of intersection angle on the yielding behavior of left turn driver. Three type of intersection angle was considered for this study.

The result of this study confirmed the negative effect of obtuse angled intersection on left turn vehicle driver and pedestrian interaction. The results showed that driver at obtuse angled intersection showed more non-yielding behavior than other typed intersection. At obtuse angled intersection driver tends to accept small gap. At this type of intersection driver can turn very easily than right angled intersection. This easy movement gives a driver confidence of passing the conflict area quickly. Some risky driver takes this advantage and accept small gap, which is unsafe for pedestrian/cyclist. Because when they accept small gap their velocity become quite high. Due to this tendency number of sudden brake at this type of intersection is quite high. Driver’s sight of view is very wide at obtuse angled intersection. For this reason driver can take decision of turning before he reach the crosswalk of minor road. This can be another reason of this type of non-yielding behavior. Keeping this matter in mind further study will be necessary for finding a solution of this problem.

Though the line of sight of drivers with an acute-angle approach to their left may be obstructed by the body of certain vehicles, driver at acute angled intersection showed more yielding behavior. At acute angled intersection drivers are very careful about their turning. This careful driving make them slow. This slow driving is good for pedestrian, because pedestrian can easily observe them. According to previous studies at un-signalized intersection, intersection angle less than 70 degree is dangerous for left turning vehicle and other vehicles with which left turning vehicle has to share the same space due to visibility problem. But at signalized intersection, left turn vehicle has to share the same signal with pedestrian or cyclist only. Left turn vehicle don’t need to pay attention to other vehicles. So when left turn vehicle make a turn at signalized intersection, interactions between him and pedestrian or cyclist should considerable. From this study it is found that if intersection angle is less than 90º it is safe for pedestrian or cyclist than other typed intersection. Because of physical movement limitation driver becomes slow at acute angled intersection at the time of turning. This slow movement decreases driver’s confidence of making a turn easily. So he becomes more conscious about the presence of pedestrian or cyclist.

For pedestrian safety at signalized intersection it is important to ensure that all road users follow priority rule. The purpose of this study was to analyze the effect of intersection angle on yielding behavior of left turning vehicle driver. After getting the result of the study it can be said that intersection angle should be considered at signalized intersection for pedestrian safety. As obtuse angled intersection are more dangerous, it is very important to give some countermeasures at this type of intersection corner to control driver’s speed.
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