Pedestrian safety analysis at a modification of skewed intersection by using conflict study

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At signalized intersection left turn vehicle (left hand traffic system) has to share the same signal phase with pedestrian or cyclist. Although a left turner has to yield pedestrian before turning at signalized intersection, accident data reveals that Pedestrians/cyclists has danger with left turning vehicles. As left turning vehicle move along the corner of a road intersection, the geometry of intersection corner has influence on turning behavior of driver. From literature review it is found that at skewed angled intersection has dangerous effect on the movement of left turning vehicle. Skewed angle at intersection corner increases the length of crosswalk and also drivers tend to increase their velocity at turning time. It is important to modify the skewed intersection corner for increasing safety of pedestrian. The purpose of this study is to introduce a design solution of skewed intersection for which left turning driver will be more careful at the time of turning when they encounter any pedestrian/cyclist. Conflict study was done from video observation data. Results of the study showed that proposed countermeasure can control the behavior of left turn driver.

Key Words : *Pedestrian Safety, Left turning Vehicle, Skewed intersection modification, Conflict study.*

1. INTRODUCTION

The purpose of the traffic signal is to control competing flows of traffic. Usually at signalized intersection pedestrian and cyclist have 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 (**Fig.1**). Although signalized crosswalks are operated to give pedestrians prioritized right of way, accident data reveals that turning vehicles are involved in most of the accidents at signalized intersections. Making turn in an intersection is a weak point for many drivers. Approximately one out of five accidents at signalized intersections involves a turning vehicle hitting a pedestrian [1]. The split between left-turning and right-turning accidents is about 60/40(right hand traffic system) [1, 2]. In Japan 49% pedestrian accidents . due to obstruction of pedestrian crossing occurred during the five year period from year 2008 to 2012 at signalized intersection. Among which 7.8% fatalities are took place between left turning vehicle and pedestrian [3]. Among many reasons invisibility, intersection geometric layout, road user behavior are notable. Visibility from within the vehicle (due to a pillar) and poor driving habits are the factors responsible for most of the difference between left turn and right turn accidents [4].

Fig.1: Interactions between left turning vehicle and pedestrian

Left turn driver tends to accept small gap with high velocity with single pedestrian and also they show the same behavior with those pedestrians who come from left side of driver [5].The Manual on Intersection Accident Countermeasures of Japan [6] suggests modifying intersection corner geometry to improve safety performance regarding accidents between left turning vehicles (left hand traffic) and pedestrians. These measures clearly suggest that understanding the effects of intersection corner design elements on the turning maneuvers of vehicles is essential, as left turning vehicle has to turn along the corner of an intersection. The angle of intersection of two roadways influences both the operation and safety of an intersection. Large skews increase the pavement area and thus the area of possible conflict (**Fig.2**). Avoid construction of skewed intersections whenever possible during the planning stage of the project development process. When skewed intersections are avoidable, the intersection should be designed so that angle between intersecting streets is as close to 90 degrees as possible[7]. But this may entail significant construction cost.

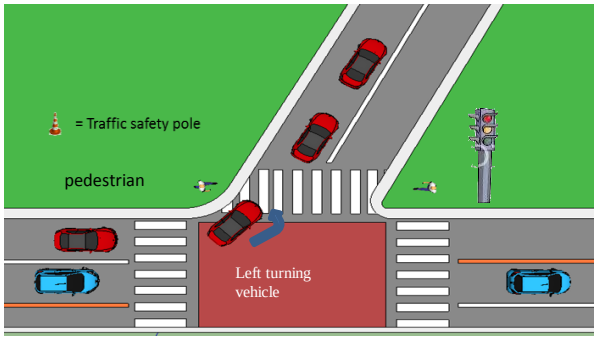

Fig.2: skewed intersection

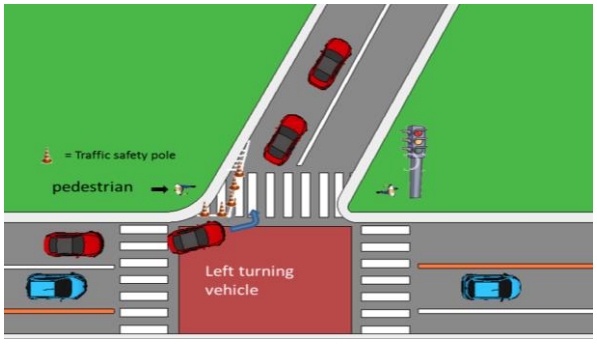

Fig.3: proposed countermeasure

It is important to find more different type low cost countermeasures or modification which will mitigate the problem of skewed intersection. The purpose of this study is to introduce a countermeasure of intersection corner (**Fig 3**) by which driver tends to show more yielding behavior.

(1) Proposed Modification

Proposed modification at skewed intersection is shown in **Fig.3**. In this modification intersection corner is modified by separating 4m distance from the road using pole (**Fig.4**). This 4m distance is considered as a pedestrian space. It is hypothesized that this separation will give a warning of the presence of pedestrian or cyclist so that before turning a driver will give a look on this space first. This will increase reaction time of left turning vehicle and pedestrian or cyclist. Any pedestrian or cyclist, who comes to the crosswalk, will get some more time to react on the presence of turning vehicle before crossing.

Fig.4: proposed modification at intersection corner

2. METHODOLOGY

This paper aims to evaluate the safety effect of the modification of a skewed intersection on the behavior of left turning driver. For this purpose left turn vehicle and pedestrian interaction at this modified intersection 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.

(1) Terminology

For getting a clear view of methodology definition of interaction, yielding behavior and non-yielding behavior in this study have 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 (**Fig.5**). 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.

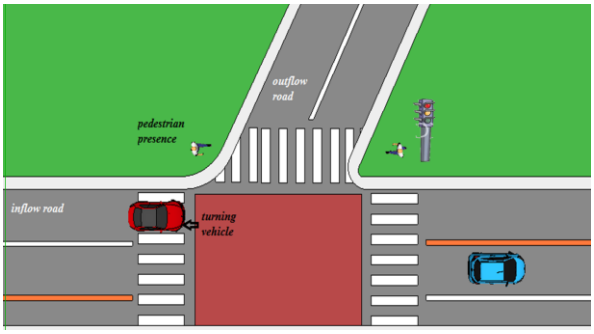

Fig.5: interaction between turning vehicle and pedestrian

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 (**Fig.6**). 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.

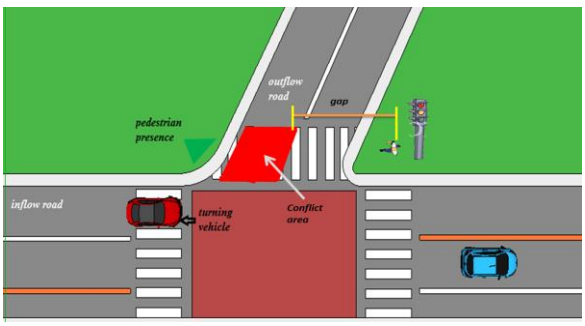

Fig.6: Gap definition

***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 small gap with high velocity [8] 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 [9]. This technique is developed at Lund University. In Swedish traffic conflict study they use TA-CS graph (**Fig. 7**) to show the severity of each sudden brake event.

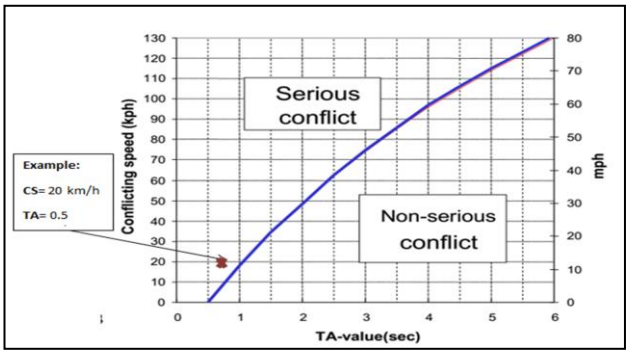

Fig.7: severity of Swedish traffic conflict technique

TA 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.

$$TA\ value = \frac{Distance\ to\ collision\ point\ (d)}{Conflicting\ speed\ (CS)} \quad (1)$$

Where, d = 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) Data collection

One video camera was used to obtain visual data during the permissive left turn phase (**Fig.8**). From this intersection data was taken on 25th December, 2013, from 7.30am to 1.00pm.

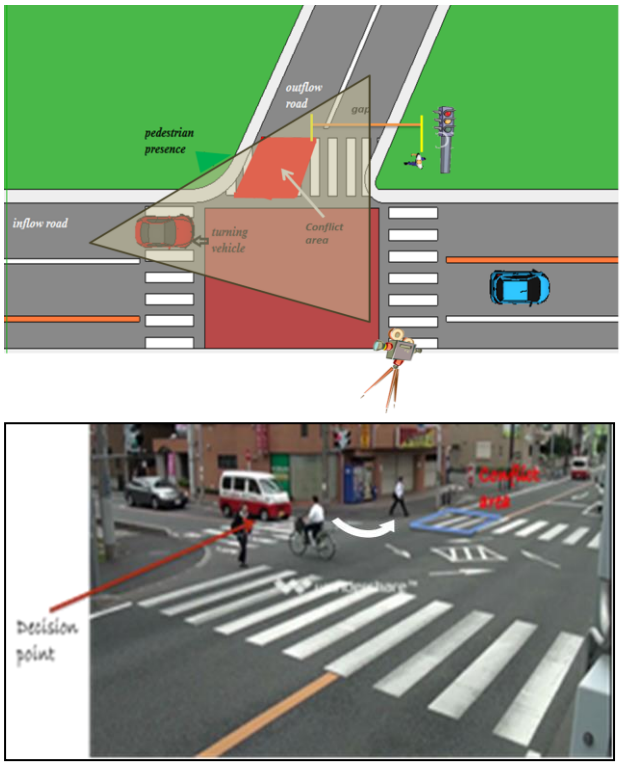

Fig.8: Camera view and data observation

(3) Data extraction

For extracting the event related with accepting small gap with high velocity, accepted and rejected gap size by left turn vehicle was measured from 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 (**Fig.8**). For measuring the severity of this type of event speed 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.

For extracting time, distance, velocity data from video, video analyzing software (Kinovea) was used.

4. RESULTS AND DISCUSSION

According to the definition of interaction, yielding behavior and non-yielding behavior, **Table 1** shows the sample of observation of left turn vehicle driver and pedestrian/cyclist interaction.

Table 1: Observation samples of left turn vehicle driver and pedestrian interaction

Type of intersection	No of interaction
No of total interaction	47
Accepted lag/gap	20
Reject gap/lag	25
No of sudden brake	2

(1) Gap acceptance

Fig.9 shows the percentage of drivers who accepted different gap at different type intersection angled intersection. All drivers in this 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 were considered small in this study.

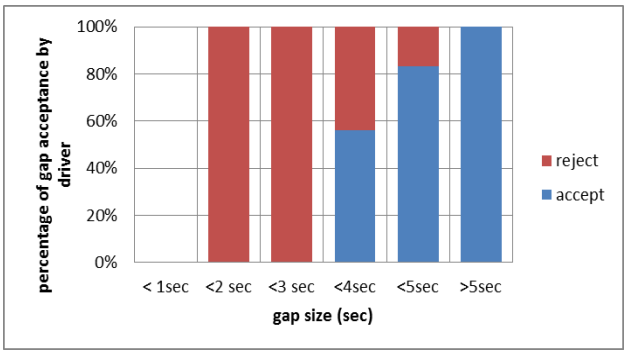

Fig.9: percentage of driver accepting versus rejecting gap

From **Fig.9** it is clear that not a single drver accepted gap less than 3 sec. Gap size less than 4 sec were accepted by 58% driver. 4 sec gap means time duration for pedestrian to rach the crosswalk. It is enough time for a driver to take a safe decision.

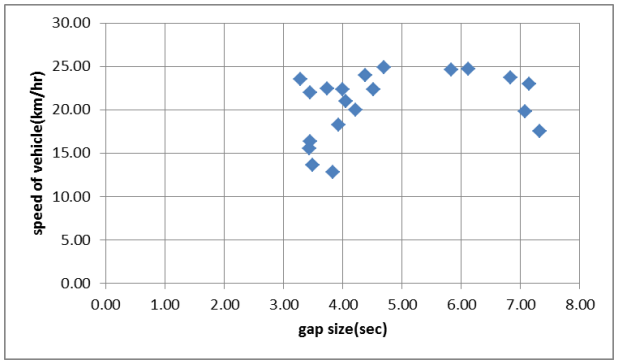

Fig.10: distribution of driver's accepted gap with velocity at conflict area

Fig.10 shows the distribution of accepted gap and velocity at conflict area of left turn vehicle driver. Graph shows that gap size greater than 3 sec are accepted by left turn vehicle driver. The speed range between 3sec and 4 sec gap are so variable.

Fig.11: Driver rejected gap safely at modified intersection corner

Video data reveals that when a driver tried to accept gap less than 4 sec if he found any pedestrian or cyclist he try to reject that gap If pedestrian made a stop than he accepted the gap very slowly.From **Fig.11** it is observed that left turn vehicle driver gave a look on the space which separated from road. This short look make him more conscious about pedestrian presence.

(2) sudden brake events

There are only 2 sudden brake occurred in this intersection (see **Table 1**).

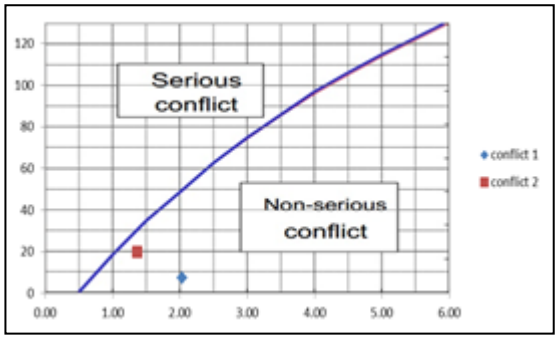

Fig.12: Seriousness of sudden brake which is taken by left turn driver using TA-CS graph

Fig.12 shows the severity of each sudden brake event by using TA-CS graph. In the graph it is clear that sudden brake event at this signalized intersection due to the modification was not so serious. From fig. 12 and fig. 13 it is clear that in this intersection driver don't accept any gap less than 3 sec. 4 sec gap is quite large to take decision. So accepting gap less than 4 sec is not a risky decision. Because of the extra space at the corner driver showed more yielding behavior.

5. CONCLUSION

For traffic operational efficiency it is not possible to give separate traffic signal for all conflicting road users. In this case yielding behavior of left turn vehicle is very important for pedestrian safety. pedestrian and cyclists are vulnerable road user. Left turn vehicle driver's careless movement is very much dangerous for pedestrian. At skewed angled intersection left turn vehicles driver's movement is quite dangerous than normal intersection the due to straightness (almost near to 180 degree) of the corner. It is important to modified these type of intersection.

In this study a modification has been introduced which is very low cost to implement. Safety effects of this new modification was done by video observing the interaction between left turn vehicle and pedestrian/cyclist. Results of this study presented that driver showed a good yielding behavior towards pedestrian and cyclist due to the modification. From video data it was observed that before making a turn (**Fig.11**), left turn vehicle driver give a look on the space which separated from road. This short look make him more conscious about pedestrian presence.

It increases the reaction time of left turn vehicle driver. If he found any pedestrian or cyclist in this space he showed yielding behavior by stopping car. This space also increase reaction time of pedestrian. When a pedestrian or cyclist reached at this space became slow or stop smoothly if he found any driver make a turn.

In conclusion, this study tried to provide an example of a cheap modification of skewed intersection. A more example should be needed for pedestrian safety at signalized intersection with skewed intersection corner.

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