Gap Acceptance Behavior of Turning Vehicle at Crosswalk Considering Pavement Design Type

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Now a days “shared space” concept become prevalent for pedestrian safety. Among many features of “shared space” concept using brick pavement is one of prevalent characteristics. It is very common practice for turning vehicle to share the crosswalk with pedestrian to complete their turning maneuver at signalized intersection. As crosswalk is a space which is shared by turning car and pedestrian, brick pavement can be provide on crosswalk of signalized intersection according to shared space concept. Gap acceptance behavior of turning car was studied at three signalized intersection in Japan. The effect of brick pavement is compared with presence of red color and baseline condition. Gap acceptance behavior of turning vehicle is modeled by using logistic regression. The results show that driver shows more yielding behavior by rejecting smaller gap during left and right turn maneuver on crosswalk with brick pavement which indicates that brick pavement has more visual effect to driver than red color.

Key Words: *Turning vehicle, Gap acceptance, Pedestrian safety, Crosswalk, Pavement design*

1. INTRODUCTION

For traffic operation efficiency it is not always possible to give separate signal phase for all type of road users. Separate traffic signal for pedestrian is operated only if conflicting road user volume is heavy on pedestrian crossing. For moderate traffic volume it is difficult to provide isolated traffic signal for all road users. In that case turning vehicle have to share the same signal phase with pedestrian. As turning vehicle has to use the pedestrian crossing to complete their manoeuvre, pedestrian-turning vehicle conflict is very common phenomenon at signalized intersection. At crosswalk pedestrians are given prioritized right of way. It means that turning vehicle has to yield pedestrian first when they interact with pedestrian at crosswalk. . But accident data reveals that Pedestrians has danger with right tuning 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[1)].One of the main reason of this type of accidents is inappropriate gap selection by turning driver.

Drivers are always seeking the right opportunity to cross the intersections by themselves. This opportunity is named “gap” and the behavior is called “Gap acceptance”[2)]. Incorrect gap acceptance may cause accidents between road users[3, 4)]. 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 at priority area. Sun et al. applied logit and probit model to analyze driver’s yielding patterns at an unsignalized pedestrian crosswalk[5)]. A logistic-regression model was developed to predict driver’s yielding or gap acceptance behavior considering different factors including presence of pedestrian crossing treatments[6)]. Miho Asano modelled left turn driver’s gap acceptance behavior to predict how driver considers the position of pedestria[7)]. A gap acceptance study was conducted to interpret driver's overlooked behavior towards cyclist at roundabout[8]. Different population and place had different critical gaps[9]. Gap acceptance study is appropriate for analysis driver's behavior.

Some researchers 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.[10, 11, 12, 13, and 14]).

Keeping this point (road features) in mind the main objective of this study is to evaluate how left and right turn driver move into crosswalk with different pavement design at the presence of pedestrian on crosswalk or near the crosswalk. Since this study based on observational data it was impossible to assess driver characteristics in depth.

2. METHODOLOGY

(1) Data collection

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)**. Almost all characteristics except pavement design are similar in these three intersections. But there is no separate signal phase for pedestrians. Pedestrian follow the same signal time with 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. The average demands of

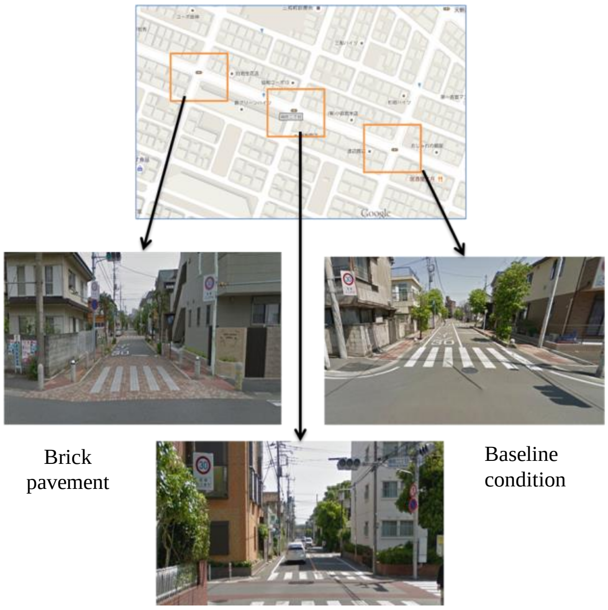

Fig.1 Three site with different intersection approach design
Source: Google map.

turning vehicle, pedestrian, cyclist and signal cycle time are presented in **Table 1**. The traffic demand are very low in these intersections. Data were collected during December, 2014- January, 2015, during the day light from 9.00am to 4.00pm by video recording. It was winter season and the weather was sunny and clear.

(2) Data Extraction

Total 30hrs video was observed from all three intersections. All interaction are observed from 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[15]. This software

Table 1 Traffic conditions and Geometric characteristics at observational sites

Pavement type	Avg. left turning car (veh./hr)	Avg. right turning car (veh./hr)	Avg. pedestrian /cyclist		Green time (Total cycle) (sec	Intersection corner		Width of Major road (Carriage-way) (m)	Width of Minor road (Carriage-way) (m)
			Ped./hr	Cyc./hr		angle	Corner cutoff (m)		
Baseline condition	6	3	12	17	46 (80)	90°	2.31	8.5 (6)	6.21 (6)
Red colored pavement	8	5	9	13	41 (80)	90°	1.05	8.5 (6)	6.8 (6)
Brick pavement	5	2	7	13	42 (80)	90°	2.03	8.5 (6)	6.5 (6)

is mainly used for sport analysis. With parameters calibration by 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. Butterworth filter is used for filtering data in Kinovea. **Fig 2** shows an outline of detailed description of video analyzing procedure. From real field length and width of crosswalk was measured. This length was used to calibrate the video image using calibration pane.

(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 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 pedestrian. 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."

"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 driver reach near the crosswalk. According to the definition of lag and gap, measurements are made of the number of seconds which are available to turning car before the pedestrian arrive the conflict area (**Fig.3**).

To estimate the gap acceptance probability distribution empirical data is collected. After collecting

Fig 2: Video analysis procedure by Kinovea

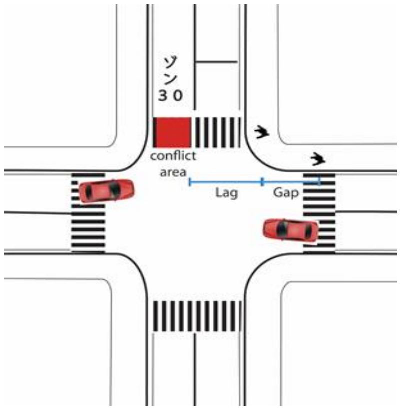

Fig 3: Gap definition

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.**

$$P(x) = \frac{\text{No.of observed accepted gaps/lags}}{\text{No.of observed accepted and rejected gaps/lags}} \qquad (1)$$

To analyse left turn gap acceptance logistic regres-

Table 2 Left and right turn vehicle's gap acceptance data

Pavement type	Left turn			Right turn		
	Gap accept	Gap reject	Total	Gap accept	Gap reject	Total
Baseline condition	19	17	36	9	7	16
Red coloured	26	18	44	12	10	22
Brick pavement	14	16	30	7	6	13

sion method was used. It was found that logistic regression is appropriate for modelling a situation in which drivers a lot of opportunities where driver has to take yes/no decision. The logistic regression model is

$$P(x) = \frac{1}{1 + e^{-b_0 - b_1 x}} \quad (2)$$

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[16]. For measuring critical gap Raff method has been used in this study[17]. 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[18, 19].

3. RESULTS AND DISCUSSIONS

(1) Left turn Gap Acceptance

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

Fig. 4 shows the effect of different pavement

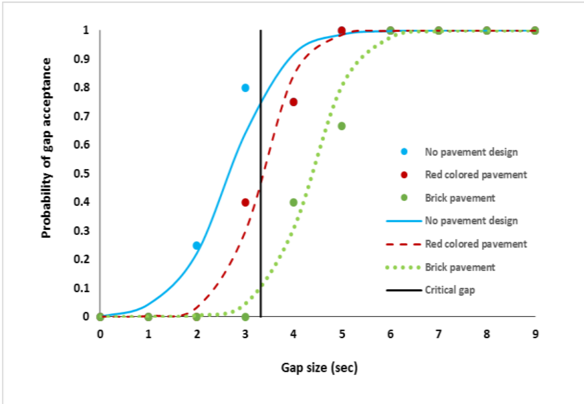

Fig 4: Predicted probability that drivers accept gaps to make left turn through crosswalk. Solid vertical line indicates critical gap size 3.32 sec

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**).

Table 3 Statistical model for left-turn gap acceptance

Pavement type	Coefficient	Left turn				Right turn			
		Estimate	Standard error	R^2	$Pr>\chi^2$	Estimate	Standard error	R^2	$Pr>\chi^2$
Baseline condition	b_0	-4.909	1.658	0.734	<0.0001	-4.944	2.096	0.581	<0.0001
	b_1	1.828	0.633			1.605	0.688		
Red coloured	b_0	-8.494	3.336	0.887	<0.0001	-4.024	1.517	0.429	<0.0001
	b_1	2.543	1.004			1.241	.459		
Brick pavement	b_0	-9.745	4.271	0.841	<0.0001	-4.931	2.565	0.471	<0.001
	b_1	2.232	0.980			1.235	0.673		

Fig. 5 shows the effect of 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. 5** it is revealed that right turn driver at red coloured pavement has almost same probability to accept smaller gap than 3.09sec. The summary of logistic regression results are described in **Table 3**.

4. CONCLUSIONS

Crosswalk is a very crucial area for road users especially for pedestrian. Pedestrians are more vulnerable road user than vehicle. So the safety of pedestrian at intersection should be ensured properly. 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 pedestrian. Two intersections with provision 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 clear positive effect has been found for application of brick pavement on crosswalk for gap acceptance study. Percentage of left-right turn driver to accept larger gap than critical gap was high at brick pavement crosswalk.

From **Table 1** it is given that the corner cut-off is smaller at red coloured intersection. This small corner cut-off make the intersection corner compact. Due to this compactness car could not move easily during left turn. But for 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 tend to accept small gap than brick pavement. It gives a meaning that driver at red coloured intersection were not so influenced by the red colour. Left turn driver reached at intersection with red coloured pavement intended to accept small gap. But due to the compactness of intersection corner he did not get the confident 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.

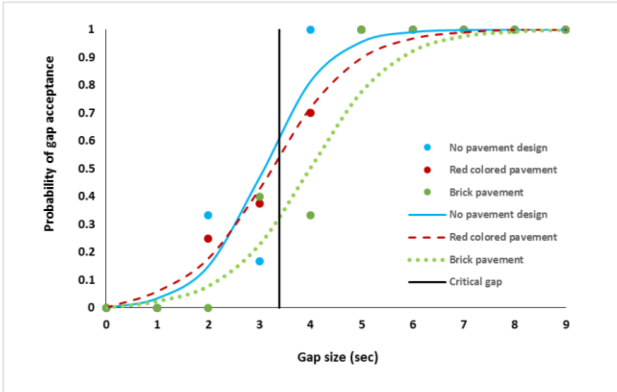

Fig 5: Predicted probability that drivers accept gaps to make right turn through crosswalk. Solid vertical line indicates critical gap size 3.39 sec

Finally this study concluded that driver at 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.

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