Investigation of Pedestrian's Gap Acceptance behavior at Crosswalk

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Abstract

Walking is one of the main transport modes and more sustainable to human society. Pedestrians need safe facilities to be utilized easily and facilitate transportation with adequate speed. Issue of safety is great importance for facilities like various kinds of crosswalk in which movement of pedestrians interacts with vehicles. One of the effective parameters of pedestrians' safety in different kinds of crosswalk is the issue of pedestrians' gap acceptance encountering of vehicles. Investigating pedestrians' gap acceptance, parameters of age, gender, length of vehicle, start-up lane (slow/fast) and waiting time have been obtained and measured by filming and questionnaires in this study and an acceptable model of pedestrians' gap acceptance has been devised. Results of this study suggest that parameters of gender, start-up lane (slow/fast) and waiting time have significant effects on gap acceptance. Critical gap also has been computed by relations presented by HCM and has been compared with amounts obtained by the devised model in this study.

Keywords: *pedestrian, gap acceptance, crosswalk, critical gap*

1. Introduction

Pedestrians need safe facilities to be utilized easily and facilitate transport with adequate speed, but walking has differences depending on type of facilities and regarding dimensions of movement and behavior. For instance, pedestrians have more movement freedom in sidewalks in comparison with different kinds of crosswalks.

Two issues of safety and availability are much important in studies of pedestrians. Although both issues are paramount in all traffic facilities, but safety outweighs availability in facilities such as various kinds of crosswalks where pedestrians interacts with vehicles. One of efficient parameters of safety of pedestrians in different kinds of crosswalks is pedestrians' gap acceptance while encountering vehicles.

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A critical gap (the smallest gap that no pedestrian accepts less than that) is defined for every pedestrian based on gap-acceptance theory. Any pedestrian who reaches a crosswalk makes an assessment of adequateness of present gap to cross the street and decides to accept or reject the gap. If the gap is missed, next gap is taken into account until an acceptable gap is created and the route is crossed. Critical gap is a particular quantity and is specific to each person and the probability of pedestrians' acceptance of shorter gaps is expected to develop by increase of waiting time. On the other hand, it is assumed that people's risk-taking reduces with decrease of remaining time of walking (total remaining distance of route) and people display a stronger tendency to accept bigger gaps. This quantity is also a function of individual characteristics such as age, gender and etc.

Pedestrians, in diverse traffic conditions and according to their decision-making factors, select one of the crosswalks to cross urban routes:

1. They may cross a street as a one-stage crossing when they find an appropriate gap in traffic
2. They may cross a street as a two-stage crossing, considering movement of vehicles at curb of a sidewalk and they may cross the opposite side of street based on acceptable gap in the middle of the route
3. They may cross a street as a multi-stage crossing and lane by lane

The first situation usually occurs in one-way routes. The second situation also happens when routes leading to intersection possess refuge islands, and the third situation is usually observable in routes with a high flow rate and in mid-blocks and also in intersections with a heavy traffic. Some gaps like adequate gaps and critical gaps are determined based on location features and some other are dependent on the existing conditions of the time of pedestrian's crossing (such as available gap, accepted gap and rejected gap).

2. Background of the study

Previously, investigating the issue of safety pedestrians' crossing of intersections was carried out based on movement of vehicles and their features and researchers did not pay attention to analyzing or making a model of pedestrians' behavior. As a result, investigating the process of pedestrians' gap acceptance does not enjoy much background and few studies have been administered during two last decades based on this type of pedestrians' behavior. Much more attention has been paid to this issue recently.

Investigating gap acceptance is one of the subjects that is conducted in almost all studies of designing safe crosswalks. In most studies like the one conducted by Oxley et al. [1] on the effect of age on the amount of accepted gap, the distance between pedestrian and vehicle is considered as the most significant factor for accepting adequate gaps. Also in the studies carried out by Oxley et al. and Lobjois and Cavallo [2] on the effect of age on accepted gap it is shown that factors such as age, police presence and other pedestrians' behavior affect pedestrians' accepted gap to cross a route. Also Simpson et al. [3] in their study on different classes of age of pedestrians and comparison of their gap acceptance reached the conclusion that unsafe crossing and acceptance of smaller gaps has a reverse relation with aging. Kadali and Perumal [4] also conducted a study gap acceptance in Mumbai and recognized the effect of variables such as gender, age, speed of vehicles, pedestrians' speed and direction on acceptance of adequate gap for crossing a route in Mumbai. He has used binary logit model for making a model of accepted and rejected gas. In another study, Yannis and Theofilatos [5] have investigated acceptable gap in Athens and divided effective variables into three types:

- Individual characteristics (age, gender and accessories)
- Vehicles' characteristics (speed and length of vehicle)
- Area's characteristics (vehicles that have been parked illegally)

This study indicates that accepted gap in Athens is more dependent on distance between vehicle and pedestrian, length of car, cars parked illegally and pedestrians' gender.

Pant and Balakrishnan [6] studied the gap acceptance behavior of vehicles at stop controlled intersections. They used neural networks and a binary logit model for predicting accepted gaps at rural low volume stop-controlled intersections. Their model deals with vehicle gap acceptance without incorporating the pedestrians' gap acceptance. Sun et al. [7] also conducted a study on making a model of bilateral effect of pedestrians and vehicles and took into account some variables for making an effective model of accepted gaps by pedestrians such as gender, age, waiting time, number of pedestrians who wait to cross a street with another pedestrian and type of vehicle .Tian et al. [8] used a maximum likelihood methodology to measure the driver's gap acceptance. This gap acceptance study was conducted for the motorists and they considered the queue and vehicle type as the related parameters for defining the gap events.

Zaho [9] conducted a study while focusing on making a model of pedestrians and analyzing their behavior for accepting gaps in two way stop-controlled intersections (TWSC). In this study, models of pedestrians' behavior in macro simulating software VISSIM and CORSIM have been simulated (because of their capability to make a model of interaction between vehicles and pedestrians) and calibration and credit scoring of the devised model by using pedestrian yielding behavior (how existing gaps are accepted or rejected by pedestrians) and critical gaps and obtained volumes have been studied. Hamed [10] studied pedestrians' behavior at pedestrian crossings to find more about the pedestrians who wait for the crossing and number of crossing attempts at the signalized side.

David and Rice [11] found that pedestrian accidents, especially child pedestrian accidents, were likely to take place at mid-block in residential area under clear weather conditions. Macgregor et al. studied pedestrian behavior at a midblock crossing. This was done primarily for the child pedestrian gap checking, which was important near schools. They conducted interviews with parents of children in dominated areas and observed that children were less likely to search for traffic at signalized than un-signalized intersections. In 2010, in a study published by Kuan-min et al. [12] pedestrians' gap acceptance in unsignalized intersections while encountering vehicles was discussed. This study aimed to estimate pedestrians' delay in intersections where drivers do not permit them to cross (high volume of intersection).

3. Methodology

To investigate pedestrians' gap acceptance the intersection of Ferdowsi Square and Enghelab Street was selected and filmed. Also an interviewer asked the pedestrians about their age. Figure (1) survey location and pedestrian crossing condition. This intersection has signals but due to high volume, length of crosswalk and existence of BRT stops a high percent of interactions occur when vehicles have the right of way, even when pedestrian traffic signal is green the number of vehicles is still high at approach (1).

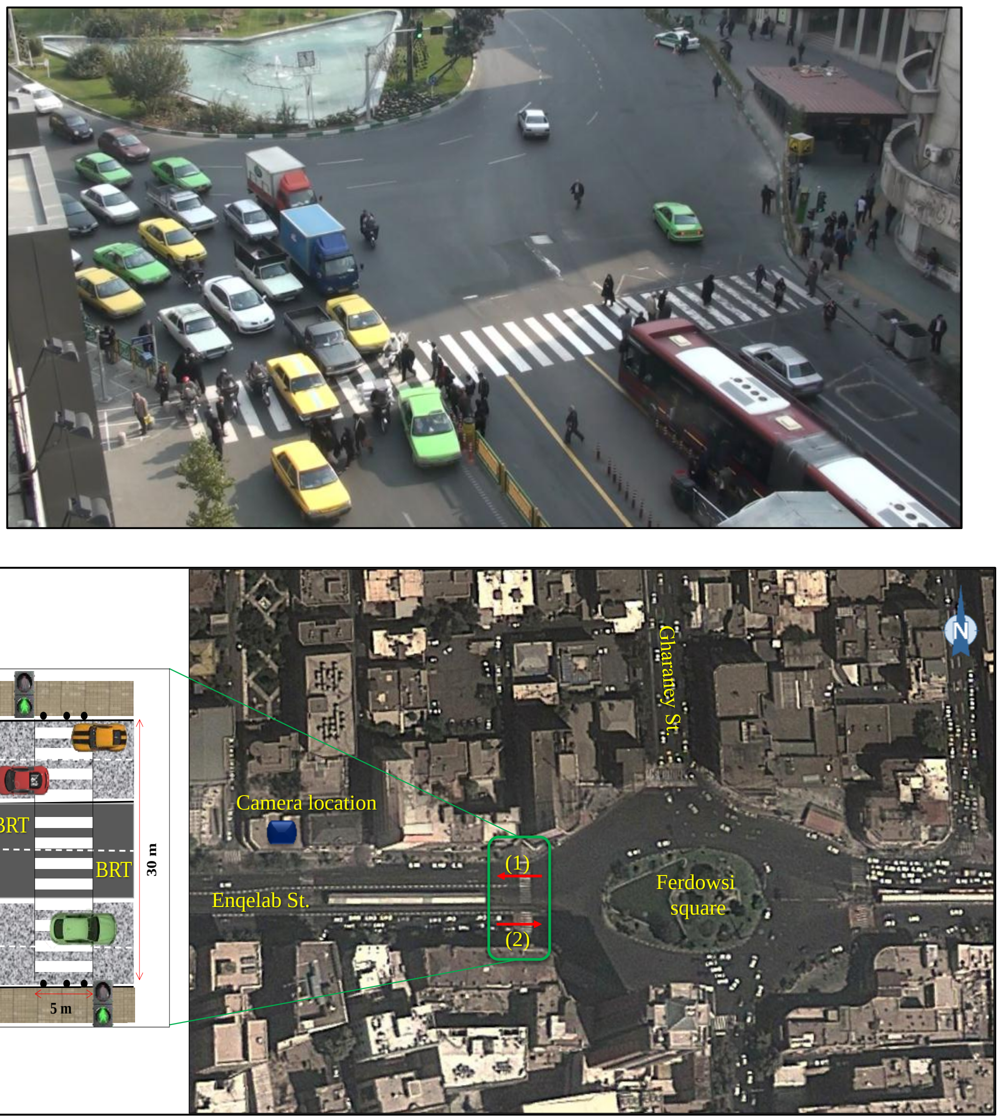

Fig. 1. Survey location and pedestrian crossing condition

Figure (2) shows the number of vehicles during one and a half hour of filming this location (from 16 to 17:30). A noticeable point in this intersection is that 73 percent of pedestrians crossed when the vehicle traffic signal was green and 89 percent of this relates to the pedestrians who enter or exit BRT stops. Consequently, regarding the fact that most of pedestrians' behavior in this area relates to their disregard for traffic signal, it is assumed that this intersection acts as an un-signalized for pedestrians. But to simulate this signalized intersection with an un-signalized the speed of vehicles in any cycle was investigated and after examining various scenarios it was found out that the speed of vehicles at initial 15 percent of green time had a significant difference with the remaining 85 percent of green time (different double-percent were investigated by T-test). Therefore, data of gaps were collected in the remaining 85 percent of green time.

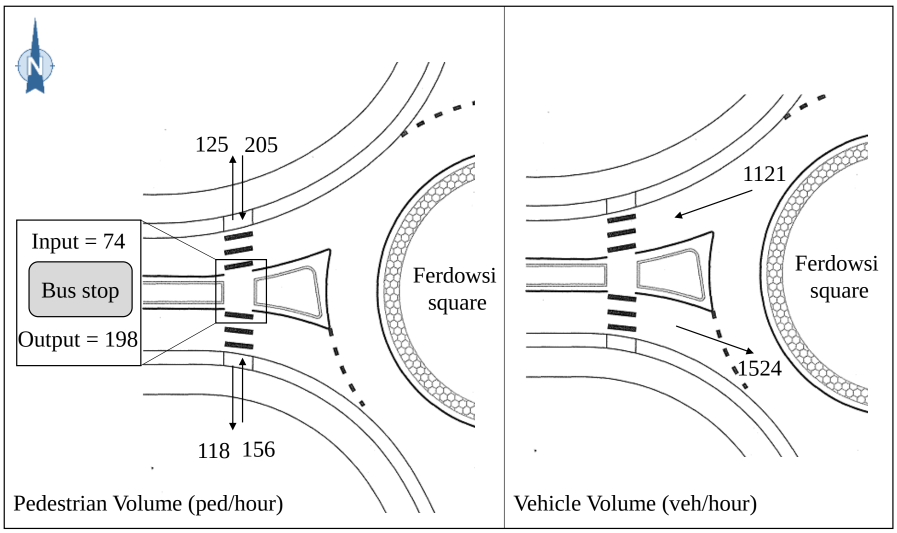

Fig 2. Volumes of pedestrians at the crosswalk of Ferdowsi Square-Enghelab Street

Reviewing the studies conducted in this realm, the required variables for computation of acceptance gap factor include:

1. Individual characteristics of pedestrians
2. Data relating to behavior of gap acceptance
    - Pedestrians' total waiting time
    - Data relating to accepted and rejected gaps. Gaps between vehicles (in case the first gap is not accepted by pedestrian) and gaps between pedestrian, time of arrival and vehicle arrival in the area (in case the first gap is accepted). These gaps can be measured by three cases of one-stage, two-stage and lane-by-lane crosswalks.
    - Waiting time at the beginning of any gap (sum of gaps before gap acceptance in any lane)
    - pedestrian's manner of crossing (on-stage, two-stage or multi-stage)
3. Characteristics of vehicles: type of vehicle and its length

Figure (3) shows a scene of length of gap in a crosswalk. The gap between bumper of car (1) crossing the crosswalk and car (2) is the length of the accepted or rejected gap by the pedestrian.

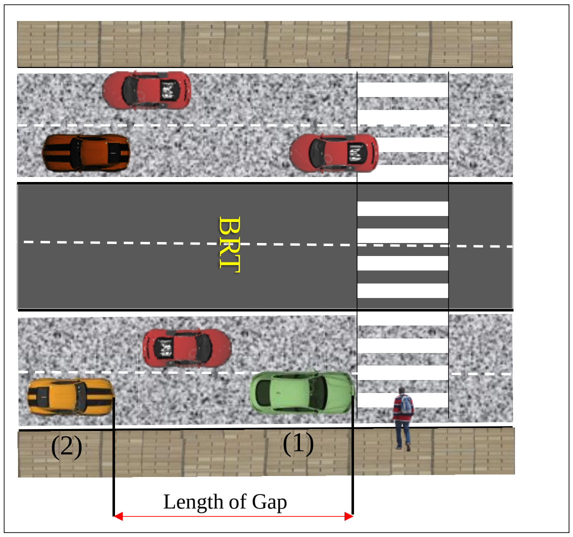

Fig 3. Scene of length of gap in a crosswalk

4. Results and Analysis

I. Modelling traffic gap

After a number of trials to statistically process the data and develop mathematical models of the minimum pedestrians' gap acceptance, a generalized linear model was selected. The final model was the following:

$$Gap = a + b + c + d \times Vehicle\ length + e \times Age + f \times Waiting + g \times (Waiting)^2 \quad (1)$$

Where,

a: the fixed coefficient of model,

b: the effect coefficient of fast or slow speed lane (if the lane is slow-speed it will be 0 and if the lane is fast-speed it will be 0.206),

c: the effect of pedestrian's gender (if pedestrian is man it will be 0 and if pedestrian is woman it will be 0.3309),

d: the estimated coefficient for variable of length of vehicle,

e: the estimated coefficient for age variable,

f: the estimated coefficient for variable of waiting time and g: the estimated coefficient for the waiting time square variable.

Table (1) shows the estimated amounts for the generalized linear model and also T-test for all variables. It can be said that this variable has been put as a significant factor in the model. Variables of start-up lane and waiting time are also near to level of 0.05 which indicates the effectiveness on answers.

Table 1. Parameter Estimates

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	0.78760	0.58147	1.35449	0.17982	-0.37154	1.94675
Start-up lane = Fast	0.20681	0.11684	1.77000	0.08096	-0.02611	0.43973
Start-up lane = Slow	0					
Gender = Woman	0.33909	0.11118	3.05002	0.00320	0.11747	0.56072
Gender = Man	0					
Waiting time	0.09053	0.04699	1.92666	0.05797	-0.00314	0.18419
Age	-0.00120	0.00385	-0.31204	0.75591	-0.00888	0.00648
Vehicle length	0.11685	0.12193	0.95837	0.34108	-0.12621	0.35991
Waiting time^2	-0.00079	0.00316	-0.24821	0.80468	-0.00709	0.00552

The goodness of fit measure R^2 is equal to 0.406 for the present model. In this model start-up lane and gender have been considered as fixed factor and other variables as covariate. Since the relation between waiting time and gap amount is not linear another variable called (Waiting time)^2 has been added to let the effect of waiting time be inserted in the model as the square or curve-like.

It can be said that as the amount of waiting time increases the amount of gap also enhances but this will be growing like a curve to points and from a point as the waiting time increases, pedestrian’s tolerance decreases and consequently shorter gaps will be accepted. Table (1) displays the fact that under the same circumstances female pedestrians choose longer gaps in comparison with male ones. The results relating to start-up lane also show that pedestrians who start moving from fast-speed lane accept longer gaps in comparison with that of slow speed lanes. But regarding the variable of age and the obtained significant level, it can be only assumed that age has a reverse relation with accepted gap in bigger samples. This assumption can be justified by looking at cultural issues (drivers’ respect for the elderly), low vision and angle of view. In Platooning Pedestrian situation when some pedestrians move simultaneously parameter of age as average and the effect of gender as the dominant gender (in case there are more than three people) or the pedestrian's gender who is in front (in case there are two persons) are inserted in the model.

II. Computation of critical gap

HCM in its 2010 version has provided relations for computing critical gap in un-signalized intersections. Regarding the initial hypothesis in this study that was based on performance of the intersection for pedestrians as an un-signalized intersection, critical gap has been computed based on relations presented in HCM 2010 (it is noteworthy that HCM utilizes the relations presented for un-signalized intersections to compute critical gap at crosswalks leading to roundabouts). Critical gap is computed for two different scenarios according to this reference:

<u>Scenario A:</u> For a single pedestrian, critical headway is computed with Equation (2):

$$t_c = \frac{L}{S_p} + t_s \tag{2}$$

For approach (1): $t_c = \frac{10}{1.47} + 1.03 = 7.83 \ s$

For approach (2): $t_c = \frac{10}{1.41} + 0.92 = 8.01 \ s$

Where, t_c: critical gap for a single pedestrian (s), S_p: average pedestrian walking speed (m/s), L: crosswalk length (10 m for one approach), and t_s: pedestrian start-up time and end clearance time (s).

But considering the fact that pedestrians usually move as a platoon in this area, another scenario is defined to compute pedestrians' critical gap as what follows:

<u>Scenario B:</u> If pedestrian platooning is observed in the field, then the spatial distribution of pedestrians should be computed with Equation (4). If no platooning is observed, the spatial distribution of pedestrians is assumed to be l. To compute spatial distribution, the analyst must make field observations or estimate the platoon size by using Equation (3):

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}} \tag{3}$$

For approach (1): $N_c = \frac{0.09 e^{0.09 \times 7.83} + 0.31 e^{-0.31 \times 7.83}}{(0.09 + 0.31) e^{(0.09 - 0.31) \times 7.83}} = 2.93 \ ped$

For approach (2): $N_c = \frac{0.08 e^{0.08 \times 8.01} + 0.42 e^{-0.42 \times 8.01}}{(0.08 + 0.42) e^{(0.08 - 0.42) \times 8.01}} = 5.07 \ ped$

Where, N_c: total number of pedestrians in the crossing platoon (ped), v_p: pedestrian flow rate (ped/s), v: vehicular flow rate (veh/s), and t_c: single pedestrian critical gap (s). The spatial distribution of pedestrians is:

$$N_p = Int\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1 \tag{4}$$

For approach (1): $N_p = Int\left[\frac{8.0(2.93-1)}{5}\right] + 1 = 4 \ \ ped$

For approach (2): $N_p = Int\left[\frac{8.0(5.07-1)}{5}\right] + 1 = 7 \ \ ped$

Where, Np: spatial distribution of pedestrians (ped); Nc: total number of pedestrians in the crossing platoon, from Equation (3) (ped); Wc: crosswalk width (5 m for both approach); and 8.0: default clear effective width used by a single pedestrian to avoid interference when passing other pedestrians (m). Group critical headway is determined with Equation (5):

$$t_{c,G} = t_c + 2(N_p - 1) \tag{5}$$

For approach (1): $t_{c,G} = 7.83 + 2(4-1) = 13.83$ s

For approach (2): $t_{c,G} = 8.01 + 2(7-1) = 20.01$ s

Where, $t_{e,G}$: group critical gap (s), t_e: critical headway for a single pedestrian (s), and N_p: spatial distribution of pedestrians (ped).

According to the presented definition for critical gaps, drawing the curve of cumulative distribution of gaps (figure 4) in these facilities lets us know that the obtained amounts by HCM relations for designing this crosswalk is more. According to the procedures suggested by Dipietro [13], if the critical gap equals accepted gap by less 50 percent of pedestrian, this amount in approach (1) will be 5 seconds and 6.5 seconds in approach (2) in facilities for single pedestrians in conjunction with figure 4. Also if the opportunities existing in these facilities are simulated according to equation (1), the amount of critical gaps in approach (1) and in approach (2) will respectively equal 4 and 5 seconds which are closer to the real amount.

If we follow the same process in Platooning Pedestrian situation, critical period in approach 1 and approach 2 will be respectively 9 and 13 seconds according to Dipietro procedure (figure 5). If existing opportunities in these facilities are simulated according to relation 1, the amount of critical gap in approach 1 and approach 2 will be respectively 7 and 10 seconds that are closer to the real amounts.

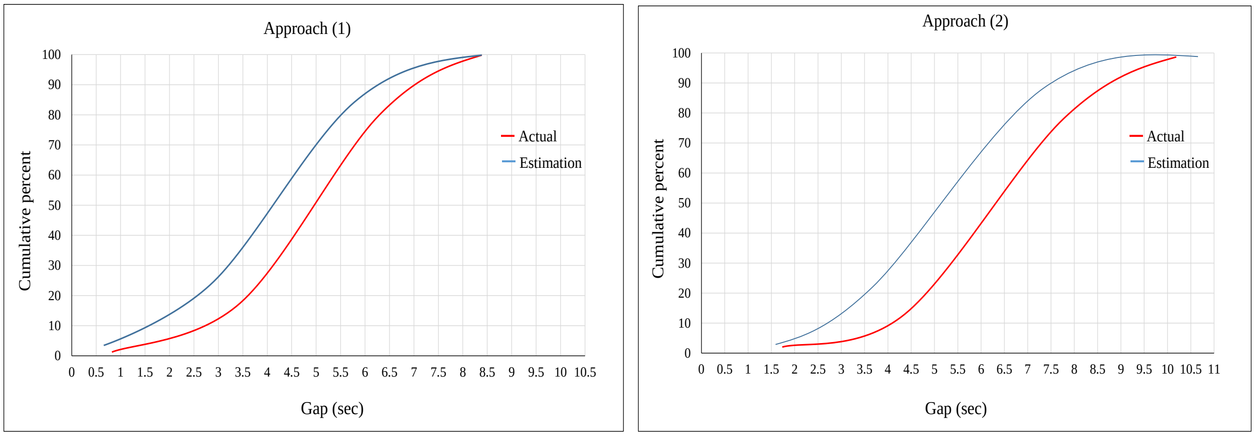

Fig. 4: Cumulative distribution of pedestrians' accepted gaps in single pedestrian situation

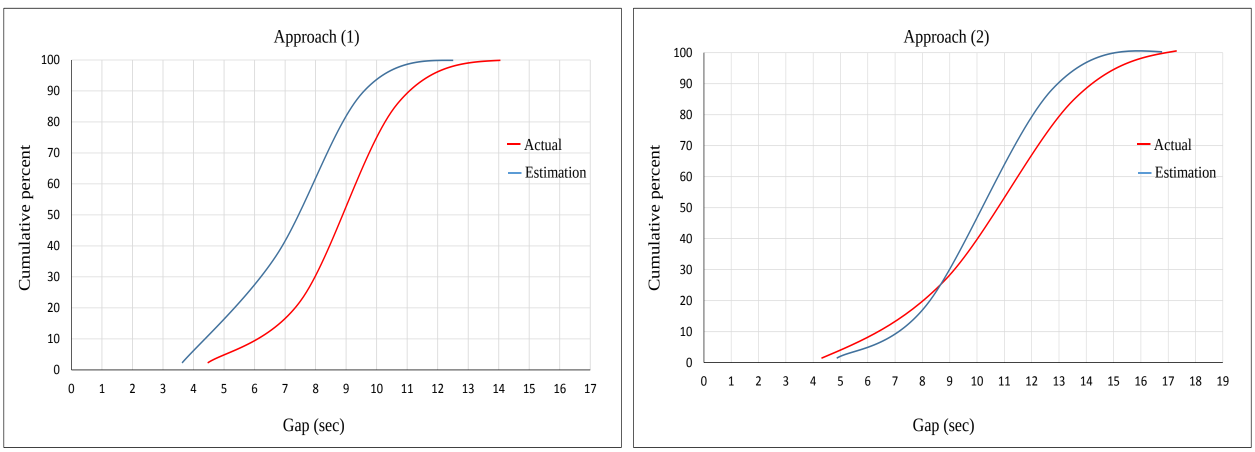

Fig. 5: Cumulative distribution of pedestrians' accepted gaps in pedestrian platooning situation

5. Conclusions

Pedestrian gap acceptance in crosswalks in intersection of Ferdowsi Square and Enghelab Street was investigated in this study. Pedestrians' gaps were analyzed in an hour and a half and their ages were asked.

Most of studies conducted in this realm obtained different data depending on type of location to make a model of pedestrian gap acceptance. According to existing facilities and after investigating various studies parameters of age, gender, waiting time, vehicle length and start-up lane (fast/slow) were obtained and a generalized linear model was made with this data. This model is made in such a way that takes into account both situations of single pedestrian and pedestrian platooning.

One of the most important cases that draws much attention in investigating pedestrian gap acceptance is the computation of critical gap. HCM 2010 has presented equations for such computation that have been used in this study, but considering the fact that these obtained amounts (especially in pedestrian platooning) had significant differences with the observed amounts, the procedure proposed by Dipietro that was based on cumulative distribution of data of pedestrian gap acceptance was also utilized. Comparison of estimated amounts attained by the presented model in this study with the obtained amounts from field observations denotes that this model relatively proper estimation of critical gap in this area. It should be pinpointed that the presented equations in HCM have been made regarding the situation of USA, therefore they have fixed coefficients that can be used to reach better results proportionate to the situation of Iran if they are calibrated. For instance, by changing coefficient of spatial distribution of pedestrians from amount of 8 to amount of 3 more realistic results proportionate to the situation of Iran will be achieved so that the difference between this procedure and HCM will reduce to less than 2 % according to Dipietro's definition, but if we take into account HCM definition for critical gap, there is still a significant difference between the observed amounts for the facilities and the amounts obtained by HCM procedure.

6- References

1. Oxley, J.A., et al., *Crossing roads safely: an experimental study of age differences in gap selection by pedestrians.* Accident Analysis & Prevention, 2005. **37**(5): p. 962-971.
2. Lobjois, R. and V. Cavallo, *Age-related differences in street-crossing decisions: The effects of vehicle speed and time constraints on gap selection in an estimation task.* Accident Analysis & Prevention, 2007. **39**(5): p. 934-943.
3. Simpson, G., L. Johnston, and M. Richardson, *An investigation of road crossing in a virtual environment.* Accident Analysis & Prevention, 2003. **35**(5): p. 787-796.
4. Kadali, B.R. and V. Perumal, *Pedestrians' Gap Acceptance Behavior at Mid Block Location.* International Journal of Engineering and Technology, 2012. **4**(2): p. 158-161.
5. Yannis, G. and A. Theofilatos. *Pedestrian Gap Acceptance for Mid-Block Street Crossing*. in *Proc., Int. Conf. on 12th WCTR*. 2010.
6. Pant, P.D. and P. Balakrishnan, *Neural network for gap acceptance at stop-controlled intersections.* Journal of transportation engineering, 1994. **120**(3): p. 432-446.
7. Sun, D., et al., *Modeling of motorist-pedestrian interaction at uncontrolled mid-block crosswalks.* Urbana, 2002. **51**: p. 61801.
8. Tian, Z., et al., *Implementing the maximum likelihood methodology to measure a driver's critical gap.* Transportation Research Part A: Policy and Practice, 1999. **33**(3): p. 187-197.
9. Zhao, Y., *Exploration of Pedestrian Gap Acceptance at TWSC Intersections using Simulation.*
10. Hamed, M.M., *Analysis of pedestrians' behavior at pedestrian crossings.* Safety Science, 2001. **38**(1): p. 63-82.
11. David, N.K.B., *The role of the physical environment in child pedestrian accidents.* Journal of advanced transportation, 1994. **28**(2): p. 171-187.
12. Kuan-min, C., et al., *Towards the pedestrian delay estimation at intersections under vehicular platoon caused conflicts.* Scientific Research and Essays, 2010. **5**(9): p. 941-947.
13. Dipietro, C.M. and L.E. King, *Pedestrian gap-acceptance.* Highway Research Record, 1970(308).