PEDESTRIAN GAP ACCEPTANCE FOR MID-BLOCK STREET CROSSING

George Yannis, Associate Professor, National Technical University of Athens

Eleonora Papadimitriou, PhD, Researcher, National Technical University of Athens

Athanasios Theofilatos, Transportation Engineer

ABSTRACT

This research aims to investigate pedestrians traffic gap acceptance for mid-block street crossing in urban areas. In particular, two aspects of pedestrians crossing behaviour at mid-block locations are examined, namely the size of traffic gaps accepted by pedestrians and the decision or not to cross the street, as well as the related determinants. For this purpose, a field survey was carried out at an uncontrolled mid-block location in the centre of Athens, Greece. In this survey, pedestrians crossing decisions were videotaped in real traffic conditions. At the same time, the speed of incoming vehicles was measured by means of speed guns. The data collected included the number and the size of traffic gaps rejected or accepted by pedestrians, the related waiting times and number of crossing attempts, the vehicle's speed, as well as individual characteristics (gender, age etc.). A lognormal regression model was then developed in order to examine the effect of various parameters on pedestrian gap acceptance, defined as the size of traffic gaps accepted by pedestrians. It was found that pedestrian's gap acceptance was better explained by the distance from the incoming vehicle, rather than its speed. Moreover, the presence of illegally parked vehicles (which may affect pedestrians' visibility), the size of the incoming vehicle and the presence of other pedestrians were found to have important effect on the size of traffic gaps accepted by pedestrians. A binary logistic model was also developed in order to examine the effect of the traffic gaps available and of other parameters on the decision of pedestrians to cross the street or not. The modeling results reveal that this type of crossing decision is largely defined by the distance from the incoming vehicles and the waiting time of pedestrians.

KEY-WORDS:

pedestrian; mid-block crossing; gap acceptance; lognormal regression; binary logistic regression.

INTRODUCTION

Many researches correlate the minimum gap from the vehicle that is accepted by pedestrians who intend to cross streets at mid-block. These parameters may be associated with traffic conditions and with vehicle and pedestrian characteristics. In most of these researches (Oxley et al., 2005; Das et al., 2002) the distance between the vehicles and the pedestrians appears to influence the most the minimum gap accepted by pedestrians. In addition, an increase in traffic density leads to smaller accepted gaps. These gaps are often described by means of probability distributions or are estimated by means of linear regression modeling. Indicatively, it can be mentioned that the minimum accepted gap has been estimated at two seconds and the mean accepted gap at eight seconds (Das et al., 2002).

Another issue often examined concerns the decision of pedestrians to cross the road or not (Chu et al. 2002; Sun et al. 2003), which has been found to depends more on the distance between the vehicle and the pedestrian and not so much on the related time gap. As a result, pedestrians may choose inappropriate time gaps, because they are not able to estimate the actual speed of incoming vehicles. Other parameters that affect crossing decisions include the presence of police enforcement and the behaviour of other pedestrians (Lobjois & Cavallo, 2006; Oxley et al. 2005). Discrete choice modeling is used by most researchers in order to estimate whether pedestrians are going to cross a street at mid-block or not (Papadimitriou et al. 2009; Lassarre et al. 2007).

However, most of the above mentioned researches were carried out in Northern and Western Europe or in the United States, where transport systems and infrastructure correspond to improved levels of service of pedestrians, resulting in a generally compliant behaviour from the part of the pedestrians as well. As a consequence, the results of these researches cannot be transferred and used in a national setting like the one of Greece, because the Greek road and transport network has different characteristics and operational conditions. Not only is the road infrastructure and traffic control often inadequate for pedestrians, but also the behaviour of pedestrians is particularly non-compliant and often risk-taking. This is partly reflected in the increased proportion of road accidents involving pedestrians in Greece.

In this context, the aim of this research is to investigate pedestrians' traffic gap acceptance for mid-block street crossing in urban areas. In particular, the effect of several factors, such as pedestrians waiting time, the presence of illegal parked vehicles etc.), the vehicles' characteristics (speed, size) and finally pedestrians' characteristics (gender, age) affect the traffic gap acceptance of pedestrians and their decision to cross or not.

For this purpose, a field survey was carried out at an uncontrolled mid-block location in the center of Athens. Moreover, a lognormal regression model was then developed in order to examine the effect of various parameters on pedestrian gap acceptance, defined as the size of traffic gaps accepted by pedestrians A binary logistic model was also developed, so that the effect of the traffic gaps available and of other parameters on the decision of pedestrians to cross the street or not is examined..

METHODOLOGY

A field survey was carried out in the center of Athens, in Solonos street. This location was chosen due to considerable volume of pedestrians. In this survey, pedestrians crossing decisions were videotaped in real traffic conditions. The data collected included the number and the size of gaps rejected or accepted by pedestrians, the related waiting times and number of crossing attempts, each vehicle's speed as well as some individual characteristics (gender, age etc.). It is important to mention that illegal parking in this area was very frequent and the presence of illegally parked vehicles was recorded during the data collection.

The aim of the survey was to videotape those pedestrians, who intended to cross vertically the Solonos street. More specifically, only pedestrians who actually crossed the street, either immediately or after several attempts (i.e. accepting the first traffic gap available or rejecting several gaps before crossing) were captured; pedestrians who abandoned the crossing task after some attempts, and sought for a crossing opportunity elsewhere, were not included in the sample. Particular care was taken that data were recorded only during the green signal of the nearby traffic lights, so that pedestrians would make an unprotected crossing by interacting with the incoming vehicles. Moreover, congestion conditions were not included in the data. The data collected were validated and after a thorough quality control, they were introduced into a specially designed database, so that it could be possible to calculate the traffic gap that was rejected or accepted by the pedestrian in centiseconds.

The data recording of traffic gaps accepted was based on two time points: At the first point, the pedestrian is just ready to set foot on the street. In the second point, the head of the vehicle has just passed through vertical virtual line indicating the pedestrian's crossing path. Therefore, the traffic gap accepted was calculated as the difference in centiseconds between the two time points. Moreover, the waiting time of the pedestrian started when someone approached the pavement until he set foot on the street. It is noted that these calculations included only the accepted gaps and not the rejected ones.

At the same time, the speed of incoming vehicles was measured by means of speed laser guns. The speed of the incoming vehicle was measured at the moment when the pedestrian just started to cross, and was considered to be constant during the pedestrians crossing time.

The continuous variables collected and their descriptive statistics are summarized in Table I, whereas the (mostly coded as binary) discrete variables considered are summarized in Table II.

Table I. Descriptive statistics of continuous variables

Variables	N	Minimum	Maximum	Mean	Standard Deviation
Waiting time (sec)	243	0	37,32	6,21	6,12
Speed (km/h)	243	4	48	25,21	7,82
Distance (m)	243	2,97	64,98	30,07	12,08
Traffic gap(sec)	243	0,50	11,11	3,29	1,76

Table II. Values and percentages of discrete variables

Variables	**Value '0'**	**Value '1'**	**% of value '1' in the sample**
gender	woman	man	56.8%
size	small vehicle	large vehicle	47.0%
crossing	did not cross	crossed	54.0%*
Illegal parking	no	yes	82.3%
Accompanied	pedestrian alone	pedestrian accompanied	11.5%
Lane	Vehicle in nearside lane	Vehicle in farside lane	25.0%
Vehicle type: Motorcycle	no	yes	34.6%
Vehicle type: Car	no	yes	26.3%
Vehicle type: Taxi	no	yes	23.0%
Vehicle type: Truck	no	yes	2.5%
Vehicle type: Bus	no	yes	8.2%
Age group: Young	no	Aged 18-35 years	39.5%
Age group: Middle	no	Aged 35-60 years	36.7%
Age group: Old	no	Aged >60 years	16.5%

*concerns more than one crossing attempts per pedestrian

It is noted that these variables are considered to be the most important ones affecting pedestrian crossing behaviour at mid-block, according to the literature (Papadimitriou et al. 2009). Additional variables that may be considered concern traffic flow and weather conditions, which were not meaningful in the present research, given that the survey took place in good weather conditions and during a period without any significant traffic variation.

RESULTS

Modelling traffic gaps

After a number of trials in order to statistically process the data and to develop mathematical models about the minimum pedestrians' gap acceptance, a lognormal regression model (Bradu & Mundlak, 1970) was selected, given that a normal distribution could be successfully fitted to the logarithm of the gaps (but not to the initial values of the gaps). It is noted that lognormal regression assumes a normal distribution for the logarithm of the dependent variable, and was thus preferred over log-linear regression, which assumes a Poisson distribution for the dependent variable. The final model was the following:

Log-Gap =0.262 + 0.009 * distance + 0.05 * size + 0.043 * accompanied + 0.048 * parking + 0.025 * gender

Where,
Distance: the space between the vehicle and the pedestrian
Size: the size of the vehicle that is small or big
Accompanied: the pedestrian is accompanied by another pedestrian or not
Parking: presence of illegally parked cars
Gender: gender of the pedestrian

The goodness of fit measure R^2 is equal to 0.455 for this model whereas all the above variables were statistically significant at 95%. A residual analysis took place in order to test the good fitness of the model. It was found that the residuals follow the normal distribution. Their mean value was almost zero and they had equal variances (homoscedasticity tests). It was also confirmed that the recorded log-gaps are normally distributed as well.

Moreover, an analysis of elasticities (e) was carried out, as shown in Table III. The relative effect (e*), as a normalization of the estimated elasticities in relation to the lowest elasticity, was also calculated in order to show clearly to which extent each of the independent variables affects the dependent variable. Although elasticity is to be typically calculated for continuous variables, it was also estimated for discrete variables in order to compare the magnitude of effects of all independent variables. The point elasticity (e_i) of the dependent variable to the independent ones for each pedestrian (i) in the sample is calculated straightforward according to the following formula, whereas the overall elasticity (e) is calculated as the average of (e_i) in the sample:

$$e_i = (\Delta Y_i \ / \ \Delta X_i)\ (X_i / Y_i) = \beta_i\ (X_i / Y_i)$$

Table III. Parameter estimates, statistical significance and elasticities in the gap acceptance model

Independent variables	**Log(gap)**			
	β_i	**p-value**	**Elasticities**	
			e_i	**e_i^***
Distance	0.009	0.000	0.423	51.62
Size of the vehicle	0.050	0.002	0.039	4.79
Accompanied	0.043	0.082	0.008	1.00
Illegal parking	0.048	0.019	0.065	7.92
Gender	0.025	0.116	0.023	2.86

The results suggest the following:

1. The distance between the vehicle and the pedestrian has the greatest effect on pedestrian log-gap acceptance. This appeared to be intuitive, because it was shown in the videotapes that those pedestrians who crossed the road when the vehicle was close to them had accepted smaller gaps than those who chose to cross the road when the vehicle was far away. Thus, the former pedestrians were more risky than the latter ones.

2. The presence of illegal parking has the second larger effect on log-gap acceptance. Illegal parking made pedestrians more careful and acceptant of larger gaps.

3. Vehicle size follows with the third higher elasticity. It appears that pedestrians accept larger gaps when facing larger vehicles.

4. Men appear to take fewer risks than women, as they generally accept larger gaps, a finding also reported by Hamed (2001).

5. The parameter that has the lowest effect on log-gap acceptance is the one indicating that accompanied pedestrians seem to accept relatively larger gaps.

The calculation of the value of e* was straightforward. If the variable 'accompanied' has an elasticity of 1, then the variable 'gender' has an elasticity of 2,86 , that is it effects the gap acceptance 2,86 times more than the 'accompanied' variable. Then the size of the vehicles will have a 4,79 greater effect on the gap and so on. It is noted, however, that the elasticities of continuous variables are not directly comparable with those of discrete variables, and consequently the estimated value of e* for 'distance' should be compared to the other e* values with particular caution. Nevertheless, the dominant effect of distance is confirmed when considering that an increase of 1% in the distance of the incoming vehicle results in an increase of 42% of the traffic gap accepted. On the other hand, all the other categorical variables' elasticities are less than 6%; although these can not be directly attributed to 'incremental changes' in the variables, they are almost 10 times lower than the elasticity of distance.

After all that a sensitivity analysis was carried out to comprehend the effect of the independent variables on the dependent variable even better. For example, in Figure 1 it can be seen that the sensitivity of the gaps accepted to the distance from the incoming vehicle increased with the size of the vehicle and with the presence of illegal parking.

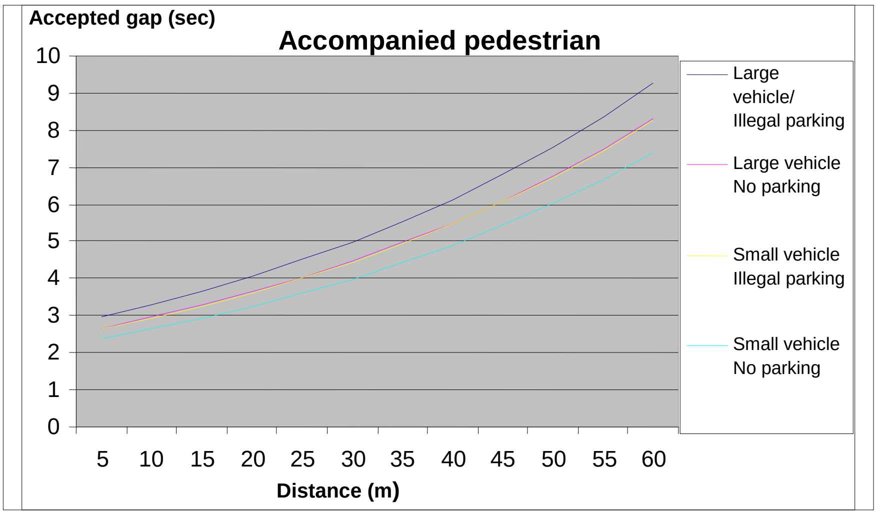

Figure 1. Sensitivity of gaps accepted to the distance from the incoming vehicle - Accompanied male pedestrians

Modelling mid-block crossing choice

A binary logistic regression (Washington et al. 2003) was selected in order to estimate the decision of the pedestrian to cross the street or not. The best model developed is the following:

U = - 5.241 - 0.25 * wait + 2.161 * gap +1.078 * car + 0.969 * parking
Where,
Wait: waiting time
Gap: the gap from the vehicle
Car: if the type of vehicle is passenger car
Parking: presence of illegal parking

It is important to outline two issues. The first is that the above equation corresponds to a Utility Function. So, the probability that a pedestrian crosses the street is:

$P=e^{u}/(e^{u}+1)$

The second is a note that in this model both the accepted gaps and the largest one of the rejected gaps were used, whilst in the previous model only the accepted gaps were used.

The elasticity analysis for this model is presented in Table 4 and the results can be summarized as follows:

1. The traffic gap has the greatest effect on pedestrians' decision to cross the street or not. It was found that, as expected, the higher the available gaps, the easier the crossing.

2. The variable with the second greater effect is the waiting time. As pedestrians keep waiting to cross the road, the probability to cross is decreasing. That may seem

counter-intuitive, but can be explained as follows: those pedestrians who intend to wait for a long time to cross the street are most careful and they will not take risks.

3. The presence of illegal parked vehicles leads pedestrians to cross the road. This may be attributed to the fact that a crossing seems safer when part of the crossing distance is taken by parked vehicles. However, illegal parking seems to have two different effects on pedestrians gap acceptance and their decisions to cross or not. This is something which needs further investigation.

4. When the incoming vehicle is a passenger car, the crossing probability increases; however, this variable has the lowest effect. It is noted that vehicle type was found to be significant in this model, whereas vehicle size was significant in the gap acceptance model.

Table IV. Parameter estimates, statistical significance and elasticities for the crossing decision model

Independent variables	**Crossing or not**			
	βi	**p-value**	**Elasticities**	
			e_i	**e_i^***
Waiting time	-0.250	0.000	0.202	12.75
Traffic gap	2.161	0.000	0.764	48.26
Type of vehicle: car	1.078	0.013	0.015	1.00
Illegal parking	0.969	0.080	0.123	7.77

It is interesting to note that none of the pedestrians' individual characteristics tested were found to be significant in the crossing choice model; it is likely that these effects are included in the 'traffic gap' variable, given that this variable was found to be affected by certain characteristics of the pedestrian. A sensitivity analysis for this model is presented in Figure 2, showing that, in favourable conditions (i.e. passenger car incoming and presence of illegal parking) pedestrians probability to cross decreases with waiting time. It appears that the majority of pedestrians would accept a 6 seconds gap. The crossing probability when a gap is larger than 6 seconds is almost 100%. Moreover, waiting time increases the probability that a pedestrian crosses the street is falling. As mentioned before, pedestrians who are willing to wait for a long time do not intend to take high risks. Similar findings are reported by Hammed (2001) and Tiwari et al. (2007), who analysed the relationship between pedestrian waiting time and crossing probability by means of survival analysis.

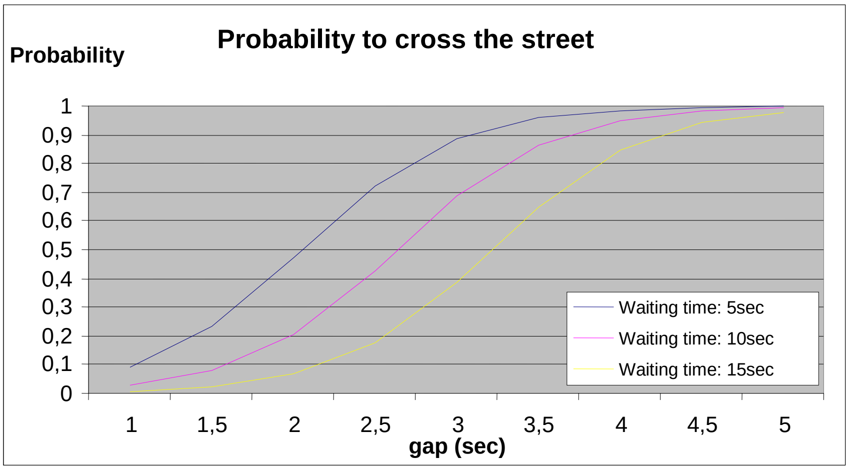

Figure 2. Sensitivity of crossing probability to traffic gaps for different waiting times

CONCLUSIONS

An experimental survey was carried out in Athens, Greece in order to investigate pedestrian traffic gap acceptance for Mid-block Street crossing in urban areas. The majority of the previous studies examined the issue of critical gap acceptance or the decision to cross the street by means of either simulation methods (Simpson, 2003; teVelde et al. 2005) or field surveys (Hine & Russel, 1996). In this research, a field survey was opted for, allowing to observe the actual crossing behavior.

With respect to analysis methods, a lognormal regression analysis was implemented for modeling pedestrians' traffic gap acceptance. It was found that the accepted gaps depend on the distance from the incoming vehicle, the size of the vehicle, the presence of illegal parking, the gender of the pedestrians and whether he is accompanied by another pedestrian. It seems that men select the highest and the safest gaps, especially when they are accompanied, when the incoming vehicle is large and when there is illegal parking.

The statistical analysis of the decision to cross the street or not was carried out by using binary logistic regression. The results suggest that pedestrians' decision to cross the street depends on the traffic gap, the waiting time, the type the incoming vehicle and the presence of illegally parked vehicles.

The results of this research confirm previous findings as regards the effects of basic roadway and traffic parameters on pedestrians crossing decisions. Moreover, it was found that pedestrians crossing decisions are strongly associated with the distance from the incoming vehicle, rather than its speed, possibly because vehicle distance can be more easily assessed by pedestrians. It is noted that in several studies report a dominant effect of distance rather than time for gap selection, whereas speed measurements are seldom available (Papadimitriou et al. 2009; Theofilatos, 2009).

Pedestrians' individual characteristics were not found to be significant in this research; only pedestrian's gender was found to affect gap acceptance. On the contrary, traffic conditions were found to be the most important determinants of crossing behaviour. This may be attributed to the fact that all survey participants can be considered to have a strong familiarity with the survey site, as this is located in a very central area, resulting in less uncertainty in the decisions of those groups of pedestrians that are often associated with particular behaviours (e.g. children, elderly).

REFERENCES

Baltes M.R. and Chu X. (2002). Pedestrian level of service for mid-block street crossings. 81st Annual Meeting, Transportation Research Board, January 13-17, Washington DC, 2002.

Bradu,D., Mundlak Y. (1970). Estimation in lognormal linear models. Journal of the American Statistical Association 65, pp. 198-211.

Chu X., Gittenplan, M., Baltes M. (2002). Why People Cross Where They Do - The Role of the Street Environment. In the Proceedings of the TRB 81st Annual Meeting, Transportation Research Board, Washington, 2002.

Das S., Manski C.F., Manuszak M. (2005). Walk or Wait? An Empirical Analysis of Street Crossing Decisions. Journal of Applied Econometrics 20 (4), pp. 445-577.

Hamed M.M. (2001). Analysis of pedestrians' behaviour at pedestrian crossings. Safety Science 38, pp. 63-82.

Hine J., Russel J. (1993). Traffic barriers and pedestrian crossing behaviour. Journal of Transport Geography 1 (4), pp. 230-239.

Lassarre S., Papadimitriou E, Yannis G, Golias J. (2007). Measuring accident risk exposure for pedestrians in different micro-environments. Accident Analysis and Prevention 39, 1226-1238.

Lobjois R., Cavallo V. (2006). Age-related differences in street crossing-desicions: The effects of vehicle speed and time constraints on gap selection in an estimation task. Accident Analysis Prevention 39 (5), 934-943.

Oxley, J., Fildes, B., Ihsen, E., Charlton, J., and Days, R. (2005). Crossing roads safely: An experimental study of age differences in gap selection by pedestrians. Accident Analysis and Prevention 37, pp. 962-971.

Papadimitriou E., Yannis G., Golias J. (2009). A critical assessment of pedestrian behaviour models. Transportation Research Part F 12, 242-255.

Simpson G., Johnston L., Richardson M. (2003). An investigation of road crossing in a virtual environment. Accident Analysis and Prevention 35, pp. 787-796.

Sun D., Ukkusuri S.V.S.K., Benekohal R.F., Waller S.T. (2003). Modeling of Motorist-Pedestrian Interaction at Uncontrolled Mid-block Crosswalks. In the Procceedings of the 82nd TRB Annual Meeting, Transportation Research Board, Washington, 2003.

Te Velde A.F, van der Kamp J., Barela J.A., Savelsbergha G.J.P (2005). Visual timing and adaptive behavior in a road-crossing simulation study. Accident Analysis and Prevention 37, pp. 399–406.

Theofilatos A. (2009). Investigation of the minimum gap accepted by pedestrians for urban street mid-block crossing. Diploma Thesis. National Technical University of Athens, School of Civil Engineering, Department of Transportation Planning and Engineering, Athens, March 2009 (In Greek).

Tiwari G., Bangdiwala S., Saraswat A., Gaurav S. (2007). Survival analysis: Pedestrian risk exposure at signalized intersections. Transportation Research Part F 10, pp. 77-89.

Washington S.P., Karlaftis M.G., Mannering F.L. (2003). Statistical and Econometric Methods for Transportation Data Analysis. Chapman & Hall / CRC Press, Boca Raton, FL.