PEDESTRIAN GAP ACCEPTANCE
FOR MID-BLOCK STREET CROSSING

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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 regression model was also developed in order to examine the effect of the traffic gaps available and other parameters on the decision of pedestrians to cross the street or not. The modelling 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.

1. INTRODUCTION

This analysis of gap acceptance at mid-block locations is very important for the improvement of pedestrians' safety in urban areas. According to related studies, crossing at mid-block locations represents most of the injuries from attempting to cross the street. In addition, crossing at mid-block results in more pedestrian fatalities than crossing at junction (FDOT, 1996; OECD, 2001).

A basic factor that influences pedestrian's crossing decisions at mid-block locations is gap acceptance. Each pedestrian is supposed to have a critical gap in mind every time he/she attempts to cross the street, which can be defined on the basis of the following formula (Wan and Ruphail, 2004):

Critical Gap = L/S + F (1)

where, L is the crosswalk length, S is the pedestrian's average walking speed and F is a safety margin (in seconds) that reflects pedestrian risk acceptance (i.e. risk-prone pedestrians have smaller safety margins). Any gap that is smaller than this critical gap is rejected by the pedestrian.

Daganzo (1981) shows that it is possible to measure and estimate the average critical gap of pedestrians from direct roadside observations. Indicatively, the minimum accepted gap has been estimated at two seconds and the mean accepted gap at eight seconds (Das et al., 2005).

Traffic gap acceptance may be then analysed by means of three approaches (Sun et al., 2003):

- deterministic approaches, where gap acceptance solely depends on the (mean) gap sizes
- probabilistic approaches, in which the probability of accepting a gap is calculated as a random variable from a distribution that best fits the data
- modelling approaches, which correlate the minimum gap from the vehicle that is accepted by pedestrians who intend to cross streets at mid-block with various parameters.

These parameters that affect minimum gaps and risky crossings in general may be associated with traffic conditions (Hine and Russel, 1993) as well as with drivers' behaviour (Himanen and Kulmala, 1988) and pedestrian characteristics (Oxley et al., 1996, Holland and Hill 2007, 2010). In most of these researches (Oxley et al., 2005; Das et al., 2005) 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.

Another issue often examined concerns the analysis of the decision of pedestrians to cross the street or not, in relation to the traffic gaps (Chu et al. 2002; Sun et al. 2003). In some cases, this decision has been found to depend more on the distance between the vehicle and the pedestrian and not so much on the related traffic gap. A study carried out by Isler et al. (1998) aimed to investigate the child pedestrians' crossing gap thresholds and it indicates that almost two-thirds of the children reported that they used the distance rather than the time in order to assess the available gaps. Because of this inadequate strategy, 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; Yang et al., 2006; Zhou and Horrey 2010). Discrete choice modelling 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 other settings, like the one of Greece, where roads and transport network have different characteristics and operational conditions. More specifically, the road infrastructure and traffic control are often inadequate for pedestrians, but also the behaviour of pedestrians is particularly non-compliant and often risk-taking in such settings (Ward et al., 1994; Yang et al., 2006; King et al., 2009).

In this context, the aim of this research is to investigate pedestrians' traffic gap acceptance for mid-block street crossing in urban areas. Data from Athens, Greece are used for that purpose, corresponding to a less pedestrian-friendly road environment and to less compliant pedestrians, compared to other studies. 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 centre of Athens. 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; Te Velde et al. 2005) or field surveys (Hine & Russel, 1993). In this research, a field survey was opted for, allowing to observing the actual crossing behaviour. Moreover, a lognormal regression model was 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.

2. DATA COLLECTION AND METHODOLOGY

A field survey was carried out in the centre 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 the number of crossing attempts, each vehicle's speed as well as some individual characteristics of the pedestrians (gender, age etc.). It is important to mention that illegal parking in this area was very frequent and the presence or not 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 the 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 from the point at which the pedestrian approached the pavement until he/she set foot on the street in order to cross. 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 at which the pedestrian just started to cross, and was considered to be constant during the pedestrians' crossing time.

The continuous variables collected during the survey 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	82.0%
accompanied	pedestrian alone	pedestrian accompanied	11.0%
lane	vehicle in nearside lane	vehicle in farside lane	25.0%
vehicle type: motorcycle	No	yes	34.0%
vehicle type: car	No	yes	26.0%
vehicle type: taxi	No	yes	23.0%
vehicle type: truck	No	yes	2.0%
vehicle type: bus	No	yes	8.0%
age group: young	No	aged 18-35	39.0%
age group: middle	No	aged 35-60	36.0%
age group: old	No	aged >60	16.0%

*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 an area and a period without any significant traffic variation.

3. RESULTS

3.1 Modelling traffic gaps

A lognormal regression model (Bradu & Mundlak, 1970) was selected for the analysis of pedestrians' gap acceptance, 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 (see also Table III):

$$\text{Log-Gap} = 0.262 + 0.009 * \text{distance} + 0.05 * \text{size} + 0.043 * \text{accompanied} + 0.048 * \text{parking} + 0.025 * \text{gender} \qquad (2)$$

Where,

Distance: the distance between the vehicle and the pedestrian
Size: the size of the vehicle (small or big)
Accompanied: the pedestrian is accompanied by another pedestrian or not
Parking: presence of illegally parked vehicles
Gender: gender of the pedestrian

The parameter estimates and their statistical significance (p-value) are presented in Table III. It is also noted that variables' interaction terms were tested (e.g. distance*vehicle size) but none of them was found to significantly affect log-gaps.

In order to examine whether there is a high degree of linear dependence between some of the independent variables, multicollinearity tests were carried out such as the VIF-estimate (variance inflation factor) and tolerance. If multicollinearity exists (high VIF-estimates), this may possibly mean that the coefficient estimates cannot be partially interpreted. More specifically, according to O'Brien (2007), the VIF-estimate was calculated as follows:

$$VIF = 1/(1-R_j^2) \qquad (3)$$

where R_j^2 represents the proportion of variance in the j^{th} independent variable that is associated with the other independent variables in the model and $1-R_j^2$ is the tolerance.

All estimated values (tolerance values are above 0.2, VIF values are lower than 10) indicate that the significant independent variables are not correlated. 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%.

Moreover, an analysis of variables 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 (Yannis et al., 2010). The point elasticity (ei) 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 (ei) in the sample:

$$e_i = (\Delta Y_i / \Delta X_i)\,(X_i / Y_i) = \beta_i\,(X_i / Y_i) \qquad (4)$$

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

Log(gap)				
			Elasticities	
Independent variables	βi	p-value	ei	ei*
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

It may seem counter-intuitive that the variable ‘speed’ was not found to be significant. However, it should be taken into account that it does influence the dependent variable indirectly because the variable ‘distance’ is significant. Having made the assumption that during vehicle-pedestrian interaction the speed of the vehicle was constant, the distance is produced if speed is multiplied by the traffic gap. The non significance of speed could be attributed to the fact that pedestrians may estimate better the distance from the vehicle than its speed.

From Table III it can be observed that 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 street when the vehicle was close to them had accepted smaller gaps than those who chose to cross the street when the vehicle was far away. Thus, the former pedestrians were more risky than the latter ones. Furthermore, 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.

It is also observed that vehicle size follows with the third higher elasticity. It appears that pedestrians accept larger gaps when facing larger vehicles. Men appear to take fewer risks than women, as they generally accept larger gaps, a finding also reported by Hamed (2001). Finally, the parameter that has the lowest effect on log-gap acceptance is the one indicating that accompanied pedestrians seem to accept relatively larger gaps.

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 some 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 cannot be directly attributed to 'incremental changes' in the variables, they are almost 10 times lower than the elasticity of distance.

Then a sensitivity analysis was carried out to comprehend the effect of the independent variables on the dependent variable. For example, in Figure 1 it can be seen that the sensitivity of the gaps accepted to the distance from the incoming vehicle increases as the size of the vehicle increases and when there is illegal parking. It is interesting to note that the distribution of accepted gaps for large vehicles and no illegal parking is practically indistinguishable from the distribution of accepted gaps for small vehicles with illegal parking. It can be said that illegal parking counterbalances the effect of vehicle size, i.e. poor visibility due to parked vehicles makes the pedestrians choose larger gaps even if the incoming vehicles are small.

The same phenomenon can be observed in Figure 2, in which it can be seen that gap values for large vehicles and not accompanied pedestrians are almost identical with gap values for small vehicles and accompanied pedestrians. Finally, it can be deducted from those two Figures that when the distance from the incoming vehicles is small, all the curves are very close to each other, indicating that all pedestrians accept similar gaps. But as the distance rises, the curves deviate more from each other, indicating more significant variations in gap acceptance.

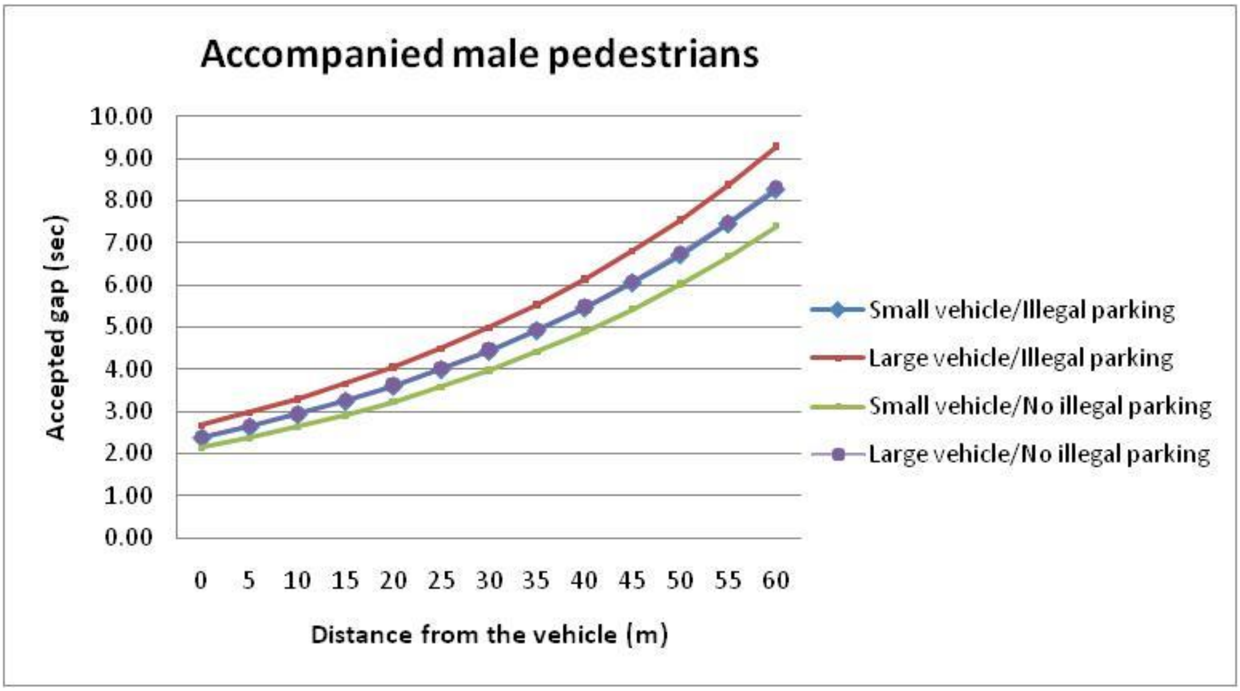

Figure 1: Sensitivity of gaps accepted to the distance from the incoming vehicle Accompanied male pedestrians

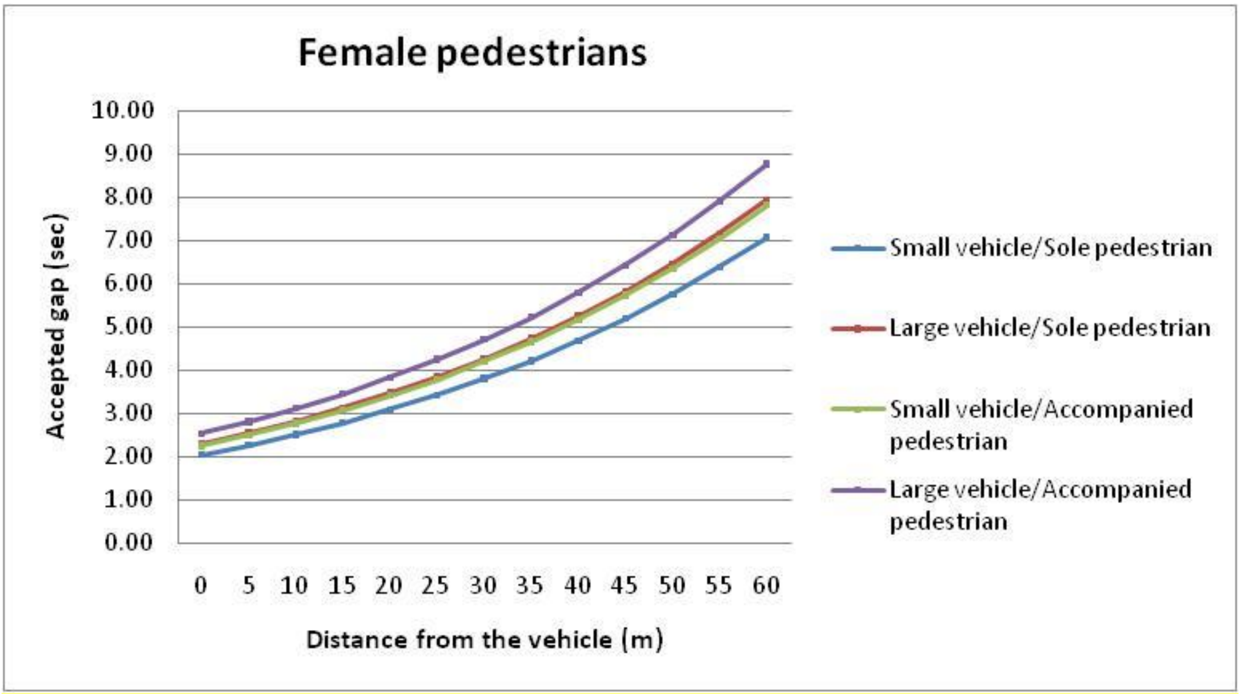

Figure 2: Sensitivity of accepted gaps from the incoming vehicle by female pedestrians - Presence of illegal parking in the area

3.2 Modelling mid-block crossing choice

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

$$U = - 3.194 - 0.25 * \text{wait} + 2.161 * \text{gap} - 1.078 * \text{car} - 0.969 * \text{parking} \qquad (5)$$

Where,
Wait: waiting time
Gap: the gap from the vehicle
Car: if the type of vehicle is passenger car
Parking: presence of illegal parking

The parameter estimates and their statistical significance (p-value) are presented in Table IV.

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

$$P = e^U/(1+e^U) \qquad (6)$$

The second is 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 final issue is that while in simple linear regression the method of the ordinary least squares is used, in logistic regression the maximum likelihood method is being applied in order to estimate the parameters and assess the goodness-of-fit of the proposed model. If the model has only a constant and we add e.g. p number of variables and the change in likelihood is significant at 5% level, we reject the null hypothesis that the coefficients for the predictive model are 0 and consequently this means a good fit.

Another test that was carried out in order to examine whether the data fit the model well, is the Hosmer-Lemeshow statistic (Hosmer and Lemeshow, 1980). The null hypothesis that there is linear relationship between the predictor variables and the log odds of the dependent variable was accepted. All the previous tests indicated a satisfactory goodness-of-fit.

The elasticity analysis for this model is presented in Table IV. In logistic regression models, point elasticities may be estimated for the continuous variables as follows (Washington et al. 2003)

$$E^{P(i)}_{x_{ink}} = \frac{\partial P_n(i)}{\partial x_{ink}} \frac{x_{ink}}{P_n(i)} = \frac{\partial \ln P_n(i)}{\partial \ln x_{ink}} = [1-\sum_{i'=1}^{I} P_n(i)]\, x_{ink}\beta_k \qquad (7)$$

Where $P_{(i)}$ is the probability of alternative (i) and x_{ink} the value of variable (k) for alternative (i) of individual (n) and I the number of alternatives including x_{ink}.

In logistic regression models, pseudo-elasticities may be calculated for the discrete variables (Shankar & Mannering, 1996; Chang & Mannering, 1999) and they reflect the change in the estimated probability resulting from the transition to one discrete value of a variable to another. The next formula shows how they can be estimated for binary variables (Ulfarsson & Mannering, 2004):

$$E^{P(i)}_{x_{ink}} = e^{\beta_{ik}} \frac{\sum_{i'=1}^{I} e^{\beta'_i x_n}}{\sum_{i'=1}^{I} e^{\Delta(\beta'_i x_n)}} - 1 \qquad (8)$$

Where I is the number of possible outcomes, $\Delta(\beta' x_n)$ is the value of the function determining the outcome when x_{nk} has changed from 0 to 1, while $\beta' x_n$ is the related value when x_{nk} is 0, and β_{ik} is the parameter estimate of x_{nk}.

The above disaggregate elasticities are estimated for each observation (i) of each individual (n) in the sample. In order to calculate the aggregate elasticity for logistic regression models, the following formula is applied (Ben-Akiva & Lerman, 1985):

$$E_{x_{ik}}^{P(i)} = \frac{\sum_{n=1}^{N} P_n(i) E_{x_{ink}}^{P_n(i)}}{\sum_{n=1}^{N} P_n(i)} \qquad (9)$$

It can be observed that 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. The variable with the second greater effect is the waiting time. As pedestrians keep waiting to cross the street, 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.

Furthermore, from Table IV it can be seen that the presence of illegal parked vehicles discourages pedestrians from crossing the street. This may be attributed to the fact that illegal parking affects pedestrians' visibility and crossing seems to be unsafe. Finally, when the incoming vehicle is a passenger car, the crossing probability decreases; 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

Crossing or not				
Independent Variables	**βi**	**p-value**	**Elasticities**	
			ei	**ei***
waiting time	-0.25	0	0.138	1.166
traffic gap	2.161	0	0.627	5.295
type of vehicle: passenger car	-1.078	0.013	0.119	1.005
illegal parking	-0.969	0.08	0.118	1

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 Figures 3 and 4, where the crossing probability is examined in relation to traffic gaps and waiting times for passenger cars. It is shown in Figure 3 that pedestrians' probability to cross decreases with waiting time. 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). 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%.

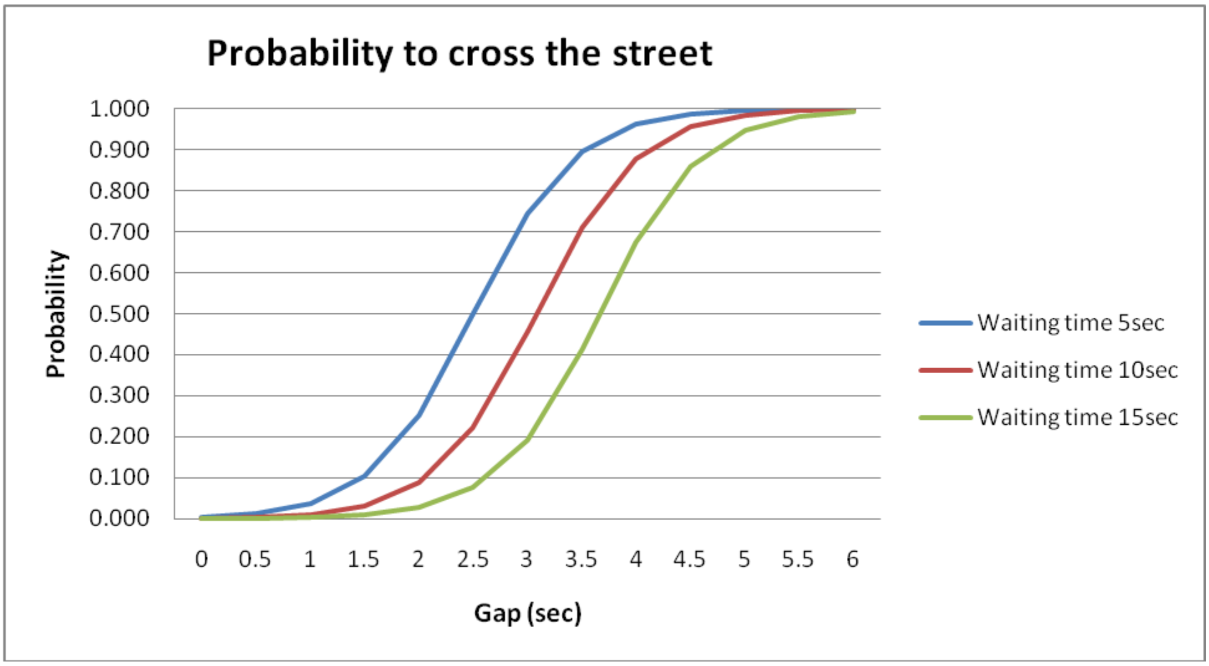

Figure 3: Sensitivity of crossing probability to traffic gaps for different waiting times when there is illegal parking

Figure 4: Sensitivity of crossing probability to traffic gaps for different waiting times when there are no illegally parked vehicles

In cases where there is not illegal parking (Figure 4) it is shown that more than 90% of pedestrians accept a gap value of 4.5 seconds in contrast to the case where there is illegal parking (Figure 3). Furthermore, in most cases in which there is illegal parking, the probability to cross the street if the time gap is slightly smaller than 2 seconds varies from approximately 5 to 25 percent. On the other hand, when there are no illegally parked vehicles, the correspondent probability varies from approximately 8 to 50 percent. These findings indicate the significance of illegal parking.

4. CONCLUSIONS

An experimental survey was carried out in Athens, Greece, in order to investigate pedestrian traffic gap acceptance for mid-block street crossing in an urban setting where the road and traffic environment are less adapted for pedestrians' needs, and the pedestrians themselves are less compliant to traffic rules.

The lognormal regression and the binary logit model were considered to be the most appropriate methods to analyse the size of the accepted traffic gaps and the probability to cross the street respectively. 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. The sensitivity of the gaps accepted to the distance from the incoming vehicle increases as the size of the vehicle increases and when illegal parked vehicles are present in the area.

The statistical analysis of the decision to cross the street or not revealed 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. Illegal parking seems to discourage pedestrians towards the decision to cross, regardless of the traffic gap. Moreover, as waiting time rises, the probability to cross the street decreases. This means that non-risk takers are willing to wait longer until a safe gap appears rather than cross the street earlier and accept a smaller gap.

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).

Because of the fact that little information was available about pedestrians' personal characteristics (such as trip purpose, origin, destination etc.) and taking into account the characteristics of Greek pedestrians and drivers, more research is needed in order to acquire more detailed data and perform a more in-depth analysis. This could enable the authorities to plot strategies and define the appropriate policy in order to optimise the pedestrians' environment inside urban areas.

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