EVALUATION OF PEDESTRIAN CROSSING SPEED IN URBAN ROADS

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ABSTRACT

Pedestrian crossings play an important role in the operation and safety of the pedestrian network, since they usually constitute critical points with high interaction and conflict between pedestrians and vehicle streams. These conflicts depend on the volume of pedestrians and traffic, as well as the hierarchy of the road crossed, which justifies the implementation of different types of pedestrian crossings. One of the key parameters of its design, particularly in the case of crossings with traffic lights, is the crossing speed. This paper focuses on a detailed presentation of the adopted methodology, concerning both the data collection, processing and the results analysis. The work was supported by a real database with 510 cases, collected from a set of seven different pedestrian crossing types all located in the city of Coimbra. Fieldwork consisted in gathering video footage, complemented by the registration of the vehicle speeds distribution using a mobile radar. Data analysis was based on the application of statistical techniques which allowed the identification and evaluation of the factors that have proven statistical significance in explaining the observed crossing speed. In general, the conclusions confirm the results of previous studies, pointing to an average of 1.22 m/s for the crossing speed, with a minimum of 0.63 m/s and a maximum of 1.83 m/s. It was found that pedestrians tend to adopt higher crossing speeds at crosswalks with traffic lights. Age, walking alone or in a group and average vehicle circulation speed were identified as the most significant explanatories variables for both crossings. Pedestrian density, crossing length, and the existence of a central refuge island, were only statistically relevant for crossings with traffic lights. The gender variable is on the verge of being considered statistically significant for crossings with traffic lights.

Keywords: pedestrian crossing speed, walking speed, crosswalks

INTRODUCTION

Through out the last decades, we have been witnessing, in several countries, a shift in the paradigm of urban mobility, mainly due to an increase in environmental awareness, alongside with a degradation of urban traffic circulation conditions. This tendency has been increasing since the 80's through a fight against an excessive usage of the private car in the urban environment, while, at the same time, alternative modes of transport were being promoted. Pedestrian circulation is increasingly considered as a privileged mode of transport, mainly in central and noble locations for environmental, health, and economic sustainability reasons, or for the preservation of public space quality.

The study of pedestrian crossing becomes particularly relevant given that they represent the critical points on the pedestrian network. These crossings depend on the severity of the conflict between the various factors, namely the pedestrians and traffic volumes involved, as well as the hierarchy of the road crossed (Ferreira, 2010).

Of the different types of pedestrian crossings available, we should highlight raised crosswalks, pedestrian crosswalks with or without a central refuge island, and traffic light crosswalks. To set the right dimension for pedestrian crossings it is important to have a correct knowledge of the pedestrian's behavior, namely their speed. The pedestrian's crossing speed directly relies on various factors, such as, age, gender, pedestrian density, physical abilities (ex.: pedestrians with reduced mobility), etc. (Ferreira, 2010).

This concern has justified the development of several research works, not always reaching consensual results. Specialty literature (Austroads, 1995; Dewar, 1992; LaPlante and Kaeser, 2007; TRB, 2000) recommends the adoption of a mean crossing speed of about 1.20 m/s to 1.22 m/s (4 ft/s). However, for traffic lights' design purposes, the adoption of inferior values is recommended in order to meet the special needs of elderly users and of those with reduced mobility. It is recurrent to adopt 1.0 m/s as the dimensional parameter (Austroads, 1995; Dewar, 1992; TRB, 2000), although in many studies this value corresponds to the 15th percentile of the crossing speed distribution.

Rastogi *et al.* (2011) have observed speed values between 0.83 and 1.02 m/s for the 15th percentile. These authors recommend a crossing speed of 0.95 m/s for the design of the infrastructure, decreasing to 0.79 m/s if the proportion of elderly people is high. In turn, Fitzpatrick *et al.* (2006) recommend a speed of 1.07 m/s decreasing to 0.90 m/s in the presence of elderly pedestrians or those with reduced mobility. As for Gates *et al.* (2006), they point to a mean speed of 1.16 m/s and to a decrease in relation to the proportion of pedestrians older than 65 years old, namely 1.10 m/s, 1.07 m/s, 1.04 m/s, 1.01 m/s and 0.88 m/s for proportions of 20%, 30%, 40%, 50% and 100% of elderly pedestrians, respectively. These authors stress that the crossing speed of 1.22 m/s is only appropriate in locations subject to a lower percentage of elderly pedestrians, children or people with reduced mobility. Tarawneh (2001) obtained the mean speed and 15th percentile of speed of 1.34 m/s and 1.11 m/s, respectively, decreasing to 0.97 m/s in the presence of elderly people.

Current Portuguese legislation imposes the adoption of a pedestrian speed of 0.4 m/s for the design of signalized solutions, a value that, as mentioned above, tends to be low regarding the characteristics of pedestrians with normal mobility.

We can still identify a fair amount of studies focusing on the identification of factors that influence pedestrian behavior. Some authors (Fitzpatrick *et al.*, 2006; Gates *et al.*, 2006; Ishaque and Noland, 2008; Tanaboriboon and Guyano, 1991; Tarawneh, 2001) find significant differences between the speeds adopted by male pedestrians [1.31-1.47 m/s] and female ones [1.23-1.40 m/s]. Knoblauch *et al.* (1996) also confirm this tendency, but they present speed values combining the effect of gender with the ages of adult and elderly individuals. Hence, for adults and elderly females, the values are of 1.46 m/s and 1.19 m/s, respectively; and for adults and elderly males, the values are 1.56 m/s and 1.31 m/s, respectively. Gates *et al.* (1996) and Tarawneh (2001) observed significant differences which vary whether the pedestrian walks alone or in group, pointing to mean speeds of 1.44 or 1.35 m/s and 1.32 or 1.33 m/s, respectively. Also pedestrian density tends to affect pedestrian speed (TRB, 2000). In a study carried out in a metro station in Shanghai, Ye *et al.* (2012) identified weight load as an important factor in explaining speed, verifying that pedestrians tend to adopt slower speeds when carrying handbags. Knoblauch *et al.* (1996) and Tarawneh (2001) have identified street width (crossing length) as an element that affects crossing speed. Knoblauch *et al.* (1996) have also identified as relevant factors the functional classification and conflicting vehicles volume.

It is still interesting to notice that mean speeds, or the 15th percentiles of crossing speed, vary from country to country. In India (Rastogi *et al.*, 2011), in Jordan (Tarawneh, 2001), in Australia (Austroads, 1995) and in Thailand (Tanaboriboon and Guyano, 1991), pedestrians tend to adopt lower crossing speeds when compared to those observed in the USA (Fitzpatrick *et al.*, 2006; Gates *et al.*, 2006; Ishaque and Noland, 2008; Knoblauch *et al.*, 1996), which is probably related to pedestrian's height.

Studies relating pedestrian crossing speed to each one of these factors are, nonetheless, still necessary. In that context, this article focuses on characterizing pedestrian speed in various types of pedestrian crossings. This type of data becomes essential to the pedestrian infrastructure design and paramount in estimating the length of waiting queues associated to conflicting traffic streams. The methodology adopted in data collection and treatment sessions, and the corresponding data analysis, are presented in detail. Additionally, the factors influencing pedestrian crossing speed are identified, and its relevance is also evaluated. The work was supported by the creation of a real database, based on the direct pedestrians observation, and complemented by the conflicting traffic streams characterization .The analyses were based on the application of statistical techniques which enabled the identification of factors that showed statistical relevance in explaining pedestrian crossing speed.

ADOPTED METHODOLOGY

This section focuses on a brief presentation of the methodology adopted for the data collection, treatment and analysis.

Selected Variables

The variables selected in this study resulted from the compilation of references from specialty bibliography (Arango and Montufar, 2008; Austroads, 1995; Dewar, 1992; Fitzpatrick *et al.*, 2006; Gates *et al.*, 2006; Ishaque and Noland, 2008; Knoblauch *et al.*, 1996; LaPlante and Kaeser, 2007; Tanaboriboon and Guyano, 1991; Tarawneh, 2001; TRB, 2000; Ye *et al.*, 2012). The following variables were taken into account: age group, gender, walking alone or in a group (group size), pedestrian density, weight load, existence of a central refuge island, crossing length, road width and vehicles mean speed.

Locations Selection

The selection of locations aimed at safeguarding a variety of situations related to the different crossings types (signalized or unsignalized; raised crosswalk), to the presence or absence of a pushbutton or a central refuge island, to the crossing length (short [0-8m], long [9-14m] and very long [15-19m], to the traffic speed in the study sections and a high pedestrian volume. Seven pedestrian crossings were selected (Figure 1), all located in Coimbra (Portugal): three signalized (Case Study 1, 2 and 3), three unsignalized (Case Study 4, 5 and 6) and one raised crosswalk (Case Study 7).

It is also worth noting that it was not possible to take into account in this study a platform crossing of short crossing length without traffic lights, because the only such crossing in the city of Coimbra had an extremely low pedestrian density.

Data Collection and Treatment

The work was supported by the creation of a real database, based on direct observations, complemented by the collection of video footage and by the registration of the conflicting traffic speeds distribution, using a mobile radar. All data was collected under favorable weather conditions, meaning that no precipitation was registered, and the pavement was dry, in order to avoid the need to insert other variables into the analysis of data variation.

On average, 45 minutes of video footage for each case study were recorded, with the objective of collecting a significant pedestrian sample, reaching a sample of around 80 pedestrians per site.

Case Study 1

Street width:	8 m
Signalized:	Yes
Push button:	Yes
Number of ways:	1
Central island:	No
Raised:	No
Lowered curb:	Yes

Case Study 2

Street width:	11 m
Signalized:	Yes
Push button:	Yes
Number of ways:	2
Central island:	No
Raised:	No
Lowered curb:	Yes

Case Study 3

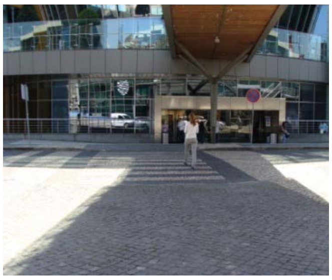
Street width:	19 m
Signalized:	Yes
Push button:	Yes
Number of ways:	2
Central island:	Yes
Raised	No
Lowered curb:	Yes

Case Study 4

Street width:	8 m
Signalized:	No
Push button:	No
Number of ways:	1
Central island:	No
Raised:	No
Lowered curb:	Yes

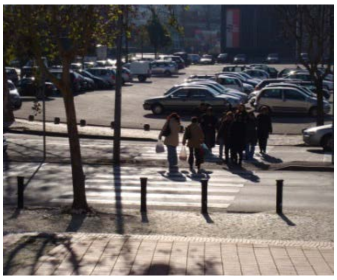
Case Study 5

Street width:	10 m
Signalized:	No
Push button:	No
Number of ways:	1
Central island:	No
Raised:	No
Lowered curb:	Yes



Case Study 6

Street width:	15 m
Signalized:	No
Push button:	No
Number of ways:	2
Central island:	Yes
Raised:	No
Lowered curb:	Yes



Case Study 7

Street width:	15 m
Signalized:	No
Push button:	No
Number of ways:	1
Central island:	No
Raised:	Sim
Lowered curb:	No

Case Studies Location (1 to 7)

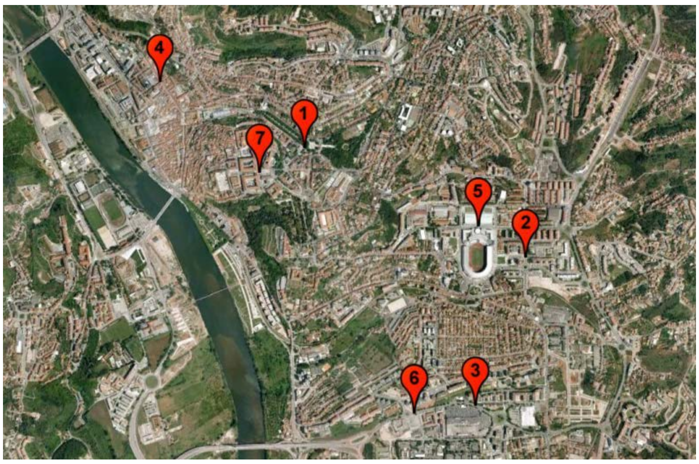


Figure 1 –Location (Source: *Google Earth*), identification and characterization of study crossings (Coimbra)

The treatment of the video footage was very thorough, producing a wide array of information, namely: time and number of crossings, age group, gender, group dimension, possible weight load (shopping bags, handbags, carrying children, etc.), and pedestrian density. Pedestrian density associated with each crossing was estimated for the moment corresponding to halfway through the crossing, having included the pedestrian under analysis in the estimation. For crossing time collection purposes, it was considered that pedestrians began their movement when they steped on the road next to the curb, and finish it when they got to the sidewalk (climbing the curb).

Data concerning pedestrians who crossed the road in an informal manner was excluded from the analysis (for instance, diagonally in relation to the road) as well as those who stopped during the crossing, and those who crossed during the intermittent green light or at the red light for signalized crossings. Concerning crossings with a central refuge island, it was only considered for the analysis the pedestrians who made their crossings in a continuous manner, in order to ensure that their speed was constant. It is important to mention, however, that crossing times were measured from one end of the crossing to the other, meaning that the time of possible slowdowns on the central refuge islands was not deducted.

At the same time, a portable radar was used to measure the vehicle's speed when approaching, in free flow conditions, the crossing under study. The collection of speed values followed a discrete and random procedure, narrowing the registry to white and black colored vehicles, until a sample of 100 vehicles per crossing was attained. The data collections took place outside of rush hour in order to ensure that vehicles approaching the crossings were driving under free flow conditions.

The equipment was used in a discreet manner (from the inside of a vehicle or camouflaged in vegetation), in order to ensure that neither the drivers nor the pedestrians would be aware, thus, influencing their behavior. Data analysis was based on the application of statistical analyses that enabled the identification and assessment of which factors proved to be statistically relevant in explaining the observed pedestrian crossing speed on urban roads. All the works was developed using the, *Statistica* software package.

RESULT ANALYSIS

This section focuses on the characterization of the collected sample and on the identification of the factors which proved to be statistically relevant in explaining crossing speed. Because it was considered that pedestrian behavior tends to significantly differ depending on if the crossing is signalized or unsignalized, it was chosen to segregate the analysis according to this variable.

General Sample Characterization

The sample was initially composed by 519 cases, resulting from the visualization of video footage. During the preliminary result analysis, however, some extreme values were observed, indicating the presence of outliers. Because these values were more than 3 times afar from the standard deviation, it was decided not to include them in the sample, hence reducing the amount of analyzed cases to 507. Globally, the sample presents the following basic characteristics (see also Table I and Table II):

1. Pedestrian age groups of youngsters ([18-24]), young adults ([25-34)], and adults ([35-44]) are the predominant ones, representing 25.4%, 14.0%, and 14.2%, respectively;

2. The percentage of female pedestrians is slightly superior to that of male ones, corresponding to the values of 54.6% and 45.4%, respectively;

3. Pedestrians, in their majority, walk in groups (55.8%), being that 78.8% walk in groups of two, 11.7% in groups of three, and 9.5% in groups of more than three;

4. 71.8% of pedestrians registered walk without carrying any type of load;

5. 26.8% of pedestrian crossings correspond to short lengths, 30.6% to long lengths and 46.2% to very long lengths;

6. 74.2% of pedestrian crossings do not have a central refuge island;

7. Pedestrian registered in unsignalized crossings represent 63.1% of the sample, while pedestrian in signalized crossings represent only 36.9%.

Figure 2 depicts the histogram of the registered crossing speed distribution, which follows approximately a normal symmetric distribution, pointing to a mean crossing speed of 1.22 m/s.

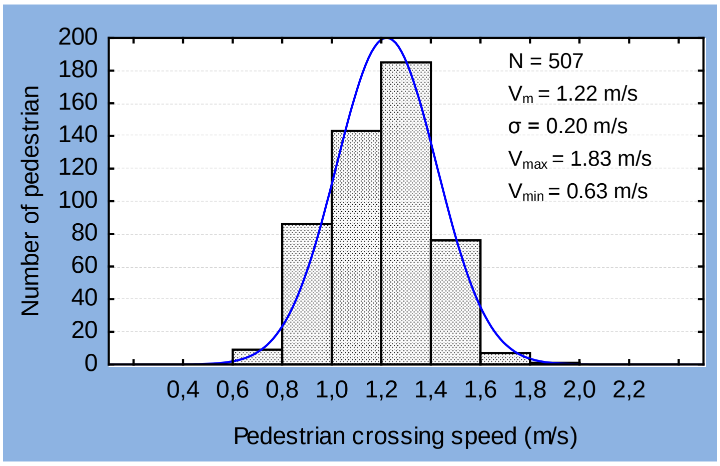


Figure 2 – Histogram of pedestrian crossing speed

In turn, 15th and 85th percentiles correspond to pedestrian crossing speeds of 1.00 m/s and of 1.43 m/s, respectively. The histograms for speed distribution according to the presence or absence of a traffic light system depict an analogous evolution, pointing to mean pedestrian crossing speeds of 1.24 and 1.20 m/s, respectively.

The general characterization of the collected sample is presented in Table I and Table II, namely the mean crossing speed values regarding the main explanatory variables collected.

Although the average values of partial samples point to values of the same order of magnitude, it identifies non-negligible differences, particularly between the extremes. The lowest average speeds are associated with older age groups and walks to the group walking, and this effect is particularly pronounced in uncontrolled crossings.

In contrast, the higher average speeds are associated with younger age groups (12-17), longer crossings and whether or not a central island exists. The central refuge island are typically associated with longer crossings that allow refuge areas for pedestrians and two phase crossings. Thus it is expected that increasing the length of the pedestrian crossing induces an increased feeling of insecurity associated with the length of exposure to risk.

Table I – Pedestrian crossing speed versus relevant factors for signalized pedestrian crossings

Signalized Pedestrian Crossing							
Factor	Level	N	V_m (m/s)	σ (m/s)	V_{15} (m/s)	V_{50} (m/s)	V_{85} (m/s)
Age Group	<12	8	1.26	0.21	1.06	1.36	1.38
	[12-17]	16	1.33	0.19	1.14	1.33	1.58
	[18-24]	42	1.29	0.26	1.14	1.14	1.60
	[25-34]	24	1.25	0.18	1.10	1.14	1.57
	[35-44]	26	1.28	0.19	1.06	1.27	1.46
	[45-54]	20	1.27	0.21	1.03	1.22	1.52
	[55-64]	19	1.15	0.18	0.92	1.10	1.36
	≥ 65	32	1.15	0.18	0.95	1.14	1.36
Gender	Female	93	1.21	0.20	1.00	1.14	1.38
	Male	94	1.27	0.22	1.06	1.22	1.57
Group Size	Alone	99	1.32	0.21	1.10	1.33	1.57
	In group	88	1.16	0.18	1.00	1.14	1.36
	2	79	1.17	0.18	1.00	1.14	1.38
	3	9	1.14	0.00	1.14	1.14	1.14
	>3	0	–	–	–	–	–
Weight Loading	Without	133	1.23	0.21	1.00	1.14	1.46
	With	54	1.27	0.21	1.10	1.24	1.57
Crossing Length	Short	60	1.19	0.18	1.14	1.14	1.33
	Long	74	1.23	0.22	1.00	1.22	1.57
	Very long	53	1.33	0.21	1.06	1.36	1.58
Central Refuge Island	With	53	1.33	0.21	1.06	1.36	1.58
	Without	134	1.21	0.20	1.00	1.14	1.38
Global Sample		187	1.24	0.21	1.06	1.22	1.46

Table II –Pedestrian crossing speed versus relevant factors for unsignalized pedestrian crossings

Unsignalized Pedestrian Crossing							
Factor	Level	N	V_m (m/s)	σ (m/s)	V_{15} (m/s)	V_{50} (m/s)	V_{85} (m/s)
Age Group	<12	3	1.15	0.09	1.07	1.14	1.25
	[12-17]	35	1.30	0.18	1.11	1.25	1.43
	[18-24]	87	1.25	0.16	1.07	1.25	1.43
	[25-34]	47	1.15	0.23	0.89	1.15	1.36
	[35-44]	46	1.21	0.19	1.00	1.25	1.36
	[45-54]	35	1.20	0.17	1.00	1.15	1.36
	[55-64]	40	1.19	0.15	1.00	1.20	1.36
	≥ 65	27	1.00	0.18	0.88	1.00	1.15
Gender	Female	184	1.21	0.17	1.00	1.25	1.36
	Male	136	1.18	0.22	0.94	1.20	1.36
Group Size	Alone	125	1.24	0.19	1.07	1.25	1.43
	In group	195	1.17	0.19	0.94	1.15	1.36
	2	144	1.19	0.19	1.00	1.25	1.36
	3	24	1.19	0.19	1.00	1.18	1.36
	>3	27	1.05	0.15	0.88	1.00	1.25
Weight Loading	Without	231	1.20	0.20	1.00	1.25	1.43
	With	89	1.18	0.17	1.00	1.15	1.33
Crossing Length	Short	76	1.17	0.24	0.89	1.14	1.33
	Long	81	1.28	0.17	1.11	1.25	1.43
	Very long	163	1.17	0.17	1.00	1.25	1.36
Central Refuge Island	With	78	1.20	0.14	1.07	1.25	1.36
	Without	242	1.20	0.21	1.00	1.25	1.43
Global Sample		320	1.20	0.20	1.00	1.25	1.36

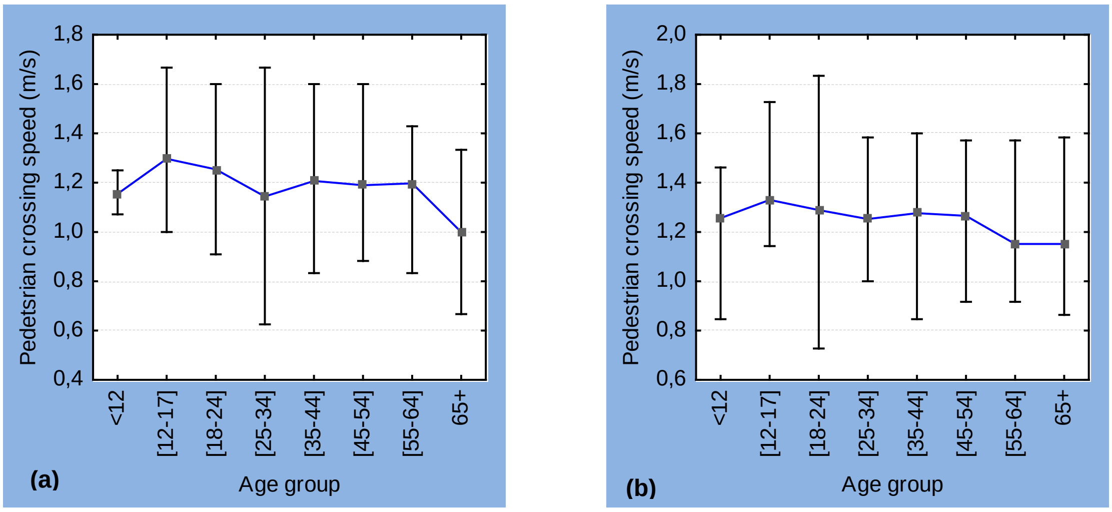
Assessment of the effect of some variables in pedestrian's crossing speed

In order to identify which are the most significant variables in explaining the pedestrian's crossing speed for crossings with or without traffic light systems, an assessment of the effect of the identified variables was undertaken.

Age

With the increase of the pedestrians' age, their characteristics tend to, in a younger stage, develop, and, in a more elderly stage, they tend to worsen, which leads us to expect that the age factor influences pedestrian crossing speed.

The analysis of Table I and Table II shows that, on average, results are similar for signalized or unsignalized crossings. As for the detailed analysis of speed distribution, it shows that there are some behavioral differences in these two types of crossing (Figure 3). When equipped with a traffic light system, the evolution of the curve is as expected, and an increase in the mean speed in youngsters and a decrease in that of elderly pedestrians can be observed (Figure 3 (a)). As for crossings without traffic lights, the behavior is more inconsistent, but the general tendencies are, nonetheless, the same (Figure 3 (b)). It is also worth mentioning that youngsters ([12-17]) are the quickest regardless if the crossing does or does not have traffic lights. The application of linear regression techniques confirms the existence of a slight tendency for pedestrian speed decrease with age, for both crossings with traffic lights (r^2=0.0607) and without (r^2=0.0800). The adjustment of a non-linear relation (3^rd^ degree polynomial) to the sample allowed for a very slight improvement in the adjustment degree in crossings with traffic lights (r^2=0.0694) and without (r^2=0.1000), hinting for the presence of multiple explanatory factors.



Legend: ■ Mean I Min-Max ○ Outliers ✳ Extremes

Figure 3 –Box and whisker diagram: pedestrian crossing speed versus age group (a) signalized and (b) unsignalized intersections

These results confirm those present in other specialty references (Fitzpatrick *et al.*, 2006; Gates *et al.*, 2006; Ishaque and Noland, 2008; Knoblauch *et al.*, 1996; Tarawneh, 2001), which identify elderly pedestrians as the slowest ones. The proximity of the attained results for elderly pedestrians when related to the state of the art should also be stressed. We also observed that pedestrians in Portugal tend to adopt slower speeds when compared to the results obtained in the United States, which in part may be related to a difference in stature.

Gender

Similarly to Fitzpatrick *et al.* (2006), Gates *et al.* (2006), Ishaque and Noland (2008), Tanaboriboon and Guyano (1991) and Tarawneh (2001), we noted that, in traffic lighted crossings, male pedestrians tend to be slightly faster than female ones (Table I, Table II, Table III and Figure 4).

In turn, in unsignalized crossings, female pedestrians tend to be the fastest. Figure 4 and Table III confirm these tendencies, being also possible to observe that, regardless of gender, pedestrians tend to decrease their speed with age. The application of the *t-student or t-test* statistical test for mean comparison shows that the differences attained between crossing speeds for both genders are not statistically significant for a 95% confidence level for crossings with traffic lights (p=0.053244) or without (p=0.161996).

Table III – Pedestrian crossing speed regarding gender versus age group signalized crosswalks (SC) and unsignalized crosswalks (USC)

Gender	Crosswalk	Age Group								
		<12	[12-17]	[18-24]	[25-34]	[35-44]	[45-54]	[55-64]	≥ 65	Global Sample
Female	SC	1.37	1.41	1.23	1.20	1.20	1.24	1.16	1.10	1.21
	USC	1.25	1.33	1.23	1.19	1.20	1.17	1.19	1.02	1.21
Male	SC	1.22	1.28	1.33	1.32	1.41	1.30	1.10	1.17	1.27
	USC	1.11	1.22	1.28	1.09	1.22	123	1.20	0.99	1.18

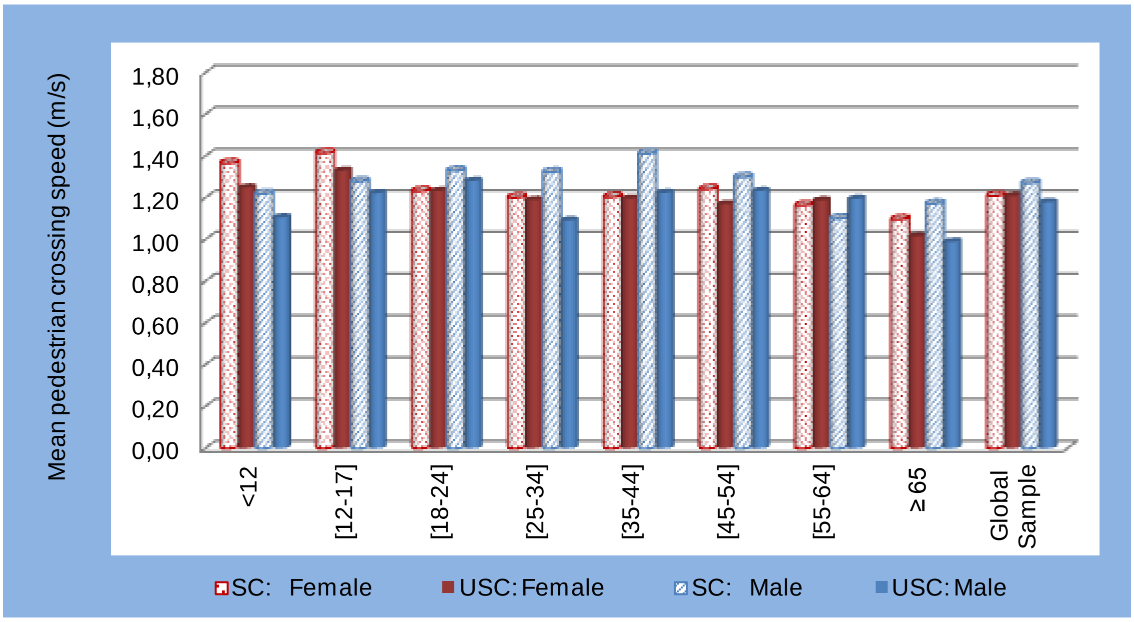


Figure 4 –Pedestrian crossing speed regarding gender versus age group for signalized crosswalks (SC) and unsignalized crosswalks (USC)

Pedestrian density

With an increase in pedestrian density, a decrease in crossing speed is to be expected, due to a reduction in the useful space per pedestrian, therefore increasing the level of disruption between the walking pedestrians (TRB, 2000). However, the general evaluation of the effect of pedestrian density points to negligible correlations (r^2=0.0062), an effect which has very little significance regardless of the presence or absence of traffic light systems. It is important, nonetheless, to bear in mind that the majority of the observed values correspond to extremely low pedestrian densities (corresponding to a B service level – TRB, 2010), which substantially limits this analysis and, in turn, its robustness and the generalization of its results (Figure 5).

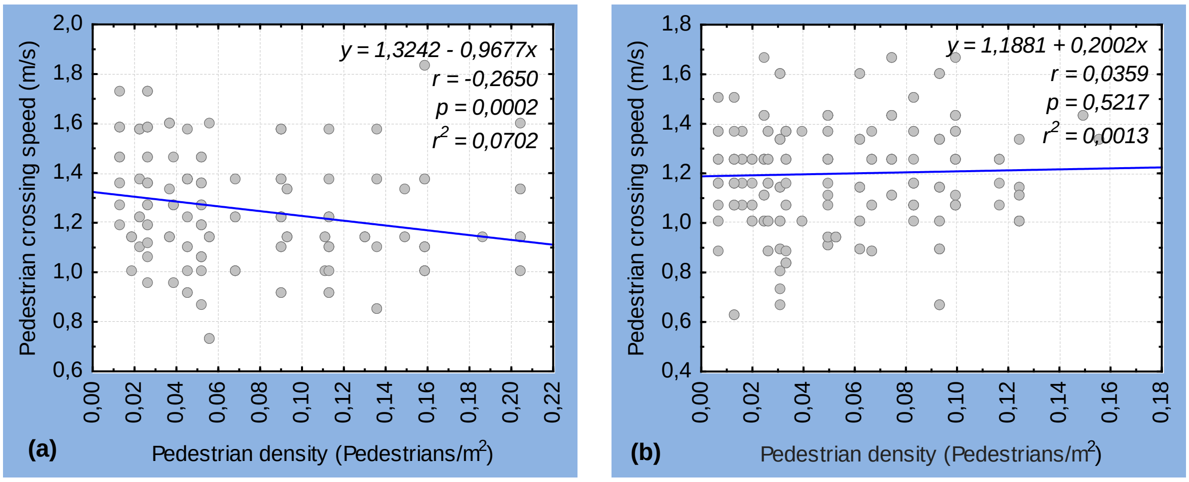


Figure 5 –The effect of pedestrian density on pedestrian crossing speed in crossings with traffic lights (a) and without (b)

Group Size

The results of the analysis regarding the effect of traveling in a group indicate that pedestrians, when walking alone, tend to walk faster than when accompanied (Table I and Table II), hence confirming the tendency seen in specialty literature (Gates *et al.*, 2006; Tarawneh, 2001). The application of the *t-test* confirms that the differences are statistically significant for a 95% confidence level for both types of crossing (with or without traffic lights). The analysis of the influence of group size allows us to conclude that, as the size of the pedestrian group (2, 3, or more elements) increases, their crossing speed decreases for both types of crossing (Table I and Table II). The application of linear regression techniques confirms the presence of a slight correlation tendency and a slight tendency for a decrease in pedestrian crossing speed as the group dimension increases for signaled crossings (r^2=0.1209) and unsignalized (r=^{2}0.0647), respectively.

Weight Load

The effect of carrying a weight load did not prove to be statistically significant for the crossing speed. Nonetheless, it was observed that, in crossings with traffic lights, pedestrians carrying loads tend to travel faster than those carrying no load (Table I and Table II). However, in unsignalized crossings, pedestrians carrying no load tend to adopt faster speeds (Table I and Table II). This tendency for a decrease in speed for pedestrians carrying loads observed in unsignalized crossings confirms the results obtained by Ye *et al.* (2012). The application of the *t-test* confirms that the results are not statistically significant for a confidence level of 95% for crossings with traffic lights (p=0.213274) and without (p=0.512926).

Crossing Length

In general, the analysis of the influence of crossing length showed that, as the length (short, long, and very long) increases, pedestrian crossing speed also increases (Table I, Table II and Table IV). Although with lower values, this tendency confirms the results observed in the specialty literature (Knoblauch *et al.*, 1996; Tarawneh, 2001). For unsignalized crossings, however, a tendency for a decrease in speed as the length of the crossing diminishes can be observed. The application of linear regression techniques confirms the presence of a slight increasing tendency for pedestrian crossing speed as the length of the crossing also increases for signalized crossings (r^2=0.0686), being negligible for unsignalized crossings without traffic lights (r^2=0.0066).

Central Refuge Island

The analysis of the effect of this variable shows that the pedestrian crossing speed in crossings with traffic lights tends to increase when a refuge island is present (Table I and Table II). The application of the *t-test* to traffic lighted crossings confirms that the differences are statistically significant for a confidence level of 95% (p=0.887336). This aspect tends to be related to the fact that pedestrians tend to use the time when the traffic light is green to do the entire crossing in a single stage. For unsignalized crossings, however, there is no observed behavioral change; in this type of crossing, pedestrians tend to maintain their crossing speed (Table I and Table II).

Mean Vehicle Traveling Speed

There are several scientific studies substantiating the existence of a correlation between vehicle traveling speed and road width (Knoblauch *et al.*, 1996). Result analysis shows a tendency for an increase in crossing speed as the mean conflicting vehicle traffic speed also increases, regardless if the crossing type does or does not have traffic lights (Table IV). It may, thus, be inferred that the feeling of insecurity associated with the traffic stream is visible in the adoption of higher speeds by pedestrians.

Table IV –Summary of the link between crossing length and road width with pedestrian crossing speed and vehicle traveling speed

Pedestrian Crossing	Case Study	Crossing Length (m)	Mean Pedestrian Crossing Speed (m/s)	Carriageway Width (m)	Mean Vehicle Traveling Speed (km/h)
Signalized	1	8	1.19	8	22
	2	11	1.23	11	34
	3	19	1.33	19	48
Unsignalized	4	8	1.17	3	20
	5	10	1.28	10	44
	6	15	1.20	7	38
	7	15	1.15	15	22

The application of linear regression techniques confirms the presence of a slight correlation tendency, although with no statistical significance (r^2=0.0669 for signalized crossings, and r^2=0.0513 for unsignalized ones). The presence of a direct relation between the increase of mean vehicle traveling speed and the increase of road width should also be stressed (Table IV), namely in signalized crossings (r^2=0.9504).

POTENCIAL APPLICATION TYPES

The results attained have proven to be extremely promising for the development of technical recommendations adapted to the design of the various crossing types, namely concerning the estimation of clearance times associated to traffic light systems in order to ensure a safe crossing for every segment of the population. These results have also proven to be essential in the estimation of vehicle delays and vehicle queue length associated with pedestrian crossings, and inherently design of vehicle stocking lane lengths.

But it is possible to identify a multiple other types of applications. For example, using a Geographic Information Systems (GIS), it is possible to integrate the representation and special analysis aspects, hence boosting the creation of maps identifying the different types of crossings that exist in a particular area. Based on the cleaning times adopted by each signalized crossing it is possible to set different pedestrian maps associated with different objectives, namely: faster paths, safer paths, etc. Figure 6 depicts this type of concept as an example of application, having the seven case studies presented in this study as its basis.

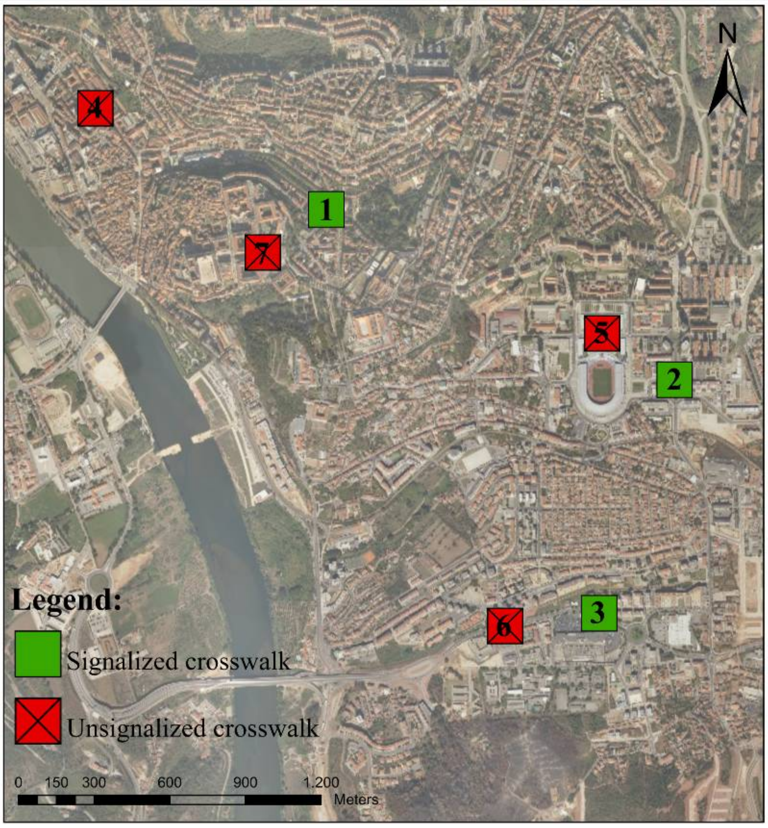


Figure 6 – Schematic representation in GIS (ESRI ArcMap-10) of the studied pedestrian crossings

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In a prospective view, associating GIS technology with multidimensional methods of analysis, it was possible to build a sophisticated decision support system in which, for example, one city's crossings could all be classified according to one or more multi-criteria analysis methods using data stored in the GIS itself. Consequently, such classifications could then be graphically represented in the cartography in the GIS. Such a system would, hence, provide very useful indications on the cases in which an intervention is essential, which could be divided into phases according to the financial resources available.

CONCLUSIONS AND FURTHER WORK

The current study focused on the characterization of pedestrian crossing speed and in the identification of factors that influence its estimation. The conclusions present in this study confirm, in general, the results in specialty literature, pointing to mean crossing speeds of 1.22 m/s, with a minimum value of 0.63 m/s and a maximum of 1.83 m/s. It has also been observed that, generally, results differ whether the crossing are signalized or unsignalized (1.24 m/s and 1.20 m/s), being that, in general, slightly faster speeds were observed in signalized crossings. Such results may be related to the fact that, during the moment of crossing, pedestrians were walking as fast as they could before the light would turned red.

It is also important to emphasis that, in the global sample collected, the lowest crossing speed observed was 0.63 m/s, with a 15th percentile of 1.0 m/s. Even when taking into account the age group of elderly pedestrians, with ages of 65 or more, the 15th percentile assumes the value of 0.95 m/s and of 0.88 m/s for crossings with or without traffic lights, respectively. This fact depicts the inadequacy of the Portuguese legislation regarding the speed value imposed for the designing of the pedestrian infrastructures (0.4 m/s).

It was confirmed that there are several factors that affect the speed adopted by pedestrians. Age, traveling alone or in a group (group size), and mean vehicle traveling speeds were identified as the most significant variables in explaining crossing speed. In turn, pedestrian density, the crosswalk length, and the presence or absence of a central refuge island only proved to be statistically significant for in signalized crossings.

The final results are extremely interesting, enhancing the elaboration of technical recommendations adjusted to the designing of the various types of crossing, namely concerning the estimation of cleaning times associated with traffic light systems in order to ensure a safe crossing for every segment of the population. These results are equally relevant for the estimation of vehicle queue lengths in association to crosswalks. On the other hand, using a Geographic Information Systems (GIS), it is possible to integrate the representation and special analysis aspects, hence boosting the creation of pedestrian maps representing different aspects/objectives: crossing types; faster paths; safer routes, etc.

In order to promote pedestrian trips in urban areas, the research work should proceed towards increasing the size of the data sample, as a means to include more crossing type variability and assess the influence of other factors, namely regarding pedestrian density. Finally, we should proceed towards the development of a simple mathematic model for the estimation of the correct pedestrian crossing speed for each type of crossing, based on a limited set of explanatory variables easily measurable and which may be used as a support tool for local technicians responsible for the management of the road and pedestrian network.

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