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PEDESTRIAN BEHAVIOUR IN URBAN AREA

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ABSTRACT: The pedestrian behavior is influenced by several factors, including: characteristics of the user, numerousness of group, road infrastructures and environmental factors.
These factors were studied by means the collection of data carried out in the city of Oristano (Sardinia-Italy) on eleven sidewalks and five crosswalks.
The objective was to study the pedestrians behavior, researching the link between independent variables and the dependent variables that, for sidewalks was only the pedestrian speed while for crosswalks were the speed of crossing, the crossing time, the waiting time and the total time.
The regression models were constructed by using ten sidewalks and four crosswalks so ignoring one for each. In the construction, were considered more variables that gradually were excluded on the basis of the p-value.
The models thus detected were deemed significant according to their coefficient of determination and were validated with data from the sidewalk or crosswalk excluded from the construction of the same.
Both for sidewalks that crosswalks were found some reliable models.
The models construction is useful to improve the understanding of the pedestrians behavior and then obtain useful indications to design pedestrian infrastructures with characteristics closer to the real pedestrians behavior.
The present study aims to give greater importance to pedestrians, analyzing how they relate with the urban context in which they live and how it conditions their behavior, so as to design infrastructure in which they feel an integral part and main actors of the urban scene, giving them the respect they deserve and a new sense of belonging to the city in which they live.

Keywords: Pedestrian behaviour, sidewalk, crosswalk, urban area.

1. THE PEDESTRIAN MOBILITY IN URBAN AREA

In the past, we only move by walking, and for this reason roads were built for mankind and paths were limited to walking distances; with the advent of the car and the increased covered distances, even the city began to grow: streets, have been conceived and designed primarily for motor traffic, to the detriment of pedestrian component. Only recently a turnaround is emerging, with greater consideration of the quality of pedestrian spaces and of vulnerable road users.

2. Individualization of the area

The area of study is the city of Oristano (Sardinia-Italy).
Oristano presents considerable problems with regard to pedestrian infrastructures, like insufficient sidewalks width, improper placement of street furniture, inadequate positioning of parking lots, poor lighting; ect. The choice of survey sites was based on roads where pedestrian movement is more considerable, to collect more data.
The downtown roads taken into consideration, all convergent to the main city square, are five, all characterized by activities and services for citizens.
All roads have one lane and one travel direction, with the sidewalk on each side, parkings arranged on one or two sides depending on the road width and without traffic lights. The sidewalks characteristics are:

Road	Side	Width [m]	Pedestrian Number	Mean Pedestrian speed [m/s]	Parking
Contini	Dx	0.95	556	0.89	No
Contini	Sx	0.95	346	0.94	Si
Figoli	Dx	1.10	1023	0.98	Si
Figoli	Sx	0.80	944	1.03	No
Mazzini	Dx	1.50	599	0.99	Si
Mazzini	Sx	1.45	295	1.00	No
Mazzini (Large)	Sx	5.90	804	0.98	Si
Tharros	Dx	1.55	719	0.94	No
Tharros	Sx	1.35	1099	0.93	Si
Tirso	Dx	1.90	1360	0.94	Si
Tirso	Sx	1.90	1155	0.97	Si

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The pedestrian crossings characteristics are:

Road	Width [m]	Pedestrian Number	Vehicles Number	Mean Pedestrian speed [m/s]	Waiting Time [s]	Parking
Contini	4.5	690	1073	0.82	1.07	Si
Figoli	6	516	1066	0.87	1.65	Si
Mazzini	9.5	641	1483	0.99	0.91	No
Tharros	5.5	679	1262	0.95	0.89	No
Tirso	7	727	722	0.94	0.95	Si

The Level of Service, calculated with the HCM method is generally very low.

3. Data collection

Reliefs were made on sidewalks located near the square and on the first pedestrian crossing. The data was collected using video recording for each section and in good weather conditions, on weekend, in the shops opening hours. The next step was to collect all the data relating to single pedestrian: for each street were recorded separately the two sidewalks and the pedestrian crossing.

For sidewalks, has been taken into consideration every pedestrian pace to determine the travel time and to calculate speed. For pedestrian crossings was considered every pedestrian passed from one part to another so to determine waiting time, crossing time and to calculate pedestrians speed. Pedestrians age was determined subjectively by the operator. Each pedestrian was cataloged according to age in five categories and was distinguished the individual pedestrians from groups different for the number of people composing them.

4. Data processing: the models

It is studied the pedestrians behavior on pedestrian infrastructure, first with respect to sidewalks, then pedestrian crossings. Regression models are constructed using the experimental variables; in particular the dependent variable Y_i is linked to the independent variables X_i, by:

$Y_i=ß_0+ß_1X_1+ß_2X_2+\ldots+ß_mX_m+\varepsilon$

Where $ß_0$, $ß_1$, ..., $ß_m$ are the regression coefficients and ε is the error component of the model.

Performing various tests and combining variables among them, is evaluated the level of significance, discarding the variable when the p-value exceeded 5%.

Determined the behavior pedestrian model, the validation is carried out to verify if the model is sufficiently accurate. The validation is carried out by checking the study data with other not used during the estimation of parameters and calculating the coefficient of determination.

4.1. Analysis of variables

The dependent variables describe user behavior and are strongly influenced by the characteristics of pedestrians and infrastructure. It is chosen, for sidewalks, the pedestrian speed and for pedestrian crossings the pedestrian speed, the crossing time, the waiting time and the overall time. Four dependent variables are considered:

- pedestrian speed, determined, for sidewalks, as the time to travel a section of known length and, for pedestrian crossings, as the time to pass from one side of the road to the opposite [m/s];
- crossing time, ie the time taken by pedestrian to switch from one side of the road to the opposite [s];
- waiting time, ie the time taken by pedestrian before to decide to cross [s];
- overall time, sum of waiting time and crossing time [s].

The independent variables that could affect the dependent variables performance, are:

- pedestrian age distinguished with following values: 1 - age class from 0 to 10 years old, 2 - age class from 11 to 18 years old, 3 - age class from 19 to 40 years old, 4 - age class from 41 to 65 years old; 5 - age class over 65 years old;
- group composition, distinguished with the following values: 1 - individual pedestrians; 2 - groups of two pedestrians; 3 - groups of three pedestrians; ect..
- length of walked paths: for sidewalks the length was known while for pedestrian crossings are the roadways width;
- sidewalk width [m];
- parking presence: 0 if absent and 1 if pedestrian is not visible by moving vehicles cause parking.

In addition to these are found other variables such as: pedestrian density, pedestrian space, total pedestrian flow, flow of pedestrians passed outside from sidewalk or pedestrian crossing, number of people belonging to each age class, capacity of the sidewalk, number of obstacles on the path, width, traffic flow on the pedestrian crossing, lighting, function of sidewalk. The variables are calculated for each pedestrian and at intervals of one minute and fifteen minutes.

4.2. SIDEWALKS MODELS

4.2.1. Relationship between speed and all independent variables

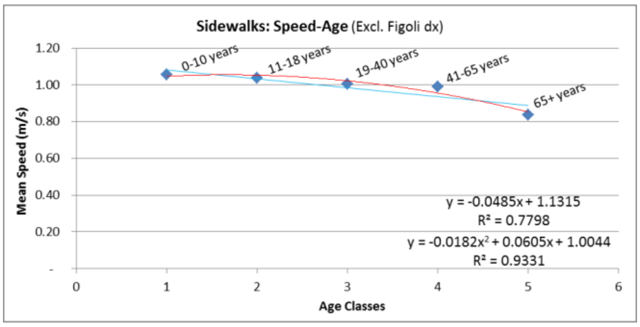
The first tests are performed with data of each passage, and after, data per minute with all variables described above; some of these are later excluded depending on the p-value; appreciable results are not obtained because the R^2 coefficient obtained in the construction phase is low, with values between 0,30 and 0,40. For this reason, the tests are performed using data at intervals of 15 minutes.

Even if the variables considered have a p-value less than 5%, it is not been possible to obtain an acceptable R^2 coefficient. It happen that, by including a few variables, others lost significance as for example, a few age classes, sidewalk width.

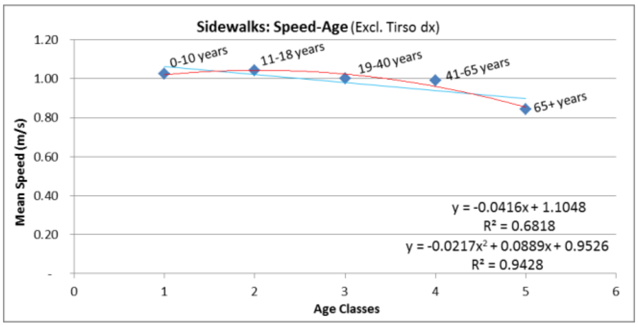
4.2.2. Relationship between speed and age classes

It is considered the relationship between number of pedestrians in each age class and speed, then differentiating speed only for each age class, regardless the number of pedestrians. In both cases, it is not possible to obtain a valid model. This is due to the fact that, in the case of non-homogeneous groups (made up of people of different ages), the velocity trend is strongly affected by the slower pedestrians.

To overcome this problem, it is considered the group as a single pedestrian with age equal to the average of its components, but it is created a multitude of data with a low significance level. So, it is considered exclusively the passage of individual pedestrians; in this way we have obtained the average speed of each age class. It is found that the relationship between speed and age classes can be expressed both by a linear model both by a polynomial model (second order). All models have good coefficients of determination in construction and in validation. In validation phase is ruled out a sidewalk at a time, noting that models obtained showed some difference. Graphs 1 and graph 2 show this.



Graph 1.



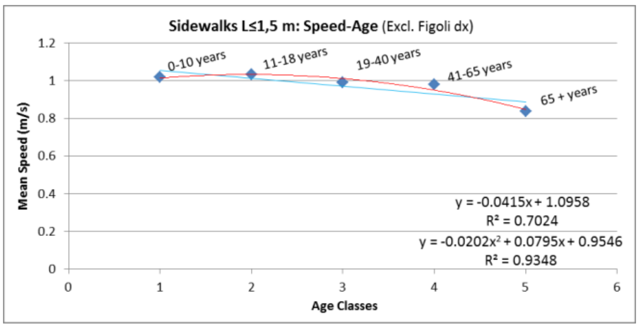
Graph 2.

The models validation for the right sidewalk of Figoli road have provided coefficients R_{Lin}^2=0,60 and R_{Pol}^2=0,87; for the right sidewalk of Tirso road are obtained R_{Lin}^2=0,82 and R_{Pol}^2=0,92. Differences between coefficients of determination both in construction and both in validation can be attributed to the different width of sidewalks that influence user behavior.

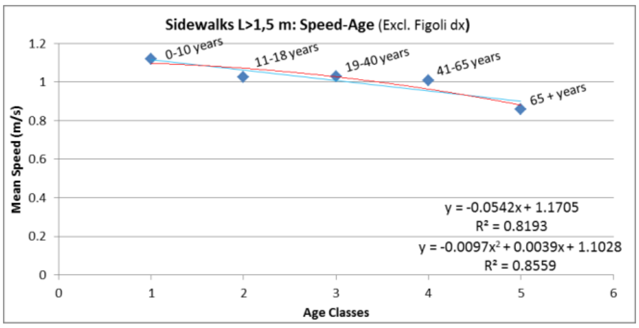
For this reason sidewalks with $L \leq 1,5$ m and those with $L > 1,5$ m are distinguished and are constructed linear and polynomial models, subsequently validated with sidewalks excluded in construction. All models have good coefficients of determination both in construction and both in validation. In validation phase was ruled out a sidewalk at a time, noting that models obtained showed regression coefficient with difference smaller. Graph 3 and graph 4 show this.

In validation, in the case of models cited above, are obtained for sidewalks with $L \leq 1,5$ m coefficients R_{Lin}^2=0,60 and R_{Pol}^2=0,90; while for sidewalks with $L > 1,5$ m are obtained R_{Lin}^2=0,82 and R_{Pol}^2=0,92.

The best models to describe relationship between speed and age classes are those in polynomial form obtained differentiating sidewalks width because they provide the best coefficients of determination in construction and in validation.



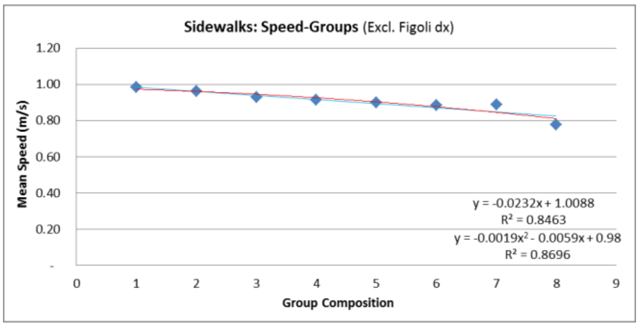
Graph 3.



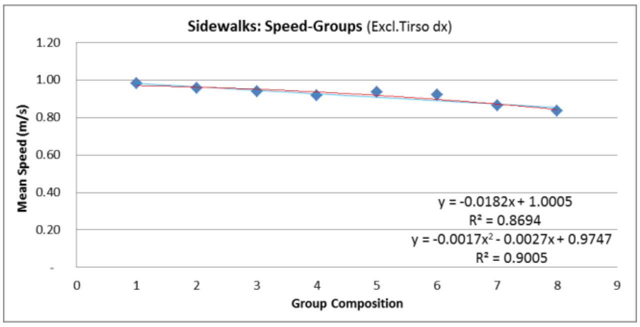
Graph 4.

4.2.3. Relationship between speed and groups composition

The relationship of the speed compared to groups, considers the number of people belonging to the group without regard to their age. In construction models is ruled out a sidewalks at a time used for subsequent validation and it is found that the relation between the speed and the groups can be expressed both by a linear model, both by a polynomial model (second order). All models had good coefficients of determination in construction, while in validation they presented coefficients sometimes insufficient. Graph 5 and graph 6 show this.

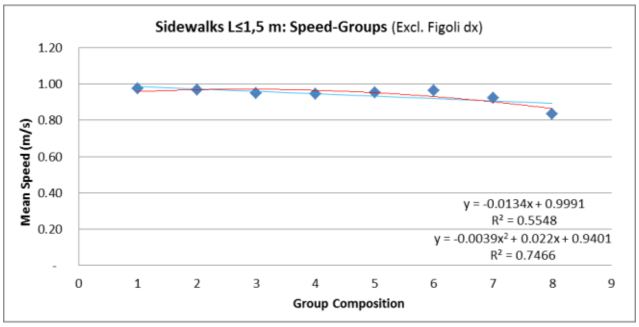


Graph 5.

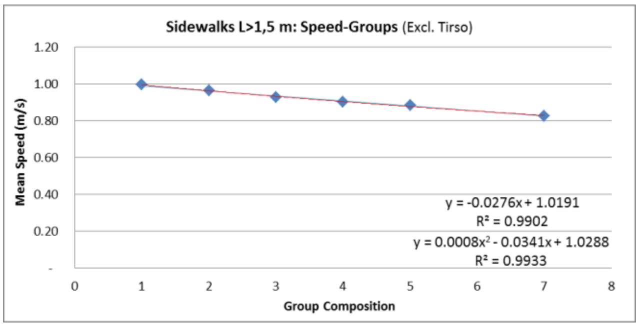


Graph 6.

The models validation for the right sidewalk of Figoli road, have provided coefficients R_{Lin}^2=0,57 and R_{Pol}^2=0,72; while for the right sidewalk of Tirso road are obtained R_{Lin}^2=0,53 and R_{Pol}^2=0,38. These results, in validation, it are possible to due primarily to the influence of the numerousness group compared to the sidewalk width and also at the presence of groups of more than five pedestrians, very few, so that provide an average speed not statistically significant. As first step, sidewalks with L≤1,5 m and those with L>1,5 m are distinguished and are constructed linear and polynomial models, subsequently validated with sidewalks excluded in construction. In validation phase is ruled out a sidewalk at a time. Coefficients of determination in construction phase of models, for L≤1,5 m decrease while those with L>1,5 m improved considerably. Graph 7 and graph 8 show this.



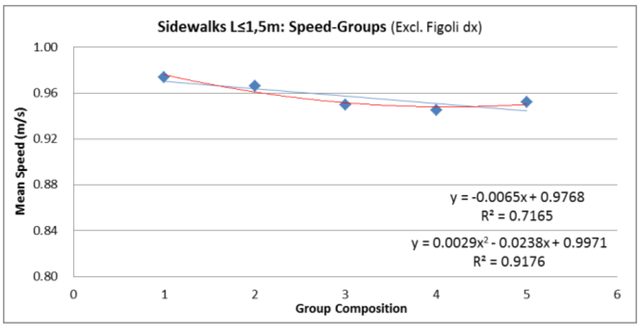
Graph 7.



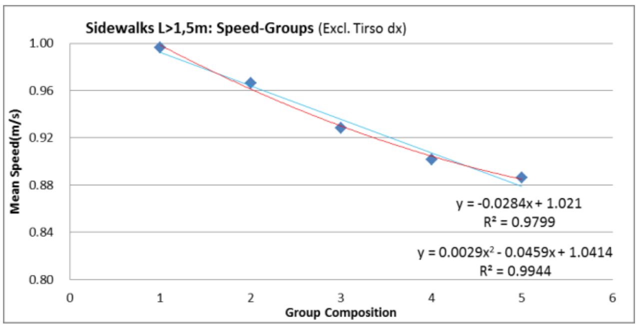
Graph 8.

In validation, for models cited above, for sidewalks with L≤1,5 m are obtained R_{Lin}^2=0,67 and R_{Pol}^2=0,66; while for sidewalks with L>1,5 m are obtained R_{Lin}^2=0,60 and R_{Pol}^2=0,65.

Later, models are constructed, distinguishing sidewalks width but excluding groups with more than five components cause their low percentage. The construction models (linear and polynomial) are validated with sidewalks excluded in construction. In validation phase was ruled out a sidewalk at a time. The coefficients of determination in construction phase of models, in the case of L≤1,5 m improved while those with L>1,5 m remained almost equal. Graph 9 and graph 10 show this.



Graph 9.



Graph 10.

The validation, in the case of models cited above, have provided for L≤1,5 m coefficients R_{Lin}^2=0,53 and R_{Pol}^2=0,77, while for L>1,5 m are obtained R_{Lin}^2=0,97 and R_{Pol}^2=0,93.
In general it is noted that in models, the average of speed of groups decreases with increasing the component number.
The best models to describe relationship between speed and groups are those obtained differentiating sidewalks width; for sidewalks with L≤1,5 m the best model is in polynomial form because it provides highest coefficient in construction and in validation, while for L>1,5 m both models (linear and polynomial) can be used because provide good coefficients but the linear form is easier.

4.3. MODELS FOR PEDESTRIAN CROSSINGS

4.3.1. Relationship between dependent variables and independent variables

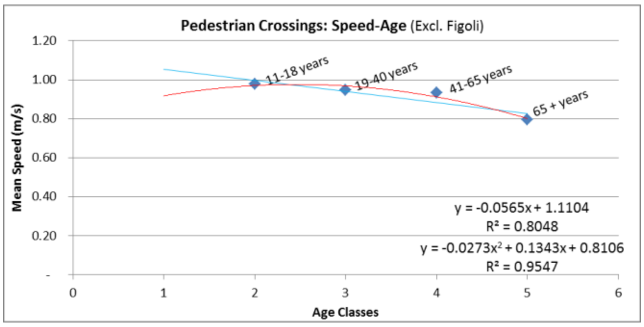
The tests are carried out using data at 15 minute intervals.
Using speed as dependent variable it is found that some variables, initially relevant for the model construction, such as traffic flow, pedestrian flow and age classes were discarded for the low p-value. The resulting model has an R^2 acceptable, but in validation doesn't not reveal an appreciable value of the coefficient of determination. This result probably is due to the fact that the speed contains information already present in other variables such as time, so crossing time is used as dependent variable. Models re constructed excluding from each, one hour in two pedestrian crossings at a time, used for model validation. It is obtained:
$Y=1,1397+0,8890X_1+0,5207X_2$ con $R^2=0,96$
where X_1 is the length of pedestrian crossing and X_2 is the parking presence in the forward direction.
The regression coefficients of the global model are always within the confidence intervals for estimates of regression coefficients of individual models; individual models, in the validation, always provided satisfactory results, so we can assume that the global model provides reliable results. The model is valid for pedestrian crossings with a length included between 5,5 m and 7,5 m.
It is not found a valid model for the dependent variable "waiting time", using the same analysis methods.
This probably derives from the fact that variables identified are not sufficient to describe the waiting time.

4.3.2. Relationship between speed and age classes

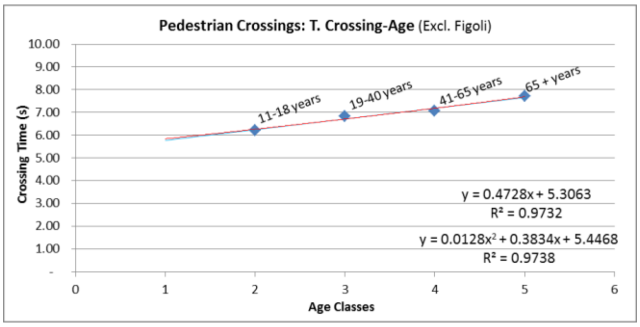
Models between crossing speed and pedestrians age are not reliable, so we differentiate the age in five classes considering only individual pedestrians. Even in this case, indeed, is not possible to find a link with groups having age non-homogeneous. All age classes of individual pedestrians, excluding the class 0-10 years old (no passages of individual pedestrians) are considered calculating the average speed of each class. In models construction is ruled out a pedestrian crossing at a time, used for the subsequent validation; the relationship between speeds and age classes can be expressed both by a linear model both by a polynomial model. All models had good coefficients of determination both in construction both in validation. The graph 11 show this.
In validation are obtained R_{Lin}^2=0,85 and R_{Pol}^2=0,93.
The best models to describe relationship between speed and age classes is the polynomial form because it provides highest coefficient in construction and in validation.

4.3.3. Relationship between crossing time and age classes

Even for the crossing time is searched a relationship with age classes, only with data relating to individual pedestrians. Such relationship can be expressed both by a linear model both by a polynomial model. In validation phase is ruled out a pedestrian crossing at a time. The graph 12 show this.
In validation, for pedestrian crossing of Figoli road, it is found that R_{Lin}^2=0,81 and R_{Pol}^2=0,82. The two models (linear and polynomial) overlap, therefore the crossing time increases linearly with age. Therefore the linear form is used because easier.



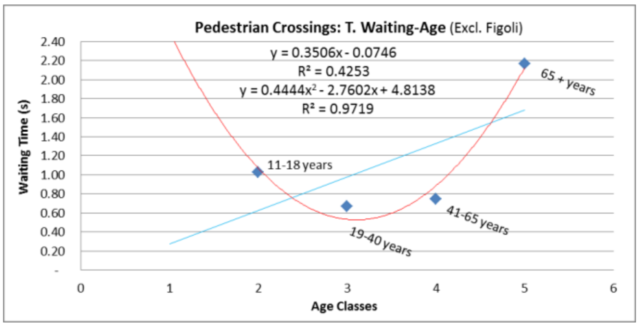
Graph 11.



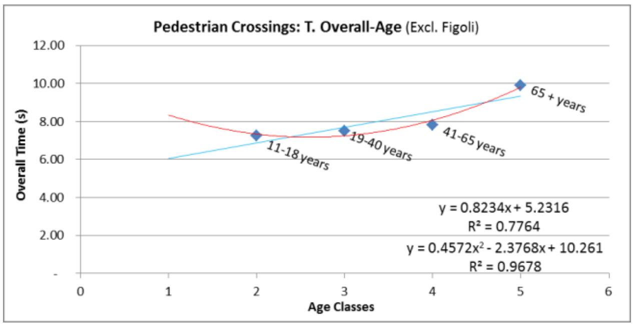
Graph 12.

4.3.4. Relationship between waiting time and age classes

Considering the waiting time, in the same manner of previous tests, ie distinguishing the data by age classes of individual pedestrians, is found a polynomial model. In validation phase is ruled out a pedestrian crossing at a time. The graph 13 show this.



Graph 13.



Graph 14.

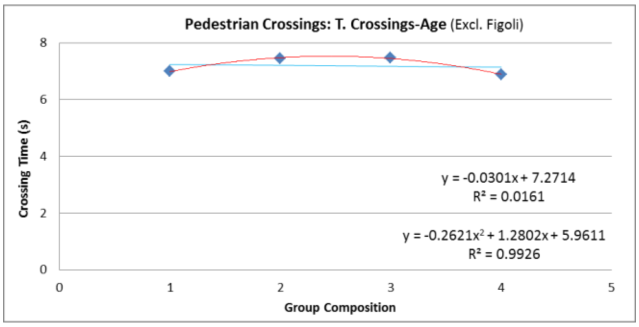
In validation, with the pedestrian crossing of Figoli road, is obtained R_{Pol}^2=0,88; similar results are obtained using other roads. Therefore, the polynomial model is suitable to describe the relationship: waiting time-age. It is observed that pedestrians who spend more time to cross are also those who spend more time to make the decision to cross.

4.3.5. Relationship between overall time and age classes

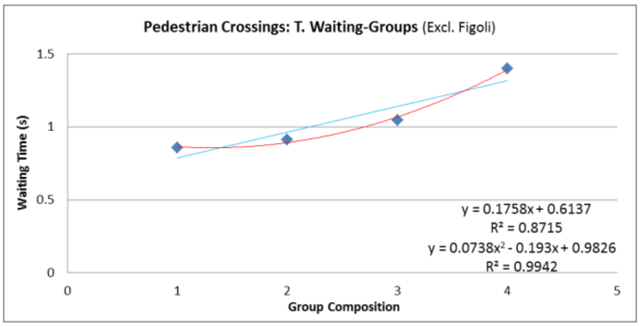
Studying the relationship between overall time and age classes, two models are obtained: linear and polynomial. In validation phase is ruled out a pedestrian crossing at a time. The graph 14 show this.
In validation, with the pedestrian crossing of Figoli road, are obtained R_{Lin}^2=0,77 and R_{Pol}^2=0,99.
The polynomial form is used because provides highest coefficients of determination.

4.3.6. Relationship between the dependent variables and pedestrians groups

In the relationship between speed and groups, two models are found: linear and polynomial. Both during construction, provided sufficient coefficients of determination: R_{Lin}^2=0,65 and R_{Pol}^2=0,75, but in validation phase ruling out a pedestrian crossing at a time, low coefficients are obtained. Therefore models found are not consider satisfactory to describe such relationship.
The relationship between crossing time and groups is described only by the polynomial form while the relationship between waiting time and groups composition can be described both by a linear form both by a polynomial form. In validation phase is ruled out a pedestrian crossing at a time. Graph 15 and graph 16 show this.
In validation, with pedestrian crossing of Figoli road, for the relationship "Crossing Time-Groups" it is obtained R_{Pol}^2=0,58, while for the relationship "Waiting Time-Groups" are obtained R_{Lin}^2=0,40 and R_{Pol}^2=0,25.



Graph 15.



Graph 16.

The relationship between overall time and groups composition can be described only by the polynomial form that provided a coefficient of R_{Pol}^2=0,99. In validation however, with the pedestrian crossing of Figoli road, is obtained a coefficient not adequate, R_{Pol}^2=0,05.
Therefore for pedestrian crossings, in the case of independent variable “group composition”, all models have a high R^2 under construction, but only the crossing time in polynomial form has also given positive results in validation.
With regard at the "Overall Time", the polynomial form provides a valid result in construction but not in validation, probably for the interference of waiting time. Similar results are found considering also the others pedestrian crossings.

This result is probably due to one of characteristics of pedestrian crossings behavior that consists in the fact that, while waiting to cross, more pedestrians gather on the edge of the sidewalk, forming a platoon in crossing phase, where it is difficult to determine the waiting time with precision.

5. CONCLUSIONS

The research is still under investigation but first results allow some considerations about pedestrian behavior.

In the case of sidewalks, width influences pedestrian behavior so models are distinguished according to the width. To describe the relationship between speed and age classes, the best models for L≤1,5 m and L>1,5 m are those in second order polynomial form because they provide the best coefficients of determination in construction and in validation.

To describe the relationship between speed and groups, the best model for L≤1,5 m is a second order polynomial form that provides the best coefficient of determination both in construction and both in validation while for L>1,5 m both models (linear and polynomial) can be used because both provide good coefficients of determination but the linear model is preferred as simpler.

In general, we observe that speed decreases with increasing age class, similarly, speed decreases with increase of component group. In both cases this reduction of speed is greater on sidewalks with L>1,5 m compared to those with L≤1,5 m, probably because individual pedestrian and groups are less affected by the space available.

For pedestrian crossings, the relationship between speed and age classes is described by a model in second order polynomial form that provides the highest coefficients of determination in construction and in validation.

The relationship between crossing time with age classes, is described both by linear form and both by polynomial form because models have similar coefficients of determination in construction and in validation; linear and polynomial models tend to overlap, so the linear model is considered more suitable to describe the pedestrians behavior as simpler.

The relationship between waiting time and age classes is described by a model in second order polynomial form that provides the highest coefficients in construction and in validation.

Finally the relationship between overall time and age classes is described by a model in second order polynomial form because it provides the highest coefficients of determination in construction and in validation.

In conclusion in relationships between dependent variables and age classes: speed decreases with increase of age classes; crossing time increase with increasing of age classes; waiting time increase considerably with increasing age classes; also overall time consequently increase with increasing age classes; this emphasize that pedestrians who spend more time to cross are also those who spend more time to make the decision to cross.

Analysis for pedestrian crossings as a function of composition groups have shown that, between all dependent variables, only crossing time gives acceptable results.

Relationship between crossing time and composition groups can be expressed only by a model in second order polynomial form with high coefficients of determination in construction phase of model and just sufficient in validation phase.

This means that group size affects the time used by pedestrians to cross.

For pedestrian crossings, finally, is determined a multiple regression model only for the crossing time that is directly proportional to length of pedestrian crossing and parkings presence in forward direction of vehicular current, in fact pedestrian starts to cross positioning himself behind the vehicle in park, which acts as a protective barrier for pedestrian to obtain a better visual contact Vehicle-Pedestrian: this reduces the path characterized by less safety.

Models do not take into account the interference between pedestrians that walk in opposite directions, gender, luggage, ect.. Future researches will take into account these additional variables.

References

Buchanan P., Heuman D., *Measuring the benefits of pedestrian improvements*, Fifth Conference on walking in the 21st Century, Copenhagen, Giugno 2004

Giustini M., *Gli anziani e la mobilità pedonale*, Istituto Superiore di Sanità, Convegno Nazionale, 1 Febbraio 2013

Ilango T., Rastogi R., Chandra S., *Behavior and perception of pedestrian walking in groups*, TRB Annual Meeting, 2011

International Transport Forum, *Pedestrian Safety, Urban Space and Health*, OECD, 2011

Jianhong Y., Xiaohong C., Nanjing J., *Impact analysis of human factors on pedestrian traffic characteristics- walking speed revisited*, TRB Annual Meeting, 2011

Kadali B., Vedagiri P., *Modelling pedestrian road crossing behavior under mixed traffic condition*, Paper n.3 ISSN 1825-3997, 2013

NZ Transport Agency, *Guide to undertaking community street reviews*, Giugno 2010

NZ Transport Agency Research, *Predicting walkability*, report 452, Agosto 2011

Obaidat M., Al-Maised H., *A knowledge-based system for pedestrian's roadway crossing behavior through video cameras*, Jordan Journal of Civil Engineering vol.1 n.2, 2007

Rahman K., Noraida A.G., *Analysis of pedestrian free flow walking speed in a least developing country: a factorial design study*, Novembre 2012

Transportation Research Board, *Highway Capacity Manual*, Ottobre 2000

Transportation Research Board, *Improving pedestrian safety at unsignalized crossings*, NCHRP report 562

US Department of Transportation, *Pedsafe: pedestrian safety guide and countermeasure selection system*, publication n.FHWA-SA-04-003, Settembre 2004